ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

PERFORMANCE ANALYSIS OF HOT ROLLING MILL ROLLS TO IMPROVE THE PRODUCTIVITY OF THE ROLLING PROCESS USING FEM

A Thesis Submitted to the Addis Ababa Institute Technology, School of Graduate Studies, Addis Ababa University

In Partial Fulfillment of the Requirement for Degree of Master of Science In Mechanical Engineering (Mechanical Design Stream)

By

Befekadu Zewdie T/Mariam

Advisor: Dr. Daniel Tilahun

November, 2015

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Declaration

I hereby declare that the work which is being presented in this thesis entitled "PERFORMANCE ANALYSIS OF ROLLING MILL ROLLS" is original work of my own, has not been presented for a degree in any other university; and that all sources of material used for the thesis have been duly acknowledged.

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Thesis Advisor	Signature	Date

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I am very grateful to all my families for their love, Special Gratitude to my wife's and my mother's encouragement. Her 'prayed' was crucial to my starting and completing of this work. Without them none of my dreams would have become reality.

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All the above people and those who are not mentioned but contribute a lot toward successful understanding of my endeavor herby merit my sincere appreciations.

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Abstract

The main objective of rolling theory is to predict the manner of the plastic deformation. In hot rolling the chief factors influencing the yield stress are the nature of the material, the temperature at which the material is rolled and the strain rate, i.e. the rate of deformation. And also the main factors that influence the mechanics of rolling may be listed as follows: the roll diameter, reduction in one pass, the initial thickness of the stock, the speed of rolling (which decides the strain rate), the nature of friction between the rolls and the material rolled, the temperature field in the billet and the rolls, the mill behavior under load, the aspect ratio, or the ratio of the width of stock to the initial thickness, etc..). Those factors creates secondary parameters and phenomena more directly related to and commonly associated with the rolling process, such as: Coefficient of draught, Spread, Coefficient of elongation, Bite angle, roll gap, slip, roll pressure, torque, work and power which are influenced by the above factors.

This thesis is to analyze the deformation of billet size 120x120x3000mm, modeling and Simulation of hot rolling roughing mill first pass by finite element method. To do this three dimensional roll and billet was developed in CATIA version 5. This 3D model was imported to ANSYS work bench 16.0. FEM analysis was done after assigning, boundary conditions, displacement, rotational velocity, and load.

From the simulated results, the Directional Deformation and Equivalent Stress for the hot rolling of billet can be worked out. The hot continuous rolling process are simulated to analyze the cause of Deformation considering the roll pass design parameters, then the roll pass optimization is worked out based on the analysis of the deformation of billet with rolls. This simulation results are verified by the actual test stress vs. Strain curve.

Keywords: Steel Industry, roll pass design, rolling process, Coefficient of draught, Spread, Coefficient of elongation, Bite angle, rolls gap and slip.

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Nomenclature

ZuSRoM	Zqualla steel rolling mill
FEM	Finite Element Method
FEA	Finite Element Analysis
ASTM	American Society of Testing Materials
R	Radius of Rolls
v	Peripheral speed of Rolls
h_i or H	Initial height
h_f or h	Final height
v_i	Entrant speed of billet
v_f	Exit speed of billet
p_r	Radial force
L_p	Arc of contact in the Roll gap
F	Tangential force
α	Roll bite angle
β	Stick to slip transition friction region
θ	Neutral point angle
Δh	Draft
V_p	Peripheral velocity
N	Deformation zone
T	Friction force
f or(μ)	Coefficient of friction
ε	Relative Deformation
ω	Roll angular velocity

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Chapter one

1. Introduction

1.1. Background of the project

Rolling mills are generally classified according to their product or their layout or temperature and are specified by the number of rolls in each stand. According to the Basis of Number of Rolls, stand may be termed as two-high, **three-high**, four-high, twelve-high or twenty-high Mills having six or more rolls are generally termed as cluster mills. The purpose of rolling is to convert material of large cross-sections into smaller sections of various shapes. This deformation is accomplished by applying compressive force through a set of rolls. [31]

The rod or bar hot continuous rolling process is a widely used industrial process because it makes possible high production and close control of the final product shape and properties to increase one country in metal technology. The level of per capita consumption of steel is treated as an important index of the level of socio economic development and living standards of the people in any country. It is a product of a large and technologically complex industry having strong forward and backward linkages in terms of material flow and income generation. It accounts for about 90 percent of all metals produced by a metal working process. Rolling is one of the oldest processes used in the metal working industry. In view of the tremendous volume and wide variety of rolled products manufactured each year, rolling can be considered to be one of the most important forming processes. Rolling processes are classified as cold or hot rolling according to whether work hardening occurs.[3]

There is no work hardening during hot rolling. In this thesis, only hot rolling of bar is considered. Simulation and Modeling of Roughing first pass Deformation of ZuSRoM. Zuqualla steel rolling mill manufactures and markets steel bars. The company was founded in 1997 G.C and is based in Debre zeite, Ethiopia.[24]

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As to its product mixes, at the time of installation it was envisaged to produce:

- **Reinforcement bars** both plain and deformed from **Diameter of 10-32 mm**; and
- **Structural Steel** shapes of:
  - Square Sections from 10-20 mm;
  - Flat Sections from 20X5 mm -50X50 mm; and
  - Angle Iron from25 X 25 X 3 mm -50 X 50 X 6 mm.

Though the machineries and equipment's initially purchased were known to be reconditioned second-hand, the installed capacity of the mill was always quoted as new technical capacity recommended by the producing factory. As a result in all documents reviewed the mill capacity is stated to be 96,000-100,000 Tons of different steel products per annum. However, the mill has never reached a quarter of this capacity in its history of more than ten years in production.

Thus even though there are other constraints that would have influenced the total production of the mill, it is hard to entirely exclude the technical problem for below capacity production of the mill. **Therefore this paper work will attempt on the analysis of the manufacturing systems of the mill and identification of impacting factors too many defects caused by due to technical problems.** One of the major reasons is deformation of billet on the **1st pass of 3- high roughing stand.** Plastic deformation of metal is the basic concept used for rolling mill, therefor due to this technical reason the Mill is currently losing much of its products as cobbles. Thus by improving the shape of the roll pass in which the material being deformed, it is possible to reduce the level of the loss to the standard.

The Enterprise has passed through years with no satisfactory results then the Mill has never been able to produce to a significant level of its installed capacity due to different technical problems. We need to concentrate on technical problems in order to recommend appropriate solutions in the upcoming production schedules. These problems should be identified and enumerated according to their importance. The following list will indicate some of the critical technical problems of the Mill:

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- Its downtime is high due to repeated interruption of the production process with different reasons. This time is estimated to be more than 155 working days in a year (in 2005). Due to this the Mill is currently losing much of its products as cutoffs, scales and cobbles. This loss is estimated to reach more than 10% of the total billet used (the standard is only 5%).

- Fuel consumption of the Furnace is very high and uneconomical due to the interruption of the process. The current Furnace capacity is estimated to produce a maximum of 16 Tons of steel products per hour with a consumption of 90kg of fuel per Ton. With the currently inflated local fuel price, this is not tolerable by all standards.

As a result, the mill had been produced a maximum of 19,450 Tons of de-bars (which is less than 20% of its said capacity) in 2007 and had been dropped to 6,317 Tons in 2004 with an average of 13,473 Tons per year for seven years (2002-2008). Comparing with the machineries and equipment's initially purchased were known to be reconditioned second-hand, the installed capacity of the mill was always quoted as new technical capacity recommended by the producing factory. Thus by improving the shape of the roll pass in which the material being deformed, it is possible to reduce the level of the loss to the standard using FEM Analysis.

Roughing or cogging mills: it includes mills producing semi products like blooms, slabs, billets and tube billets. Section mills: it includes mills producing rails, heavy, medium and light structural sections, round and square bars and wire rods, strips, Plate and sheet mills including wide and medium strip mills. Tube mills including plants for production of both seamless and welded tubes. This Schematic out line shown below in **(Figure 1.1)**

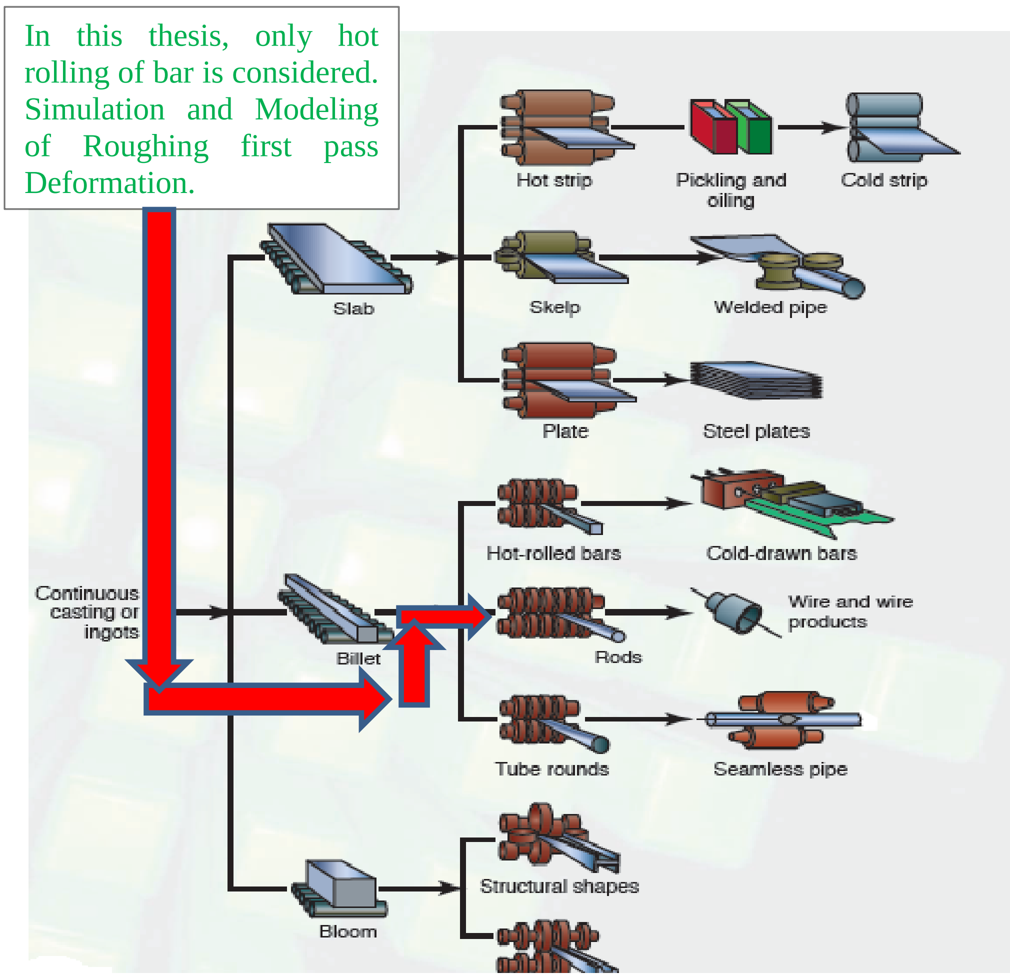

Figure1.1. Schematic out line of various Shape- Rolling and flat-Rolling operation. Source: American Iron and Steel Institute [20].

Because of the complex nature of rolling mill roll design, a thorough understanding of the available methods and conditions of their application is extremely important in order to achieve high quality rolled products. Therefore, a further investigation of existing rolling methods in general is necessary for further contribution to the solution of the roll design problem.

1.1.1. Historical Outline

The History of Rolling Mill, It Has long been thought that rolling, which accounts for about 90% of all metals produced by metal working processes, was first developed in the late 1500's. However, it was none other than the great *Leonardo da Vinci*, who, in the section of his note books dedicated to the study of mechanisms and machines, first described an exact and fully functional design of a rolling mill dedicated to the flat rolling process **(Figure 1.2).** As reported by Cianchi, "*Leonardo da Vinci* describes in his notebooks that these two machines were intended for producing sheets by making the metal pass between the principal rollers**"[8]**.

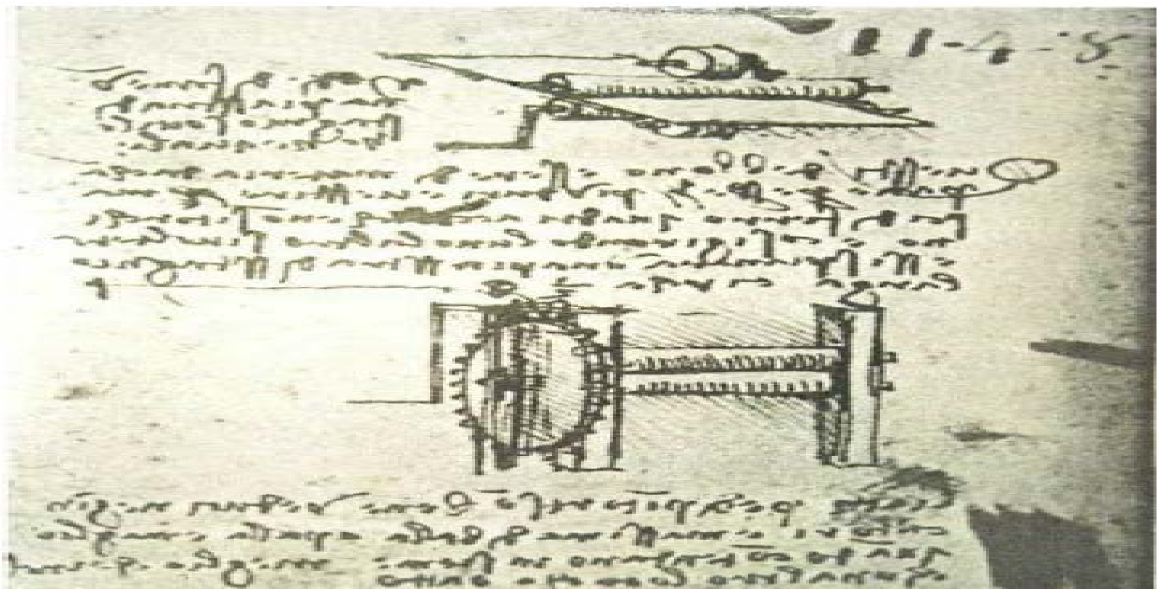

Figure1.2 Leonardo's rolling mill Design [8].

In the 1500's and 1600's very primitive mills were used to roll sheets of gold, silver, tin, and even for making coins. The use of rolls in an iron works was a German development of the 16th century. Belgium and England both started to use rolls about the same time, and so these three countries are considered as the birth place of rolling. By 1682 Great Britain had become the leading nation in the rolling industry and the first records of hot rolling appear, with large rolling mills for the hot rolling of ferrous materials near Newcastle, England. From that point and during the early part of the eighteenth century, rolling mills expanded to the continent.

During the early part of the 18th century, Christopher Polhem from Sweden, designed the first mill with 4rolls, with the backup rolls driven, in a very similar manner to how the modern Lauth mill works. In 1728 a patent for a mill to roll hammered bars was issued to John Payne in England. **(Figure 1.3)**

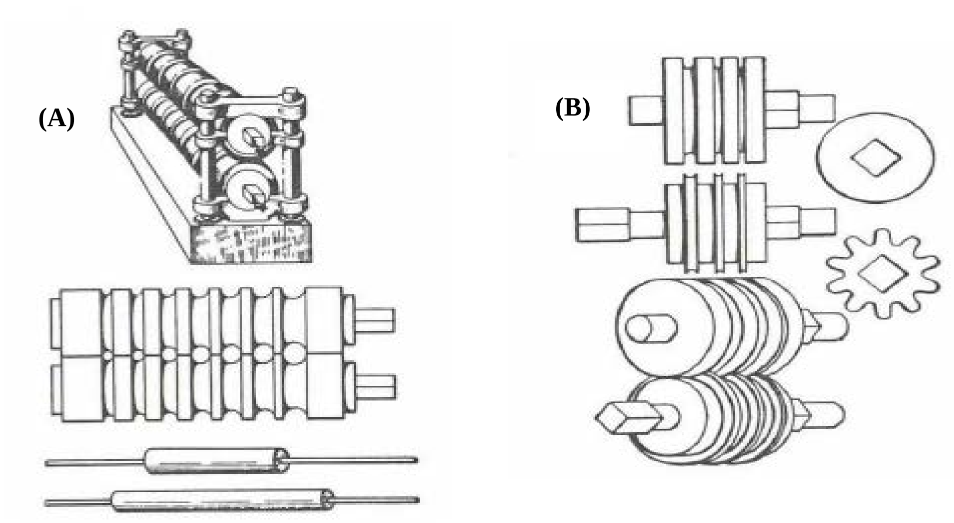

Figure1.3 (a) Rolls designed by John Paynein1728 to produce round bars
(b) English patent issued to John Purnellin 1766 for grooved mills driven in unison by coupling boxes and pinions.[8]

It is in this same period, that the general appearance of these hot mills began to change to the modern form. For example, the cast housing and the single screw on each side of the mill became a standard, as we can see in a design by William Playfield in 1782.

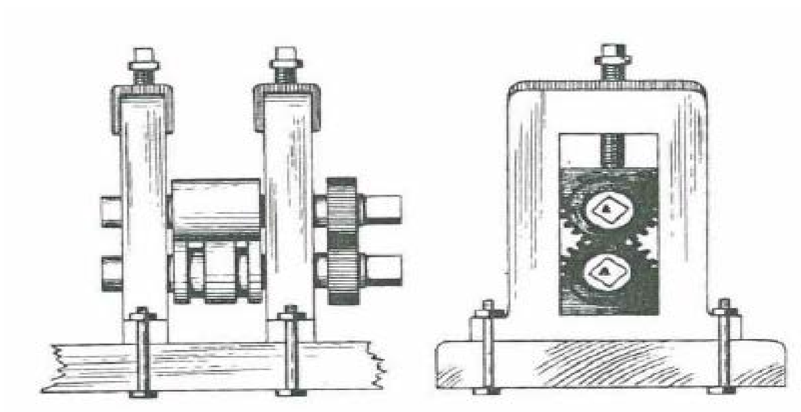

Figure 1.4 English patent specifications filed by W.Playfieldin1783 for grooved mills driven in unison by coupling boxes and pinions[8].

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In the beginning of the 19th century, the industrial revolution in England was gathering momentum, creating an unprecedented demand for iron and steel. Accordingly, rolling mill developments were numerous and important. John Bikenshaw started the first rail rolling Mill In 1820 Producing wrought iron rails in lengths of 15 to 18 feet. In 1831 the first Trail was rolled in England and the first I beams were rolled by Zores in Paris in 1849[8]. Three high mills were also introduced about the middle of the century. A British patent for such a mill, designed for rolling heavy sections, was granted in 1853 to R. Roden. In this mill, the middle roll was driven and fixed in the housing while the upper and lower rolls were adjustable in position. On the same mill, a steam-operated lifting table raised and lowered the material to be rolled.

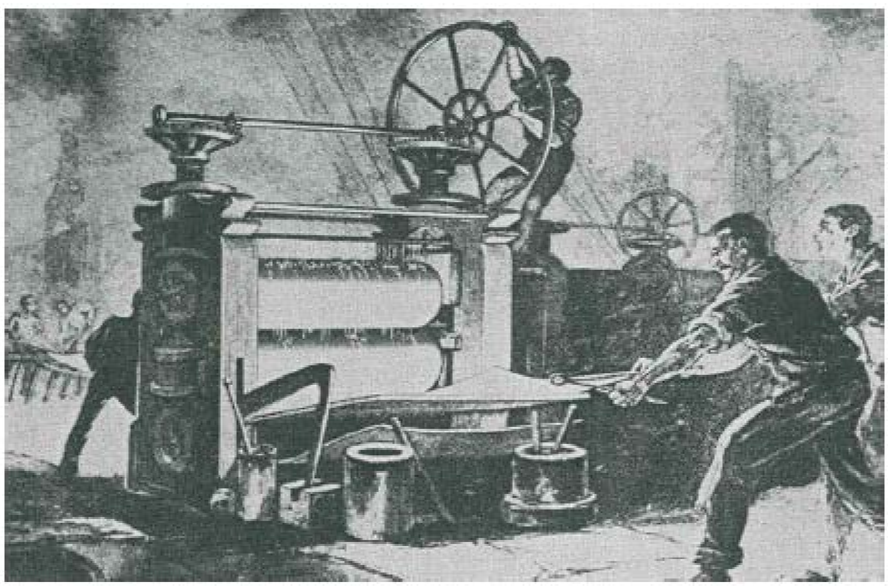

Figure1.5 Typical Sheet mill of the 1860's[8]

In midcentury, the first reversing plate mill was put into operation at the Park gate Works in England, and in 1854 it was used to roll the plates for the "Great Eastern" steamship. In 1848, R.M. Daelen of Lendersdorf, Germany, who also built the first mill of this type about seven years later, invented the universal mill. The first mill constructed on the continuous principle of rolling iron or steel was patented to Charles White of Wales [8].

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Roberts also writes: “a British patent issued in 1862 to J.T. Newton of Wales, described a predecessor to the modern cluster mill, in as much as it used small work rolls backed up by others of large diameter. The work rolls were driven but the pressure was applied by the large backup rolls, a principle utilized in both the hot and cold mills of today” [8].

The four-high mill with its rolls in the same vertical plane was introduced in 1872 by Bleckley of England; Tandem rolling of hot steel took an upsurge around 1890, and in 1892, a semi-continuous hot strip mill, with a mechanically geared two-high tandem finishing train, was built at Bohemia.

As reported by Roberts, “the first record of tandem cold rolling of steel strip goes back to about 1904, when the West Leechburg Steel Company installed and operated a 2-high 4-stand tandem mill, each stand being driven by a separate, adjustable speed dc motor. Reel tandem mill operation, with tension between stands, and a tension reel was developed around 1915, on mills in Pittsburgh, Pennsylvania” [8].

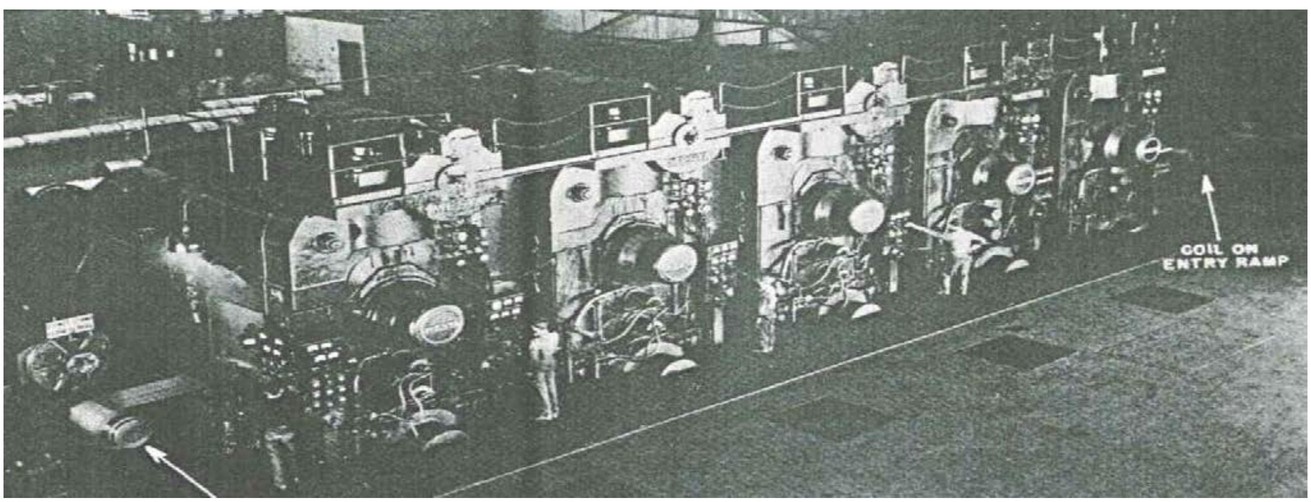

Figure1.6 48-inch, high-speed, five-stand tandem cold-reduction mill [8]

Figure 1.6 shows an example of five stand tandem mills, which came into use in the 1930’s for the production of tin plate. Six stand mills were introduced in the 1960’s with still more installed horsepower and slightly larger work rolls. In the 1970’s and 1980’s new and larger fully continuous mills were put into operation.

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Figure1.7 Rough pass in a hot rolling mill [8]

Finally, in the late 80’s and in the beginning of the 1990’s , the rolling industry began to take advantage of the development of the CNC & CAD/CAM technology, particularly applied to the design and manufacture of rolls for hot-rolled steel special section profiles.

The major development in the metal forming industry in the end of the 20th and the beginning of the 21st centuries has been the application of Finite Element Method (FEM) to the solution of complicated non-linear metal deformation processes.

1.1.2. Deformation of a material

During the metal rolling operation, mill rolls are continuously heated by a work heat due to the plastic deformation of the rolled metal, a frictional heat generated between the rolled metal and the rolls, and, in the case of hot rolling, heat transfer from hot metal work piece. Particularly in the case of hot rolling steel where the steel to be rolled is preheated to temperatures in excess of 1110°C, roll heating as a result of heat transfer can become rather excessive. When mechanical machinery move in periodical motion, stresses to the metal surfaces occur, often leading to Deformation of a material. [1]

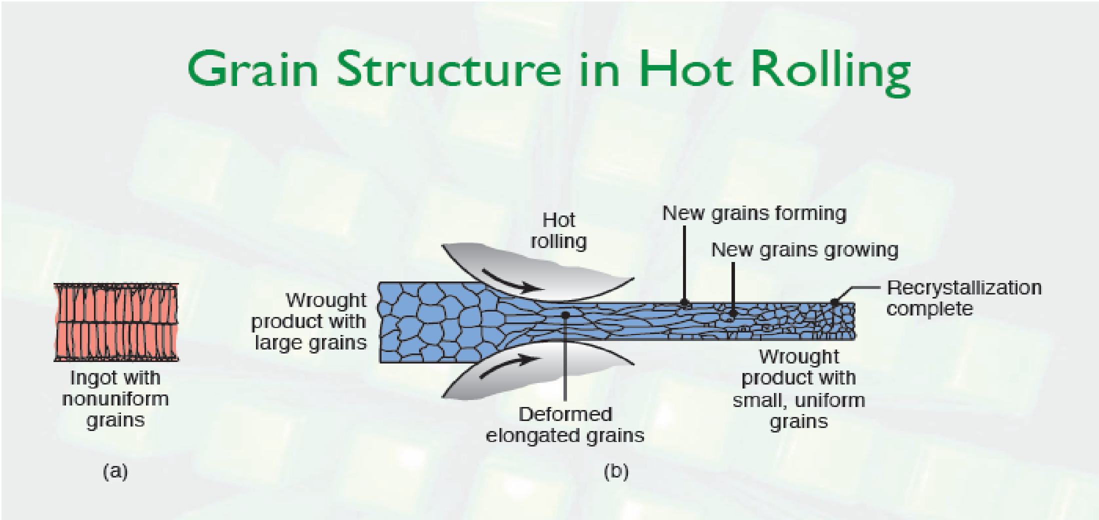

Figure1.8 changes in the grain structure of metals during hot rolling.

(a) Ingot with non-uniform grains; (b) wrought product with large grain, Deformed elongated grains, and wrought product with small, uniform grains[20]

For hot working processes, large deformation can be successively repeated, as the metal remains soft and ductile. The metal stock is subjected to high compressive stresses as a result of the friction between the rolls and the metal surface. Rolling involves passing the material between two rolls revolving more or less at the same peripheral speed but in opposite directions, i.e., clockwise and counterclockwise. The distance between them is spaced, which is somewhat less than the height of the metal stock entering them.

These rolls can either be flat or grooved (contoured) for the hot rolling of rods or shapes. Under these conditions, the rolls grip the piece of metal and deliver it, reduced in cross-sectional area and therefore, increased in length. The initial hot-working operation for most steel products is done on the primary roughing mill. These mills are normally three-high reversing mills with 450 mm diameter rolls (designated by size). One of the pre requisites of the hot rolling practice is heating the input billet from the room temperature to the rolling temperature. Rolling is classified according to the temperature of the metal rolled. **If the temperature of the metal stock is above its recrystallization temperature then the process is termed as hot rolling, whereas if the temperature of stock is below its recrystallization temperature the process is known as cold rolling. [38]**

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Hot rolling is accomplished above recrystallization temperature but below the melting point of the metal. The process of hot rolling basically consists of passing the hot billet through two rolls rotating in opposite directions at a uniform peripheral speed. During deformation of metal between the rolls the work is subjected to high compressive stresses from squeezing action of the rolls and to surface shear stresses as a result of the friction between the rolls and the metal. Therefore, work rolls for hot rolling mill should have superior resistance to compression and thermal shock. In addition the material of rolling mill, roll is required to have excellent wear resistant to meet the demand of high dimensional accuracy and surface smoothness of the rolled products.[28]

Hot rolling takes place in a number of steps and drafting / reduction is given in every stage. The ultimate draft is at a temperature above the recrystallizations or phase change temperature. Accordingly the cold stock is heated to a much higher temperature than the recrystallization temperature. Therefore, the ultimate temperature to which the work piece depends on the amount of total draft, the number of steps where the drafting is provided and the composition of the steel stock.[3]

Hot rolling is conducted by raising the temperature of the steel metal stock to its upper critical temperature to its austenitic phase, i.e., above the recrystallization temperature. Then controlled load is applied which forms the material to the desired profile and specification. The austenite grains get deformed / elongated in the rolling direction. However, these elongated grains start recrystallizing as soon as these come out from the deformation zone. Stabilizing as soon as these come out from **the deformation zone**.

The rate of recrystallization is heavily influenced by the amount of deformation applied. Heavily deformed materials recrystallize more rapidly than those deformed to a lesser extent. Indeed, below a certain percentage deformation recrystallization may never occur. In three - high mills, three rolls are arranged horizontally. Steel passes forward between the middle roll and bottom roll and backward between the middle and top rolls. This consist of upper, middle and lower rolls driven by electric motors and allows a series of reductions without the need to change the rotational direction of the rolls, i.e., directions of rotation of the rolls in three-high mills are not reversed.

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1.1.3. Rolling & its Parameters [34]

"Draught", also known as draft, is a term meant to express the reduction in cross section height/ area or reduction in height in a vertical direction when compressed between two rolls. Draft is either direct or indirect. Indirect draft results when the rolls exert on the stock in non-vertical direction. Basically it is a grinding action between the collars of two rolls rotating in opposite direction.

When part of the pass profile is inclined in between the vertical and horizontal, the deformation is caused by a combination of direct as well as indirect drafting. Up to an inclination of 45^0 with the horizontal direct drafting predominates. However, above 45^0 inclinations the effects of indirect drafting come in to play. Near 90^0 the deformation depends almost entirely on indirect draft.

"Elongation" in stock length is associated with reduction in area, as volume of metal leaves the rolls as enters them is equal. Elongation factor, i.e., the ratio of the final length to the initial length is always greater than unity.

"Spread"

- When steel stock is compressed between two rolls, it obviously moves in the direction of least resistance. There is not only a longitudinal flow but also some lateral flow, which is called 'Spread'.
- Rolling signifies one action but two reactions. The rolls apply a 'reduction' (vertically); this reduction produces an 'elongation' and 'spread' (sideways).
- The stock under vertical compression meets some longitudinal resistance to free elongation which assists in causing sideways spread.
- Spread is the flow of material at right angles to the directions compression and elongation.
- The coefficient of spread is the ratio between exit and entry width.
- The higher the coefficient of friction, higher is the resistance to lengthwise flow and more is the spread.
- Spread is the most difficult and complex of all the parameters in rolling to understand.
- The quantum of spread can never be worked out analytically. Neither any formula nor any method of computation is available to quantify spread.

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1.1.4. Deformation Processes

Deformation processes transform solid materials from one shape into another as per the roll pass design. A sequence of such processes is generally used to form material progressively from a simple geometry in to a complex shape, whereby the tools represent the desired geometry and impart compressive or tensile stresses to the deforming material through the two roll -material interface, as illustrated in Figure 1.9. Deformation processes are frequently used in conjunction with other unit operations, such as casting, machining, grinding, and heat treating, to complete the transformation from raw material to finished and assembly-ready discrete parts. Deformation processes, along with machining, have been at the core of modem mass production, because they involve primarily metal flow and do not depend on long-term metallurgical rate processes.

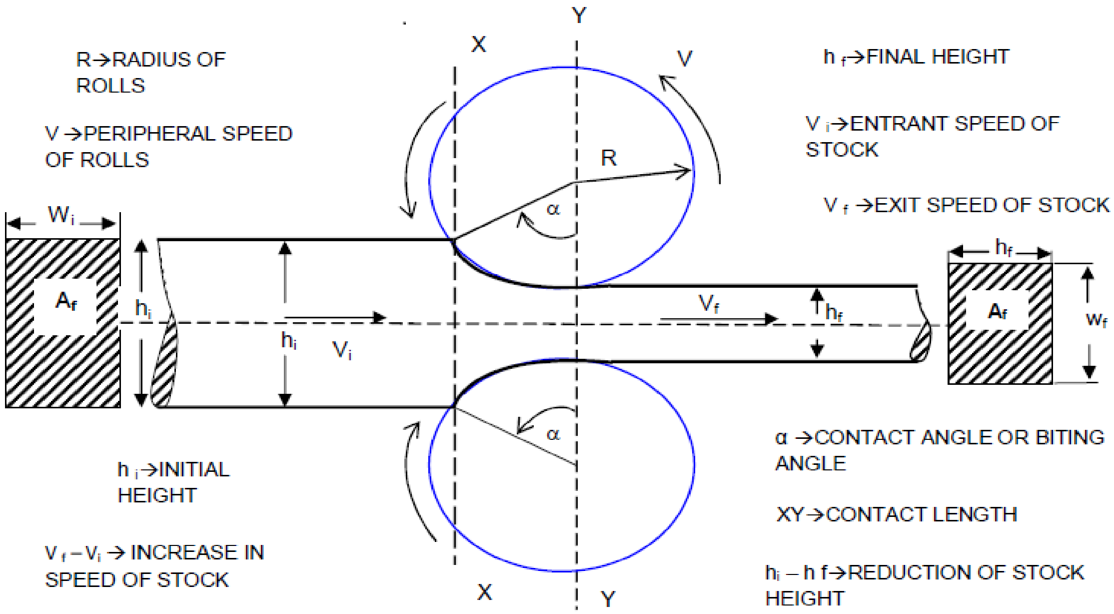

Figure1.9 Rolling Parameters [34]

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1.1.5. Classification and Characteristics of Processes

Deformation processes can be conveniently classified into bulk-forming processes (e.g., rolling, extrusion, and forging) and sheet-forming processes (e.g., stretching, flanging, drawing, and contouring). In both cases, the surfaces of the deforming material and of the tools are usually in contact, and friction between them has a major influence, as illustrated in Figure1.10. In bulk forming, the input material is in billet, rod, or slab form, and a considerable increase in the surface-to-volume ratio occurs in the formed part. In sheet forming, a sheet blank is plastically deformed into a complex three-dimensional configuration, usually without any significant change in sheet thickness and surface characteristics.[34]

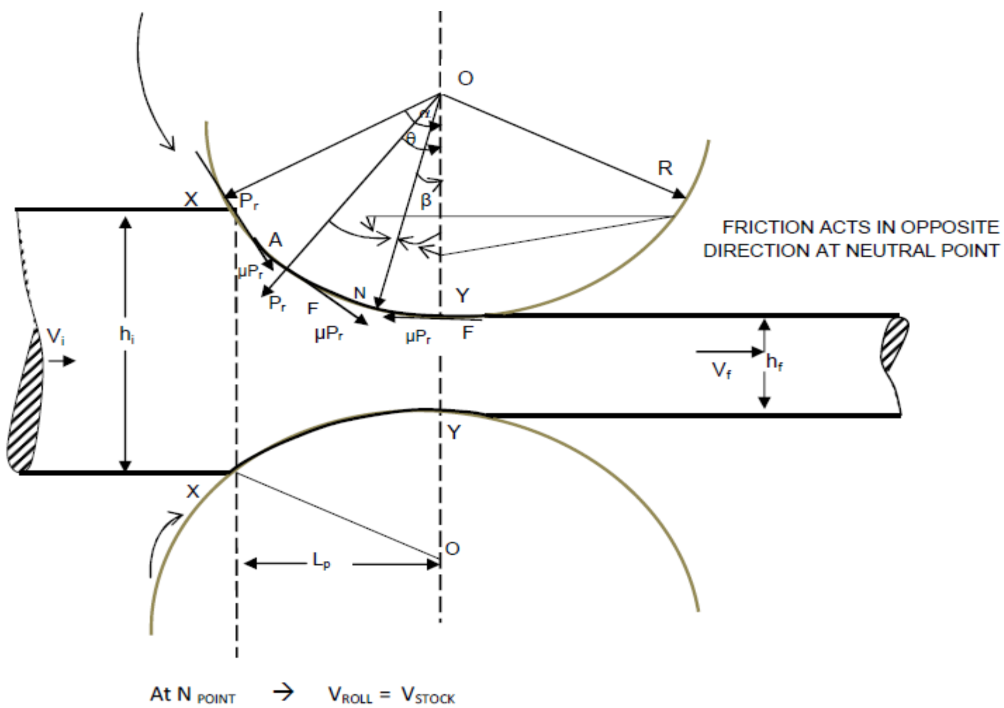

Figure1.10 Forces in Rolling and Friction acts in opposite direction at neutral point [34]

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1.2. Objective

1.2.1. General objective

The General objective of this thesis is to determine billet deformation and to predict the manner of the plastic deformation for long parts of constant cross section and the establishing of product geometry and quality.

Analyze the first pass of 3-high roughing rolling production process and estimate the deformation in the rolling contact of two rolls and billets by finite element method.

The main factors that influence the mechanics of rolling may be listed as given below:

1. Reduction in one pass.
2. The initial thickness of the billet.
3. The temperature field in the material and the rolls.
4. The aspect ratio or the ratios of the width of stock to the initial thickness.

1.2.2. Specific Objective

The specific goal of the thesis are :-

- ❖ Model the 3-high roughing mill roll and billet assembly by CATIA and transfer to ANSYS work bench software's. To obtain these parametric results modeling and analyzing finite element analysis (FEA).
- ❖ Simulation of the deformation process of the first pass of three high roughing mill (ZuSRoM).
- ❖ Comparative analysis of the simulation result based on the deformation of billet with rolls of 1st pass and the experimental result which is the actual test.

The followings are some of the benefits:

a) Minimize production cost by apply proper deformation and reduce the occurrence of loss of billets (cobbles) and having proper mounting and dismounting period as per the design.

b) By improving the production capacity then Meeting delivery schedule and time to market. The company can increase the prospect of delivering a quality product to the customer.

`

1.3. Statement of the problems [21, 23, 24, 25, 26]

Zuqualla Steel rolling mill (ZuSRoM) Enterprise one of steel bar manufacturing industries of the country, which is located at Debri Zeite 40km away from Addis. It was established 20 years back and the prime need for its establishment was to produce and supply reinforcement and structural bars that are used for various sectors including the manufacturing sector itself as main inputs.

However, recently increasing number of private investments in the sub-sector is a good indication that shows its share in the economy is growing and encouraging. But still it should be noted that these existing small number of plants are not able to utilize their huge installed capacities and they are far below capacity. As a result the country is currently obliged to import finished Iron Bars and Structural profiles by using the scarce foreign currency. As a result it is possible to say the development of the **Rolling technology** is at its infant stage in Ethiopia.

The Enterprise has passed through years with no satisfactory results then the Mill has never been able to produce to a significant level of its installed capacity due to different technical problems. We need to concentrate on technical problems in order to recommend appropriate solutions in the upcoming production schedules. These problems should be identified and enumerated according to their importance. The following list will indicate some of the critical technical problems of the Mill,

- Its downtime is high due to repeated interruption of the production process with different reasons. This time is estimated to be more than 155 working days in a year (in 2005). Due to this the Mill is currently losing much of its products as cutoffs, scales and cobbles. This loss is estimated to reach more than 10% of the total billet used (the standard is only 5%).
- Fuel consumption of the Furnace is very high and uneconomical due to the interruption of the process. The current Furnace capacity is estimated to produce a maximum of 16 Tons of steel products per hour with a consumption of 90kg of fuel per Ton. With the currently inflated local fuel price, this is not tolerable by all standards.

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As a result, the mill had been produced a maximum of 19,450 Tons of de-bars (which is less than 20% of its said capacity) in 2007 and had been dropped to 6,317 Tons in 2004 with an average of 13,473 Tons per year for seven years (2002-2008). Comparing with the machineries and equipment's initially purchased were known to be reconditioned second-hand, the installed capacity of the mill was always quoted as new technical capacity recommended by the producing factory. Then in all documents reviewed the mill capacity is stated to be 96,000-100,000 Tons of different steel products per annum.

Thus even though there are other constraints that would have influenced the total production of the mill, it is hard to entirely exclude the technical problem for below capacity production of the mill. Therefore this paper work will attempt on the analysis of the manufacturing systems of the mill and identification of impacting factors too many defects caused by due to technical problems one of the major reason is **deformation of billet on the 1st pass of 3- high roughing stand.** Plastic deformation of metal is the basic concept used for rolling mill, there for due to this technical reason the Mill is currently losing much of its products as cobbles. Thus by improving the shape of the roll pass in which the material being deformed, it is possible to reduce the level of the loss to the standard.

The biggest drawback with experimental method is that it cannot be undertaken until a prototype exists. It is also very expensive to perform deformation tests. For these reasons FEA based deformation analysis has been perceived as an excellent enhancement to the experimental method. **However the research out puts on this area is limited.**

The modeling and investigation both static and dynamic analysis will indicate the billet deformation of the first pass of 3- high roughing mills is improper deformations as per the roll pass design. Improper deformation will lead to the occurrence of loss billets (cobbles) because it will not go through the next pass. Deformation of billet in the first pass of roughing mill in FEM (Finite Element Method) analysis will have several advantages over experimental methods.
An improved control factor of product geometry based on finite element analysis will be proposed to alleviate these losses. The result of the analysis and the implementation of the design will contribute to the improvement of production cost and time.

1.4. Scope and limitation of the paper

This work will be concerned mainly with the brief presentation of various parameters that affect the rolling process and also with some of the major theories that have been presented by recent re searchers on the subject. However the research outputs on this area is limited.

Emphasis will be laid more on the mechanics of bar rolling with a critical appraisal of the various theories available on the subject, from the point of view of suitability of use for the establishment of parameters leading to the design for a specific process. The scope of this paper is to perform parametric study to investigate the effect of reduction in one pass, the temperature field in the billet and the rolls and loading condition contact stress in roll (not rollers in hot rolling terminology) and billets (raw material) and FEM simulation to study the effect of deformation on hot rolling mill roughing first pass according to the roll pass design. To minimize computational time as per the recommendation of researcher's specially for the first pass of roughing mill deformation is used two rolls without contour(grooves) for the analysis in FEM.

The concerns of the rolling process are wide and correspondingly the FEM can be applied on each of them. However, due to the limited availability of time, software materials, etc. it is difficult to cover the whole portion in this thesis work. The following are the limitations of the study:

- The analysis is done in ordinary computers, and use cracked software (ANSYS) version 16.0.
- An important parameter in the operation of hot rolling mill is **the cooling mechanism of work roll.** The determination of the best geometry of the cooling system, therefore, plays an important role in **obtaining the highest heat transfer coefficient** and in avoiding lateral water splashes. This analysis was not considered in the current study. But consideration of such things will give better result.

1.5. Organization of the paper

This thesis is organized in to five chapters. In the first chapter background, objective (General and specific), statement of the problem, scope and limitation of the paper are discussed. In chapter two a survey of literatures related to the research have been investigated. In chapter three materials used, dimensions and methods (FEM) for deformation of billets at different load conditions between two rolls on the first pass of roughing mill have been discussed. In chapter four results found were discussed and finally, in chapter five the conclusions recommendations and future work are presented.

Chapter two

2. Literature Review

2.1. Introduction

There are three zones in rolling process. These are Backward or lagging zone, Neutral Zone, Forward or leading zone. Deformation is the change in dimensions or form under the action of applied forces. Deformation is caused either by mechanical action of external forces or by various physical and physiochemical process. The process of deformation comprises the Elastic deformation, Plastic deformation, and Fracture. The plastic deformation of metal may occur by slip. Plastic deformation of metal is the basic concept used for rolling process commonly used for manufacturing of materials where smallest part are called crystal grain that has uniform properties. However, the research out puts on this area is limited. Some of the researches' outputs in relation to the objective of this thesis are:

V. Yadav1, A.K. Singh2 and U.S. Dixit3[31] In this work, the material parameters for power law and coefficient of friction are obtained using inverse analysis by measuring exit strip temperature and slip. The procedure makes use of finite element model for deformation and an analytical method for the estimation of temperature. A heuristic optimization algorithm is used for this purpose that minimizes the error between the measured and estimated flow stresses. The method is verified by conducting some numerical experiments. Less than 1% error is observed. A methodology of Yadav et al. (2013) has been employed to obtain the average temperature of both roll and strip at the interface. In this work, two sub-modules are used for obtaining the temperature distribution. One sub-module finds the temperature distribution in the strip when the heat generation due to plastic deformation and due to friction is known. The other sub-module estimates the temperature distribution in rolls, when the heat transfer through the roll-strip interface is known. [31]

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Rudolf Pernis, J. Kasala [32] The main aim of the present paper is the distribution of relative deformation in rolling zone; due to the fact that relative deformation along the length of contact arc is changed. Mathematical analysis of the distribution of relative deformation covers elliptic distribution. Average value of relative deformation in rolling zone was obtained as integral value which more accurately describes total quantity of deformation.

S M Byon , S I Kim and Y Lee [35] This documents basically concerning about, A laboratory-scale hot-plate rolling experiment, together with three-dimensional finite element analysis coupled with the proposed model. It has been performed to investigate the accuracy of the proposed constitutive model. A large-deformation constitutive model applicable to the calculation of roll force and torque in heavy-reduction rolling has been presented.
The finite element predictions of roll force based on the proposed model and the experimental results was shown to be in fair agreement whereas those based on the Misaka–Yoshimoto model, in which dynamic recrystallization was not considered, failed to predict the roll force precisely at heavy reduction.

Valentin Nikolayevich DANCHENKO [36] This paper Presented, the fundamentals of plastic deformation of ferrous metals, non-ferrous metals and alloys. The deformation is conducted in heated state for decreasing the strain resistance and increasing the plasticity of the worked metal. The rise in temperature no higher than $(0.3\text{-}0.4)T_f$ (T_f – the metal fusion temperature in absolute scale, ºK) doesn't bring the structure changes to the metal, but the acceleration of diffusion processes contributes to the healing of structure defects and drop of inner stresses in metal. At temperatures of heating higher than 0.4Tf the process of grain recovery takes place in the metal.

Kristina Nordén [12]The main aim of the present paper is the evolution and reduction of cracks during shape rolling is studied in this thesis. To accomplish this, artificial longitudinal cracks are machined along bars of high speed steel. The cracks are positioned at different sites evenly distributed along the periphery in intervals of 45°. Some of the cracks are left open and some are filled with carbon or stainless steel welds. FE simulations are performed using the commercial

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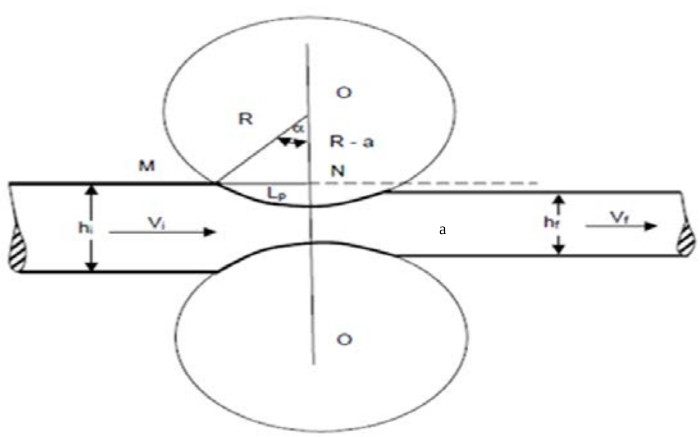
code MSC.Marc and the results from the simulations are compared with experimental ones. Generally, simulations predict less reduction than observed experimentally.

Xuetong Li, Lei Cao, Minting Wang, Fengshan Du This paper describes New flat-oval groove rolling process of multi-direction deformation is proposed to manufacture ultra-fine grain bar. Application of new groove series can introduce uniform large plastic strain into whole cross section of the material, and meanwhile satisfy the requirements of shape and size. Principle of grain refinement, based on experimental research of small specimen, is that grain refinement of ferrite is mainly dynamic recrystallization when low-carbon alloy steel is at low temperature deformation. Relationship of grain size and z-factor is also obtained through experimental research, as well as ultra-fine ferrite grain less than 1 micron. To predict strain, shape, dimensions and grain size of the material in rolling process, numerical simulation model of the warm groove bar rolling process is established via nonlinear finite element method, and distribution of grain size of the final section is obtained via finite element subroutine. The result indicates that ultra-fine grain bar rolling can accomplish at low temperature region.

Sar al Dutta. B. Tech. (Hons.), I.I.T. Analyzed the hot rolling technology process parameters such as: Hot rolling recrystallization, scale formation and its effect, rolling and its parameters, rolling force and their relationship, force rolling, pressure during rolling, roll bite condition, grooving decreases angle of contact, the maximum reduction, analysis of rolling load, friction and its effect and friction hill in rolling.

The maximum reduction



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The critical variables are $\mathbf{L_p}$ and **h**

From Δ MNO,

$$R^2 = L_p^{\ 2} + (R-a)^2$$

$$Lp^2 = R^2 - (R^2 - 2Ra + a^2)$$

$$= 2\,R_a - a^2$$

As **a** is much smaller than **R**, $\mathbf{a^2}$ ignored.

$L_p \approx \sqrt{([2\,R_a\,])} \approx \sqrt{R\Delta h}$ Where, $\mathbf{\Delta h = h_i - h_f = 2a}$

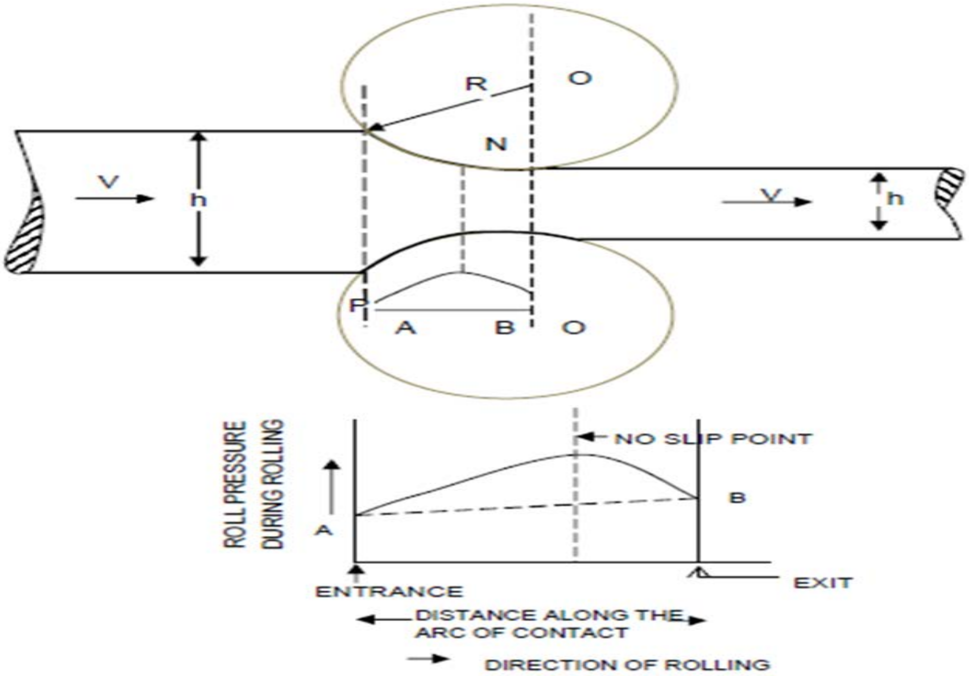
A large diameter roll permits a thicker work piece than a smaller diameter roll.

$$\mu = \tan \alpha = L_p / [\ R - \Delta\, h / 2\ ]$$

$$= \sqrt{R\Delta h}\ / [R - \Delta\, h / 2]$$

$= \sqrt{([\Delta\, h / 2\ ])}$ Therefore, $\mathbf{\Delta\ h\ max = \mu^2\ R}$

Friction Hill in rolling



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M. Graf, R. Kawalla [14] The paper presents a new method to describe and to predict the development of scale during metal forming processes, especially hot strip rolling processes. This is necessary because scale develops during all hot deformation processes over 600 °C and affects the mass loss of the raw weight as well as the surface quality of the semi-finished product. The main components of oxide scale at steel are wustite, magnetite, and hematite with various volume fractions. A challenge for the correct characterization of the total scale layer is the consideration of the strong inhomogeneity with respect to the mechanical properties of each scale component. Owing to these differences, the deformation behavior of the single oxide layers is diverse, too. As result of high deformation stresses, the oxide scale cracks, however low deformation degrees can be compensated.

Seyed Reza Motallebi1 [38] Illustrate the Influence Parameters on the Hot Rolling Process. Rolling process is one of the most popular processes in manufacturing industries in order to make different parts with a long rang variety of dimensions. In this procedure the internal raw material transform into desirable shape by at least two rolls. In comparison with other methods for analyzing 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 analyze the hot rolling process. In present research the influence 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 of part.

Huiping Hong, Yonglin Kang [15] Also Illustrates Billet and Roll Pass Optimization. In order to optimize the continuous rolling schedule for improving the quality of rolled tube billet, three dimensional thermal mechanical coupled finite element simulation is applied to analyze the multi-pass continuous rolling process of Φ100mm 37Mn5 steel tube billet from 200mm×200mm square cast bloom. Due to the larger plastic strain occurring at the corner area of the billet, the bias meshing method for the cross section of billet is used to fine the elements of surface and

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corner area. The stress, strain, temperature and rolling force of the hot continuous rolling process are simulated to analyse the cause of rolling defect, then the roll pass optimization is worked out based on the analysis of the rolling force variation. The simulated results are verified by the actual test.

Limei Jing [3] In this thesis, some previously published experimental and theoretical studies of hot rolling are reviewed. A thorough understanding of the available roll design methods, and conditions of their application is extremely important in order to achieve the objective of producing high quality rolled products. Successful hot roll design is dominated by the calculations of some important parameters, which describe two-dimensional (2D) or three-dimensional (3D) deformation in the work piece. These parameters, such as roll separation force, torque, elongation, spread and draft, are discussed in detail. The method or formula for the calculation of each parameter is different for each set of different application conditions. A thorough study of these methods in different application cases will lead to the optimized design of hot rolled products.

PUNEET KATYAL Presents result concerning the simulation of the actual housing model on the software . Rolling is defined as a process in which metal is formed through a pair of revolving rolls with plain or grooved barrels. The metal changes its shape gradually during the period in which it is in contact with the two rolls. Rolling is a major and a most widely used mechanical working technique. A Rolling mill is a complex machine for deforming metal in rotary rolls and performing auxiliary operations such as transportation of stock to rolls, disposal after rolling, cutting, cooling, melting. The problem of failure of Rolling Mill Housing was there in industry, which can be efficiently solved by using CAE.

DENG Wei. ZHAO De-wen. QIN Xiao-rnei , GAO Xiu-hua , DU Lin-xiu , LIU Xiang-hua[33] In this thesis, A new linear integral method for bar hot rolling on roughing train was obtained. First for plastic deformation energy rate, equivalent strain rate about Kobayashi's three-dimensional velocity field was expressed by two-dimensional strain rate vector; then the two-dimensional strain rate vector was inverted into inner product and was integrated term by term. During those processes boundary equation and mean value theorem were introduced; for friction

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and shear energy dissipation rate. Definite integral was applied to the solution process. Sequentially, the total upper bound power was minimized and the analytical expressions of rolling torque. Separating force and stress state factor were obtained. The calculated results by these expressions were compared with those of experimental values. The results show that the new linear integral method is available for bar rough rolling analysis and the calculated results by this method are a little higher than those of experimental ones. However, the maximum error between them is less than 10%.

Alejandro Rivera Muñiz [8] A nonlinear finite element model of the hot and cold rolling processes has been developed for flat rolling stock with rectangular cross section. This model can be used to analyze the flat rolling of cold and hot steel rectangular strips under a series of different parameters, providing the rolling designer with a tool that he can use to understand the behavior of the steel as it flows through the different passes. The models developed, take into account all of the non-linearities present in the rolling problem: material, geometric, boundary, and heat transfer. A coupled thermal-mechanical analysis approach is used to account for the coupling between the mechanical and thermal phenomena resulting from the pressure-dependent thermal contact resistance between the steel slab and the steel rolls. The model predicts the equivalent stress, equivalent plastic strain, maximum strain rate, equivalent total strain, slab temperature increase, increase in roll temperature, strip length increase, slab thickness % reduction (draft), and strip’s velocity increase, for both the cold and hot rolling processes. The FE model results are an improvement over the results obtained through the classical theory of rolling. The model also demonstrates the role that contact, plastic heat generation and friction generated heat plays in the rolling process.

AZoM, MMFX Steel Corporation of America[6] .This paper describes the testing and results of the Strength of Conventional Steel vs. MMFX2 Steel, the result shows the typical stress-strain curves for MMFX2 and ASTM A615 materials. MMFX2 rebar is a high-strength, uncoated corrosion-resistant reinforcing steel that has double the strength of traditional steel (120 ksi vs 60 ksi). This unique product results in less steel, less congestion, better constructability and faster construction times.

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K.P. Rao a,*, Y.K.D.V. Prasad b,1, E.B. Hawbolt In this paper, the softening behavior of a medium-carbon steel under hot working conditions in multi-stage compression is presented. Continuous and interrupted compression tests were performed in the temperature range 800–1100°C at strain rates of 0.1, 1 and 8 s-1. The interrupted deformations were conducted with delay times varying between 1 to 20 s after achieving a strain of approximately 0.2 to 0.4 in the first stage. The fractional softening has been predicted by three different methods, namely the offset-stress method, the back-extrapolation stress method and a currently proposed strain-recovery method. It has been found that the back-extrapolation stress method normally predicts higher reloading stress and hence a lower fractional softening than that of the offset-stress method. The strain-recovery method yields consistent results in the estimation of fractional softening that can be used in predicting the deformation mechanism. Influence of various parameters on fractional softening (estimated using the offset-stress method) during inter-hit delay. The deformation strain prior to softening was about 0.2–0.3. The multi-stage compression tests were performed in the temperature range of 800–1100^{0}C at strain rates of 0.1, 1 and 8 s-1.

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Chapter Three

3. Material, Methods and conditions

3.1. Material

Table3.1. List of material and its equivalency

-	USA	Great Bretain	China	Germany	Japan	Russia
Reinforcing	ASTM A615	BS4449	GB1499	DIN488	JIS G3112	Gost 5781

3.1.1. Raw material [Billet]

***Table3.2.* List of material and their characteristics**

Material: ASTM A615 GRADE 60

Properties of Billet			
	A	B	C
	Property	Value	Unit
1	Density	7.85E-06	kg/mm^3
2	Isotropic coefficient of thermal expansion		
	Coefficient of therman expansion	9E-06	C^{-1}
	Reference temperature	22	C
3	Iso tropic elasticity		
	Derive from	Young's Modulus and poisson's	
	Young's modulus	1.1E+11	Pa
	Poisson's ratio	0.3	
	Bulk modulus	9.1667E+10	Pa
	Shear modulus	4.2308E+10	Pa
4	Bilinear Isotropic hardening		
	Yield strength	4.2E+08	Pa
	Tangent Modulus	2E+10	Pa
5	Strain-Life parameters		
	Display curve type	Strain-Life	
	Strength Coefficient	1E+09	Pa
	Strength Exponent	-0.169	
	Ductility coefficient	0.213	
	Ductility Exponent	-0.33	
	Cyclic strength coefficeint	1E+10	Pa
	Cyclic strain hardening exponent	0.094	
6	Tensile yield strength	4.2E+08	Pa
7	Compressive yield strength	4.2E+08	Pa
8	Tensil Ultimate strength	6.2E+08	Pa
9	Compressive Ultimate strength	6.2E+09	Pa
10	Isotropic thermal conducitivity	0.0605	$W/mm/^0c$
11	Hardness	120	HB
12	Specific heat	434	$J/kg/^0c$
13	Isotropic Resistivity	1.7E.07	ohm m
14	Isotropic relative permeability	1000	μ/μ_0

`

3.1.2. Roll

***Table3.3.* List of material and their characteristics**

Material: NODULAR PEARLITIC CAST IRON

Properties of Rolls			
	A	B	C
	Property	Value	Unit
1	Density	7.2E-06	kg/ mm^{-3}
2	Iso tropic coefficient of thermal expansion		
	Coefficient of therman expansion	8E.06	C^{-1}
	Reference temperature	22	C
3	Iso tropic elasticity		
	Derive from	Young's Modulus and poisson's	
	Young's modulus	2.9E+11	Pa
	Poisson's ratio	0.211	
	Bulk modulus	1.1534E+11	Pa
	Shear modulus	8.2576E+10	Pa
4	Bilinear Isotropic hardening		
	Yield strength	6.2E+08	Pa
	Tangent Modulus	1E+11	Pa
5	Strain-Life parameters		
	Display curve type	Strain-Life	
	Strength Coefficient	7.93E+08	Pa
	Strength Exponent	0.094	
	Ductility coefficient	0.4482	
	Ductility Exponent	-0.6483	
	Cyclic strength coefficeint	8E+09	Pa
	Cyclic strain hardening exponent	0.2	
6	Tensile yield strength	6.2E+08	Pa
7	Compressive yield strength	6.2E+08	Pa
8	Tensile Ultimate strength	8.3E+08	Pa
9	Compressive Ulitimate strength	8.3E+08	Pa
10	Isotropic thermal conducitivity	0.0323	$W/mm/^{0}c$
11	Hardness	214	HB
12	Specific heat	506	$J/kg/^{0}c$
13	Isotropic Resistivity	0.0006	ohm mm
14	Isotropic Relative permeability	502	μ/μ_0

`

3.2. Rolls and Billets Dimensions

3.2.1. Billet (Raw material) basic dimension and standards [24,25,26]

A billet is piece of raw steel, before it is shaped into a finished product. A billet is a length of metal that has a square cross-section. Billets are created directly via continuous casting or indirectly via hot rolling an ingot or bloom. Billets are highly malleable and ductile, which allows them to be hot or cold "worked" to give them the specific shapes and properties desired. Final products include bar stock and wire.

The furnace and mill capacity have been designed taking into consideration the Size of the billets for designing criteria. Length of billets, (including continuously cast) shall be supplied in lengths between 3 m and 12 m as per the design.

Table 3.4 Commonly used size of billets in hot rolling production process (Dimension in mm)

Square size	**100x100**	**120x120**	**125x125**	**130x130**	**150x150**
Length	**3000-12000**	**3000-12000**	**3000-12000**	**3000-12000**	**3000-12000**

For this study a simulation model was performed using of ***120x120x3000*** mm billet dimensions.

Modeling of billet by CATIA

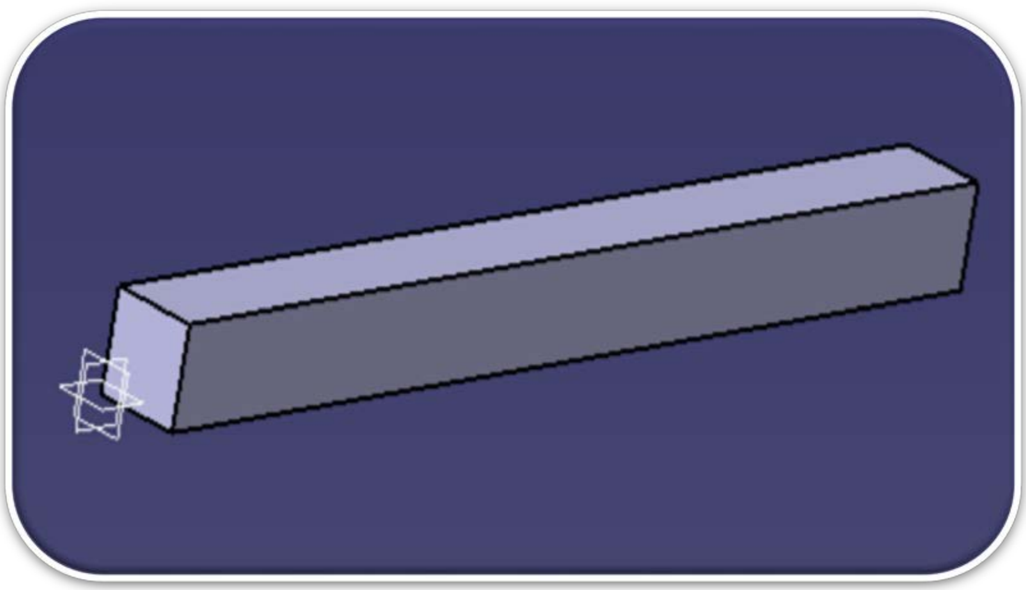

Figure3.1 Billet size 120x120 x 3000mm, Modeling of Billet.

`

3.2.2. Rolls Basic Dimension and Standards *[21, 24, 25, 26]*

Rolls are required to carry out the heavy work of reduction necessary for hot rolling. Rolls are tools which have to take all kinds of stresses, loads from normal and abnormal rolling and changing with roll wear during a rolling process. Rolls are regularly redressed to rebuild the desired shape and to eliminate the worn, fire-cracked and fatigued surface, and they never last as long as roll users would like.

The final goal is always to increase the quality of finished rolled products (tolerances, surface) and at the same time to increase the length of rolling process, to improve roll performance and to reduce the risks of roll damage.

Rolls come in a wide variety of sizes, the smallest roll weighs only a few kilograms, the heaviest around 250tons a piece, and the variety of grades used is also wide, from ductile iron to tungsten carbide, covering all kinds of tool steels and special steels, used only for rolls.

This study is concerned mainly with Zuqualla Steel Rolling Mill Enterprise hot rolling of first pass of roughing mill billet deformation. 3-high-roughing mill stand was suitable for hot rolling of the billets with initial cross-section 120 mm square and 3 m initial length in 8 passes. The rolling mill production was 70 billets per hour. The mass of one billet was 230 kg. The rolling material was reinforcement steel mark **Z** according to American standard ASTM A615 GRADE 60. The initial temperature of the rolled material in the first pass was 1100 C°. The roll speed was 133.6 rpm. The total length of the roll was 2300 mm, the roll barrel length was 1500 mm and the roll barrel diameter was 450 mm. The roll machining due to wearing was estimated after 4500 rolling tons of steel. Figure3.2 and Figure3.3 shows the roll design and groove distribution. Pass shape rolling sequence (pass schedule) between rolls and corresponding grooves are numbered.

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The plant roughing mill roll is seen in figure below :

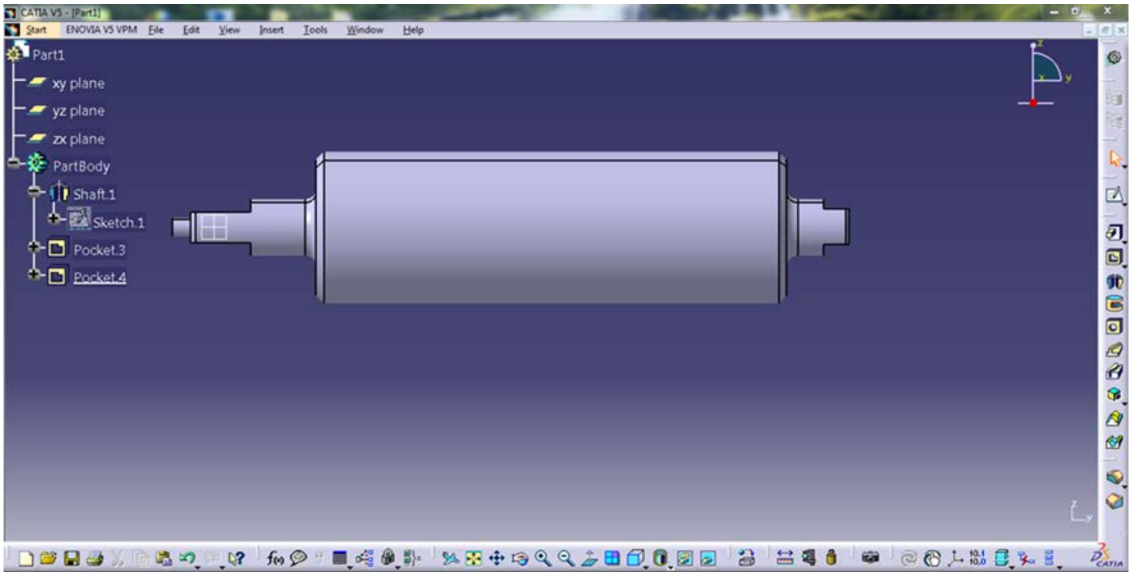

Figure3.2   Roughing Mill Roll

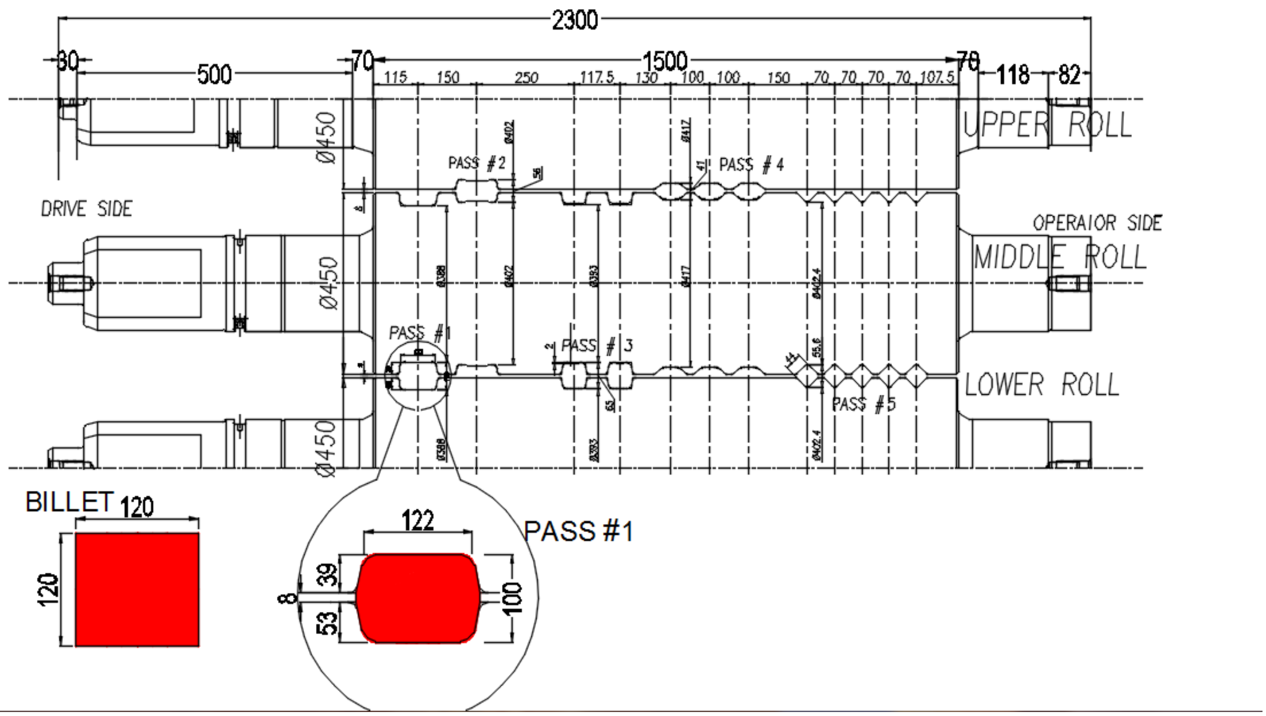

Figure3.3 3-High Roughing Mill Groove distribution

3.3. Methods

To fulfill the objectives of the study the following are used.

3.3.1. Geometrical Modeling Generation

The Rolls and Billet model development as well as the corresponding static and dynamic analysis is performed by using CATIA and ANSYS version 16 software.

In order to facilitate the finite elements analysis the real model of the rolls and billets can be simplify. The roller type Nodular Pearlitic Cast iron and the billet type ASTM A615 GRADE 60 ware used on this study because Zuqualla steel rolling mill used this types of rolls for 3-high roughing mill stands and Billet as a raw material. The main objectives of rolling theory are to predict the manner of the plastic deformation. The basic physical phenomena, that occurs within the arc of contact between the billet and the cylindrical rolls causing deformation of billets through plastic yielding.

3.3.2. Basic Concepts in Rolling Process

3.3.2.1. Geometrical Relations

At the hearth of the rolling operations is the process during which the plastic steel passes between at least two rotating rolls (right circular cylinders). In a most accustomed configuration the axes of rolls are parallel and lie in the same plane, so called “exit plane”. Clockwise rotation of one roll and the simultaneous counter-clockwise rotation of the other roll are maintained by motor drive via set of spindles. Processed billet is drawn into the deformation zone by the friction forces developing along the contact interface between the rolled steel and the rotating rolls.

An idealized sketch of a rolling pass is depicted in Figure 3.4.

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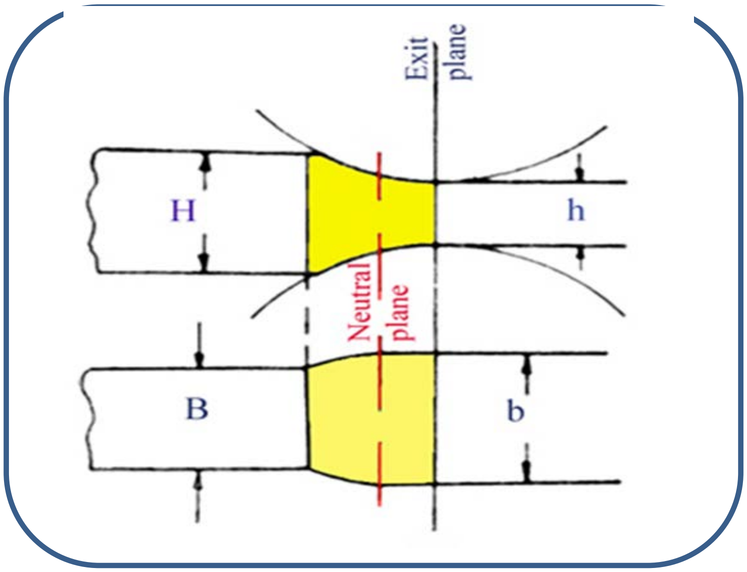
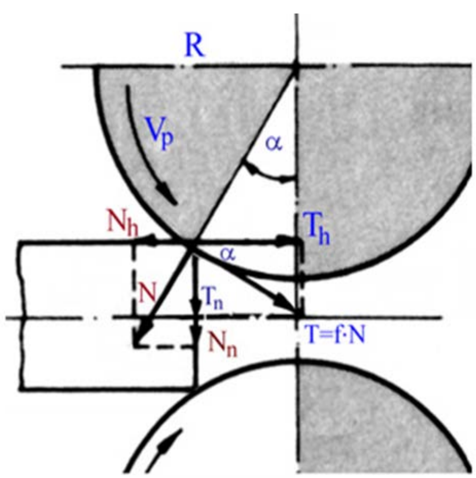


Figure3.4 Top and side views at the deformation zone [45]

Before the rolling can commence, steel has to be re-heated in special furnaces to temperatures of 1100 – 1200 ^{0}C Deformation. Process that follows can be generally described as a sequence of rolling passes whereby the vertical cross-section area of the rolled cylinder is gradually decreased. To enable this series of passes, rolls are assembled within so called housing. Housing is a major frame within a more complex assembly called rolling mill stand. Rolling mill stand is equipped with a mechanism which allows for changing the height "h" (see Fig 3.4 above) between the passes.



Single pass [considering first pass rouging mill rolls]

In order to discuss the basic principles of rolling, we shall analyses relations during the single passing of a cuboid through a gap between the grooves less rolls. Single rolling pass will occur when the horizontal resultant of friction force overcomes the horizontal resultant of the steel deformation force. Figures 3.5 and 3.6 Show decomposition of relevant vectors and sliding velocities.

Figure3.5 Force vectors at the instant of bite [45]

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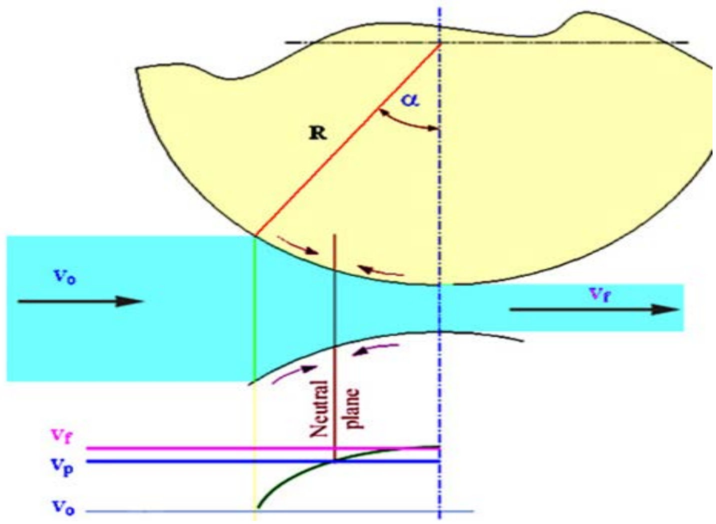

Figure3.6 Velocity distribution in the deformation zone; the curved arrows indicate the direction of the resultant friction force that arises due to the difference between the surface (peripheral) velocity of the roll and the plastic flow velocity at the surface of the rolled steel.[45]

In order to start the rolling pass, the tangent of the bite angle must be smaller than the coefficient of friction f.

[Referring to figure 3.5]

N = deformation force

T = friction force

N_h =N sin α and T_h = Tcos α = f Ncos α

∴ Nsin α = f Ncos α

$$\mathbf{f = \tan \alpha}$$

The height reduction (draft) and the lateral spread are defined as follows (refer to Fig 3.4 above):

$\Delta h = H - h$ and $\Delta b = b - B$

`

The maximum draft is delimited by the following factors:

- the ability of rolls to pull the rolled bar into the deformation zone (roll bite),
- the maximum force that can be resisted by rolls without the roll fracture, and
- the maximum reduction that can be sustained by rolled material without appearance of cracks in the rolled steel.

3.3.2.2. Roll Bite Condition

For the work piece to enter the throat of the roll, the component of the friction force must be equal to or greater than the horizontal component of the normal force.

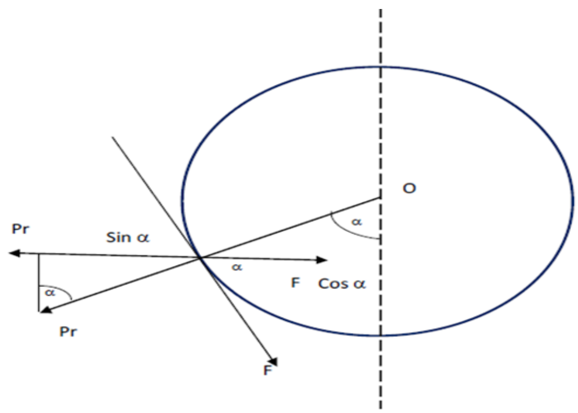

Figure 3.7 Roll bite condition [34]

$$F\ cos\ \alpha \geq\ P_r\ sin\alpha$$

$$\frac{F}{P_r} \geq \frac{sin\alpha}{\cos\alpha} \geq\ tan\ \alpha$$

It is known that

$$F\ =\ \mu\, P_r \qquad or \quad \mu\ =\ \frac{F}{P_r}\ =\ tan\alpha$$

$$\therefore \mu\ =\ tan\ \alpha$$

`

F is a tangential friction force & P_r is radial force

• If tan α > μ, the work piece cannot be drawn.

• If μ = 0, rolling cannot occur.

3.3.2.3. Deformation in rolling zone

Geometrical characteristic of rolling zone is shown in Figure 3.8. Total relative deformation ε obtained for one pass of material through rolling mill is given: [32]

$$\boldsymbol{\varepsilon = (h_0 - h_1)/h_0} \quad (1)$$

where h_0 is thickness of material at the input into rollers and h_1 is thickness of material at the output from rollers. However, the equation (1) does not describe distribution of deformation in the rolling zone. Point E in rolling zone (see Figure 3.7) is characterized by distance x from origin of coordinates and thickness h_x. Then, relative deformation ε_x of rolled material after pass from point B to point E is given by formula :

$$\boldsymbol{\varepsilon_x = (h_0 - h_x)/h_0} \quad (2)$$

where thickness h_x is established by equation of a circle with diameter 2R and displacement y_0 in Y direction within the distance y_0.

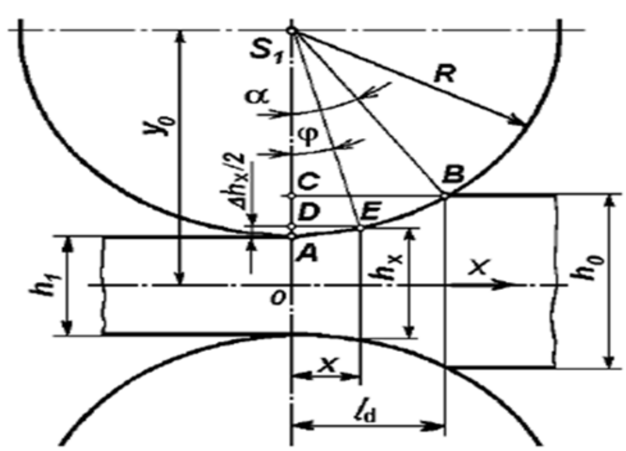

Figure 3.8 Geometry of rolling zone [32]

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$$x^2 + (y - y_0) = R^2 \quad (3)$$

Thickness h_x is equal to double of Y coordinate in point E

$$h_x = 2(y_0 - \sqrt{(R^2 - X^2)}) \quad (4)$$

Displacement of circle center y_0 is equal to the sum of roller radius R and half thickness of material at the output $\frac{h_1}{2}$

$$y_0 = R + \frac{h_1}{2} \quad (5)$$

Substituting the equations (4) and (5) into the equation (2) gives the relation

$$\varepsilon_x = (h_0 - h_1 - 2R + 2\sqrt{(R^2 - X^2)}))/h_0 \quad (6)$$

It can be seen that total relative deformation ε (see equation (1)) is involved in the equation (6). By introducing the substitution ε into the equation (6) and after retreatment we obtain the equation which describes distribution of relative deformation in rolling zone along the length of contact arc l_d.

$$\varepsilon_x = \varepsilon - 2 \cdot \frac{R}{h_0} \quad (1 - \sqrt{(1 - \frac{x^2}{R}} \quad)) \quad (7)$$

Coordinate x belongs to the interval [0, l_d]. The length of contact arc l_d can be obtained from formula

$$l_d = \sqrt{(R.\Delta h - \frac{\Delta h^2}{4})} \quad (8)$$

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3.3.2.4. Deformation zone

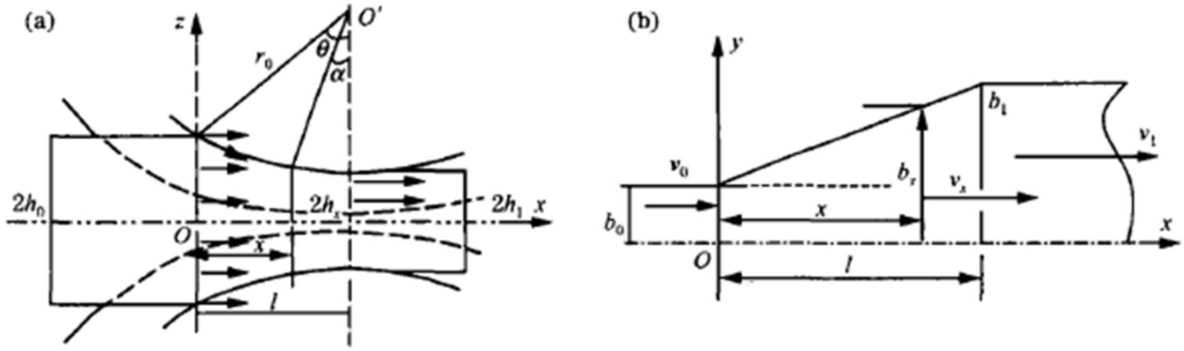

Figure3.9 (a) Deformation zone of the first stand (b) and half of spread in deformation zone [30].

The plastic deformation is assumed to occur in the domain BCHG as shown in Figure 3.9.

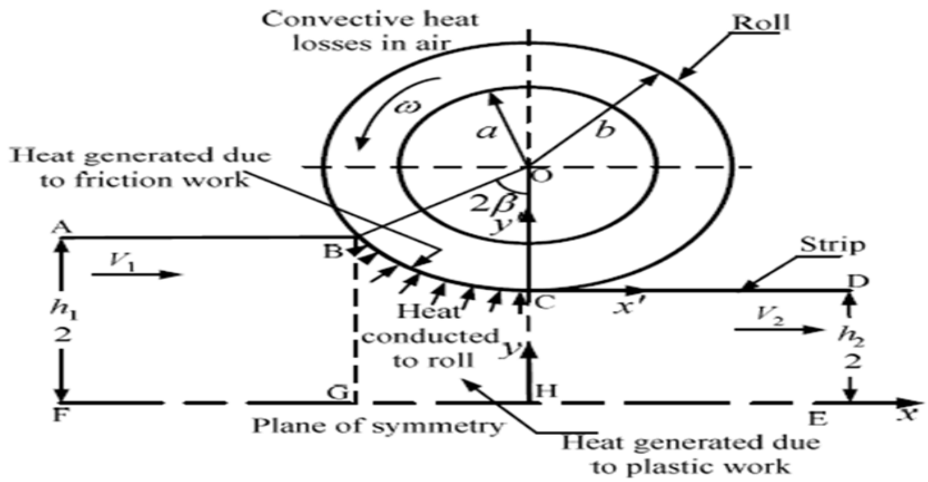

Figure 3.10 Geometric arrangement of the heat generation for roll and billet[31]

3.3.3. Analytical Methods in contact stress analysis [18]

Generally speaking, nonlinear analysis involving contact can be quite challenging to solve when the contacting area changes during the load history. However, ANSYS Workbench Simulation has very robust contact technology, along with diagnostic tools that can help the user obtain converged, accurate solutions.

In finite element analysis, if two independent parts are present, there is no stiffness relationship defined between them, and the resulting stiffness matrices will be uncoupled — consequently,

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one part may pass through the other during the course of the simulation. Contact elements are required to define the interaction of two or more sets of meshes to prevent such penetration. ANSYS contact elements typically support four different algorithms: augmented Lagrangian, pure penalty, Multipoint constraint, and Lagrange multiplier methods. The default and most commonly-used option is the augmented Lagrangian formulation, which can be thought of as a variation of the pure penalty method.

The process of hot rolling basically consists of passing the hot billet through two rolls rotating in opposite direction at a uniform peripheral speed. When they are in mesh the region of contact is theoretically surface contact in rolling deformation zone.

During deformation of metal between the rolls the work is subjected to high compressive stresses from squeezing action of the rolls and to surface shear stresses as a result of the friction between the rolls and the billet.

The general goal for contact analysis is to determine:

- Contact stresses transmitted across contacting interface
- Contacting area
- Friction introduces another kind of nonlinearities

A small amount of positive or negative relative sliding can change the sign of frictional forces/stresses completely.

In the common physical sense, surfaces that are in contact have these characteristics:

- They do not interpenetrate.
- They can transmit compressive normal forces and tangential friction forces.
- They often do not transmit tensile normal forces.

They are therefore free to separate and move away from each other.

Contact is changing-status nonlinearity. That is, the stiffness of the system depends on the contact status, whether parts are touching or separated. Physical contacting bodies do not interpenetrate. Therefore, the program must establish a relationship between the two surfaces to prevent them from passing through each other in the analysis. When the program prevents interpenetration, we say that it enforces contact compatibility.[18]

Simulation offers several different contact algorithms to enforce compatibility at the contact interface.

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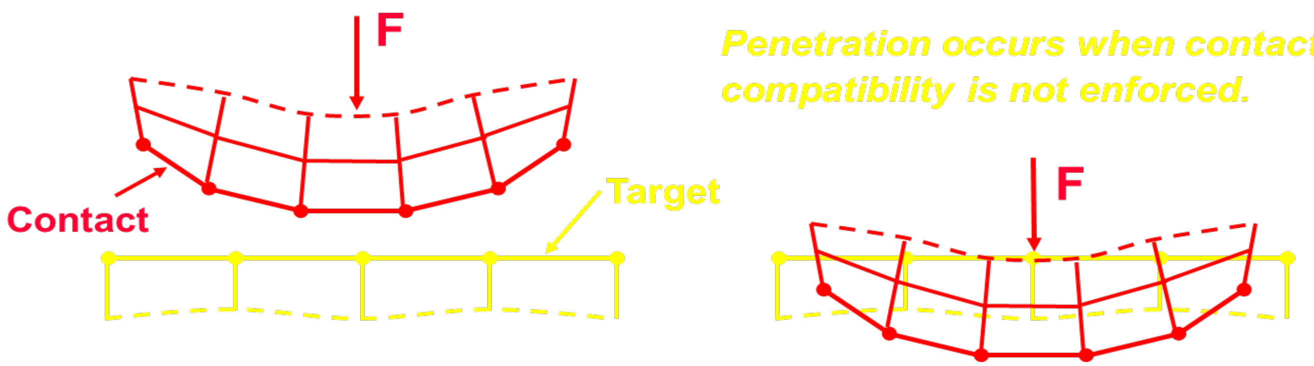

Table3.5 Below summarizes some pros (+) and cons (-) with different contact formulations[18]

	Pure Penalty		Augmented Lagrange		Normal Lagrange		MPC
+	Good convergence behavior (few equilibrium iterations)	-	May require additional equilibrium iterations if penetration is too large	-	May require additional equilibrium iterations if chattering is present	+	Good convergence behavior (few equilibrium iterations)
-	Sensitive to selection of normal contact stiffness		Less sensitive to selection of normal contact stiffness	+	No normal contact stiffness is required	+	No normal contact stiffness is required
-	Contact penetration is present and uncontrolled		Contact penetration is present but controlled to some degree	+	Usually, penetration is near-zero	+	No penetration
+	Useful for any type of contact behavior	+	Useful for any type of contact behavior	+	Useful for any type of contact behavior	-	Only bonded contact behavior is allowed
+	Either Iterative or Direct Solvers can be used	+	Either Iterative or Direct Solvers can be used	-	Only Direct Solver can be used	+	Either Iterative or Direct Solvers can be used
+	Symmetric or asymmetric contact available	+	Symmetric or asymmetric contact available		Asymmetric contact only		Asymmetric contact only
+	Contact detection at integration points	+	Contact detection at integration points		Contact detection at nodes		Contact detection at nodes

Contact stress is generally the deciding factor for the determination of the requisite dimensions of rolled billet as per the design. Different research on rolling process action have confirmed fact that beside contact pressure, Coefficient of draught, Spread, Coefficient of elongation, Bite angle, roll gap, slip (back ward and forward),sliding velocity, cooling system as well as other factors such as frictional forces also influence the formation of surface defect on the product bar surface. Thus the thorough study of contact stress between rolls and billet is crucial in roll pass design.[43]

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In hot rolling the chief factors influencing the yield stress are the nature of the material, the temperature at which the material is rolled and the strain rate, i.e. the rate of deformation. When the working temperature is only slightly higher than the temperature of recrystallization, the speed of recrystallization and grain growth in the hot material is usually so slow that the deformed structure is maintained to the next pass. This may be explained by the fact that when the billet is compressed between the cylindrical rolls, the effective total frictional resistance to metal flow in the transvers direction is much greater than that in the direction of rolling; thus the bar is encouraged to elongate in the direction of rolling.[28]

3.3.4. Deformation of Billet on the 1st Pass of 3- High Roughing Mill

3.3.4.1. Deformation analysis by FEM

Introduction

ANSYS, which is a finite element analysis (FEA) simulation software, is used to simulate the essential condition, stress (Equivalent), directional deformation and boundary conditions, effect of the deformation of billets. Further, it helps to determine the geometric modeled response to specified condition. The geometric models, which simulate the physical components of two rolls and billets, are used as an input for finite element analysis in ANSYS software.

However, ANSYS software is capable of modeling physical components in geometric models finite element analysis, software CATIA used for geometric modeling in this study. CATIA employs a parametric, feature-based approach for creating models and assemblies.

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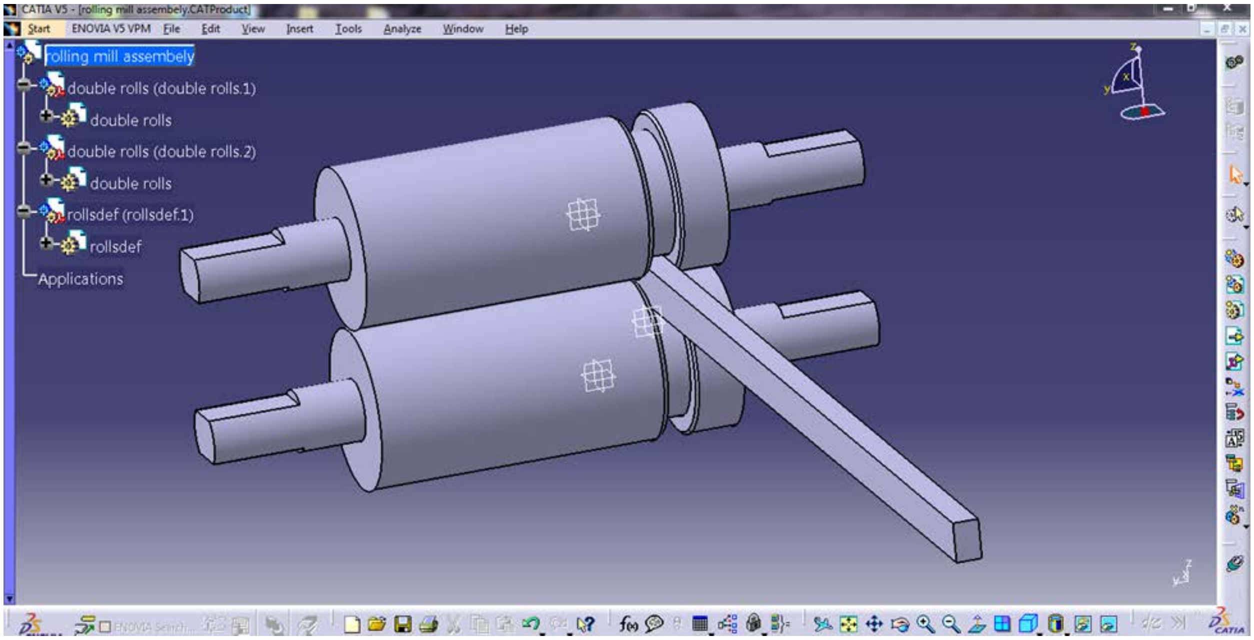

Figure3.11 Assembly of middle and bottom rolls of 3-high roughing mill (ZuSRoM)

The procedures followed for determining solution for selected solution options discussed below.

The rate of deformation is :

- a function of material properties
- exposure time
- exposure temperature
- and the applied structural load.

3.3.4.2. Geometric Modeling

The geometric models that simulate the physical components of rolls and billet for deformation analysis purpose are discussed below. The deformation of a hot rolled work piece can be described by the three important design issues: elongation, spread and draft. Models that have been done taking in to account the objective of the thesis are: **(1) Billet and (2) Rolls of Roughing three high mill stands of ZuSRoM.**

The following steps were used for the aforementioned modeling and analysis:

Step 1: By using the roll pass design proper orientation of the 3-high roughing mill, the rolls and the billet assembly generated. Then the 3D model for the mill 1st pass is generated as shown in Figure 3.12.

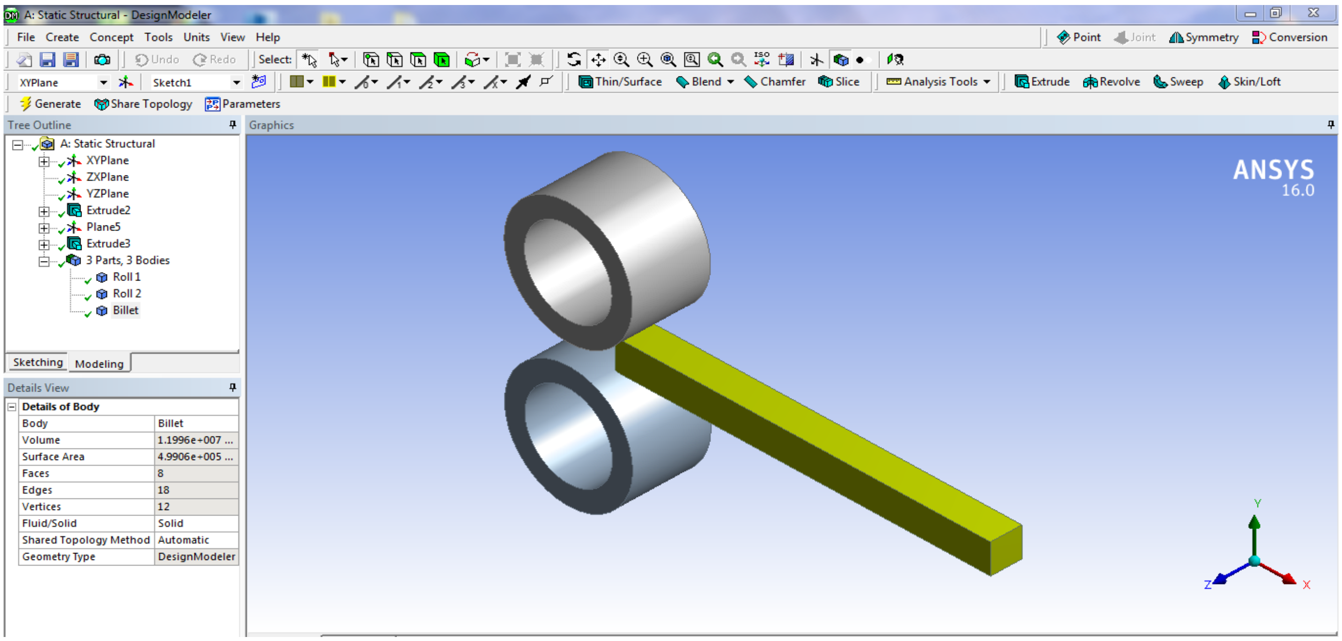

Figure 3.12 The geometric models (rolls and billet)

For the work piece to enter the throat of the roll, the component of the friction force must be equal to or greater than the horizontal component of the normal force. This may be explained by the fact that when the billet is compressed between the cylindrical rolls; and the effective total frictional resistance to metal flow (billet) in the transverse direction is much greater than that in the direction of rolling; thus, the bar is **encouraged to elongate in the direction of rolling**. [43]

From the analysis of these, in order to save computational time and the conditions of the billet temperature directly from the furnace, roll gap and bite angle of rolls and billet which is concerned on the 1st pass of roughing mill are in the range of parametric analysis of roll pass design. Therefor for this research the rolls and billet contacts considered as flat not grooved (seen in figure 3.12 above)

The maximum possible bite angle is illustrated in figure 3.12, showing a free-body diagram of the forces acting upon a bar entering a pass. As can be seen by the large roll bite on the right, the resultant force pulling the bar into the roll bite is reversed into a force pushing the bar out. This force is equal to zero at the inverse tangent of the coefficient of friction.

The surface speed of the roll is V. The initial value of velocity of the work piece is V_0.The velocity of the work piece is highest at the exit of the roll gap and is denoted by V_f. Because the surface speed of the roll is constant, there is relative sliding between the roll and the strip along the arc of contact in the roll gap L_d . At one point along the contact length, the velocity of the work piece is the same as that of the roll. This is called the neutral, or no slip point. To the left of this point, the roll moves faster than the strip, and to the right of this point the work piece moves faster than the roll. Hence the frictional forces, which oppose motion, act on the work piece as shown in Figure 3.13.

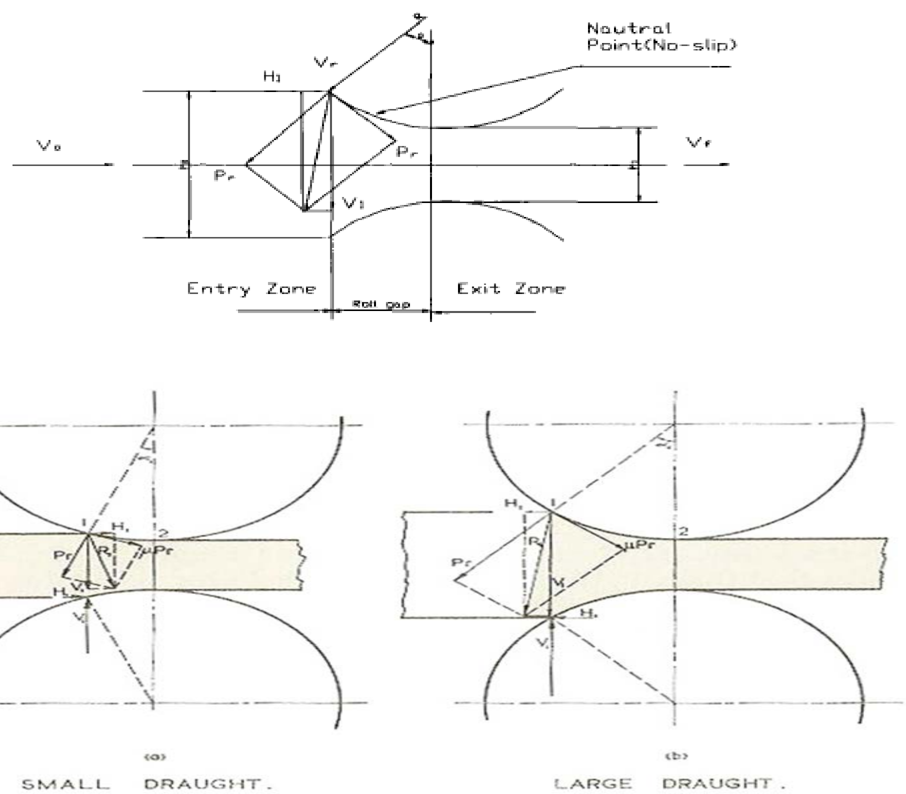

Figure 3.13 A free-body diagram of the forces acting upon a bar entering a pass for maximum possible bite angle[3].

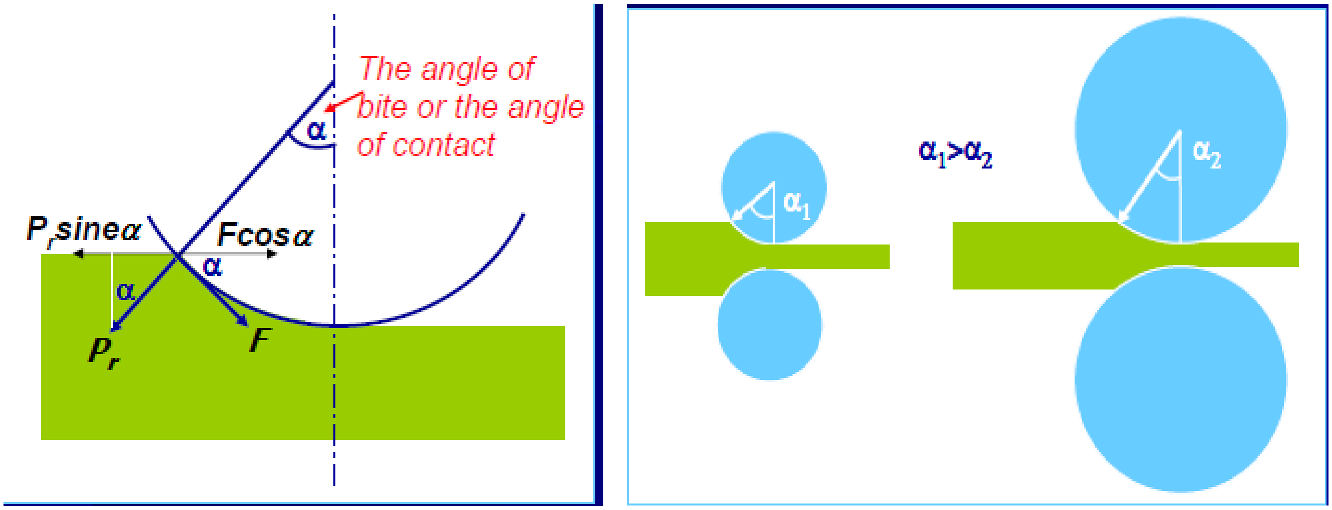

Figure 3.14 Roll bite conditions [20]

where: F is a tangential friction force

P_r is radial force

- If tan α > μ, the work piece cannot be drawn.
- If μ = 0, rolling cannot occur.

Therefore Free engagement will occur when μ > tan α

- Increase the effective values of μ, for example grooving the rolls parallel to the roll axis.
- Using big rolls to reduce tan α or if the roll diameter is fixed, reduce the h_o.

Step 2: Contacts and Joints (see in Figure3.15)

3.3.4.3. Contact

(Illustrates the contact of the bottom and middle rolls)

The Joint feature is a tool used to create joints between different geometries of different bodies together so that their contact regions will be treated as shared topology when meshed in the ANSYS Mechanical application. Contact pairs couple general axisymmetric elements with standard 3-D elements.

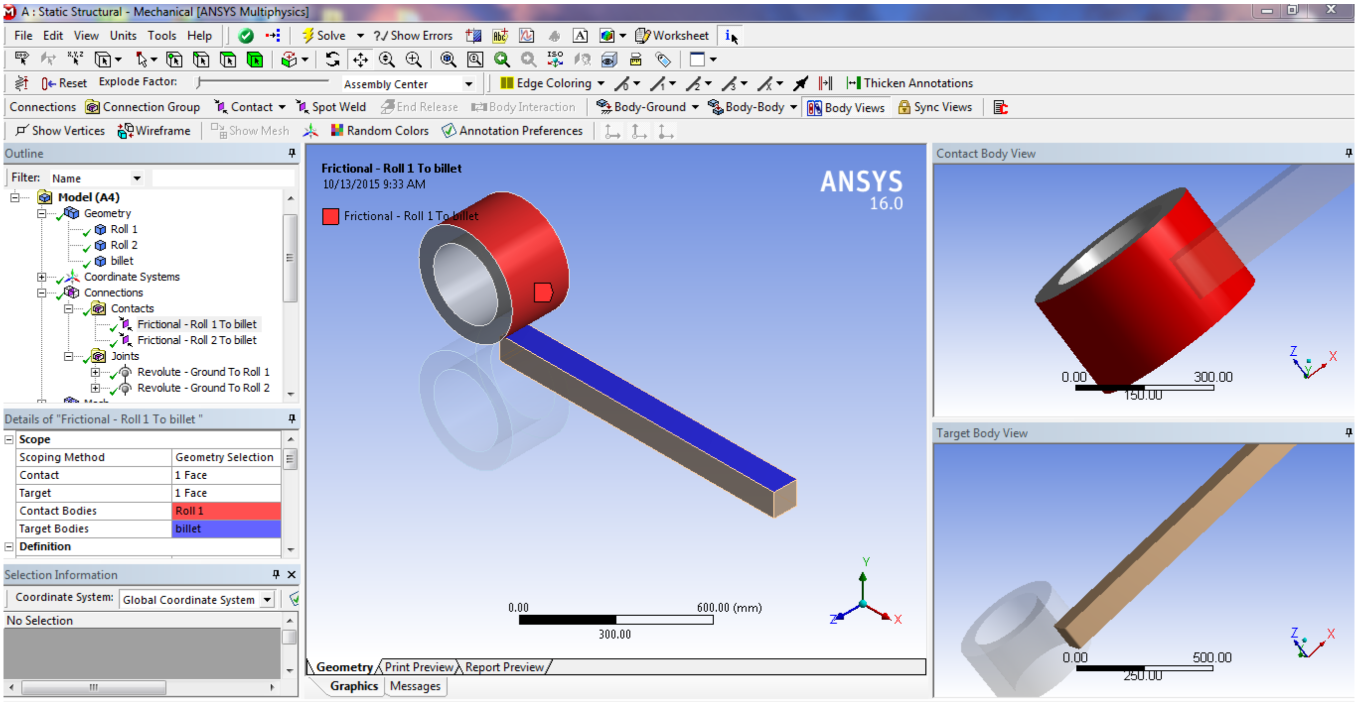

Figure3.15 contact between rolls and billet

3.3.4.4. Joint

(Illustrates the joint of the bottom and middle rolls)

The process of hot rolling basically consists of passing the hot billet through **two rolls rotating in opposite direction** at a uniform peripheral speed. During deformation of billet between the rolls the billet is subjected to high compressive stresses from squeezing action of the rolls and to the surface shear stress as a result of the friction between the rolls and the billet. From this thesis analysis, in order to save computational time in ANSYS workbench the rolls modeled as a hollow cylindrical. (See figure3.15)

A general has six degree of freedom, three translations and three rotations. The rolls are rotating by its own axis. Revolute joint (constrained degree of freedom: UX, UY, UZ, ROTX, ROTY, ROTZ). For the rolls the rotating is fixed, therefore the points on rolls joint have only one degree of freedom (z axis, ROTZ). For this rolls analysis ANSYS workbench compute the middle rolls (Revolute Ground to Roll1) and Bottom roll (Revolute Ground to Roll2) the constrained degree of freedom both for middle and bottom roll taken as ROTZ. (See figure3.16)

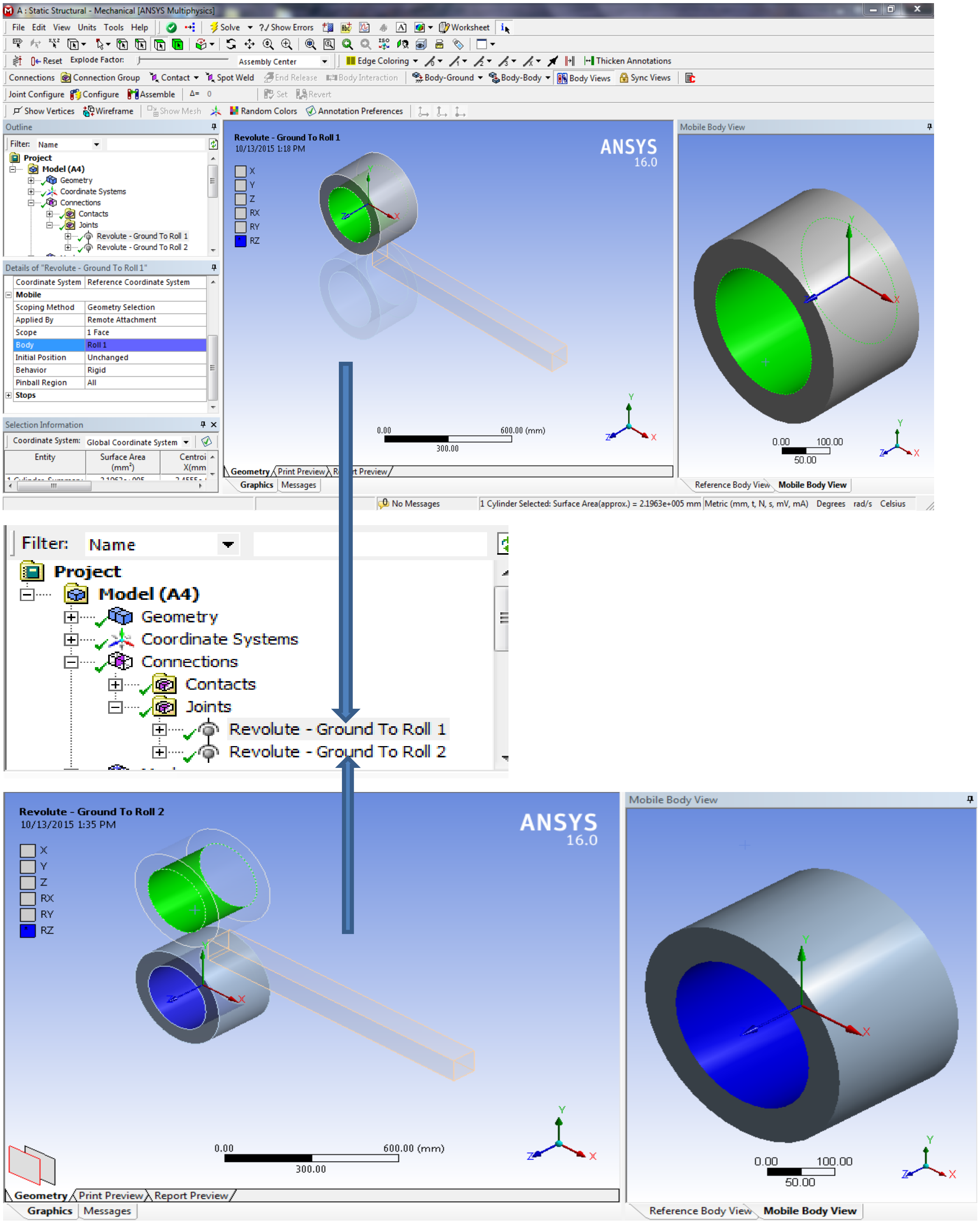

Figure3.16 Joint between rolls and billet

Step 3: Link Thermal Analysis to Structural Analysis (see Figure 3.17)[42]

The metal flow behavior in a hot rolling process is a complex phenomenon, which is complicated due to tonsorial stress distribution that is influenced by the material properties and deformation parameters such as temperature, strain and strain rate. In a wire rod and bar rolling plant processes, the aim of energy conservation and saving can be achieved by reduced resource consumption of process energy and by efficient use of plant installation and utility. **Temperature** is the main process variable needed for every operation in hot rolling process for any value addition activity and to minimize the energy use. It is a tool to improve productivity of the steel hot rolling plant by controlling the rolling process heat and its wastages.

ANSYS Workbench Mechanical can link a thermal analysis to a structural analysis, sharing Engineering Data, Geometry and Model directly. When directly linked, bodies in the structural model cannot be suppressed independently of the thermal Analysis and meshing and contacts cannot be set differently.[42]

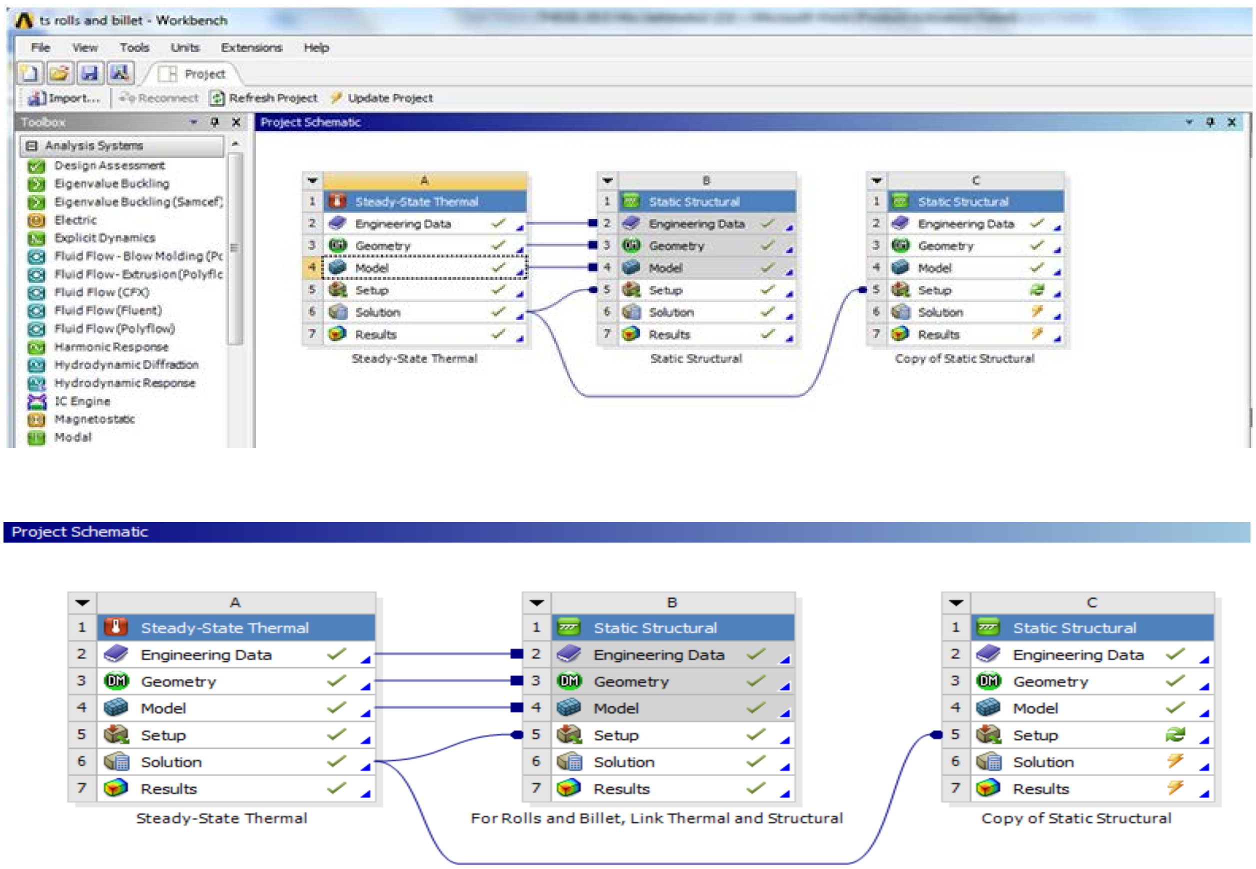

Figure3.17 Link Thermal Analysis to Structural Analysis

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A structural analysis can be linked at the Geometry level, then have to re-do all of the Model details, including desired Coordinate Systems, Connections (including Contacts), and meshing controls. This keeps the structural analysis independent of the thermal analysis. Temperatures can be mapped.

This article explores methods that let the user keep the Model controls while maintaining an independent structural analysis, so that bodies can be suppressed, contacts and meshing can be tweaked only if desired, and temperatures are still mapped from the thermal analysis.

Link Thermal Analysis to Independent Structural Analysis Keeping Model in ANSYS Workbench Mechanical

- Details of Creating an Independent Structural System

The following familiar result has the two models directly linked. The mesh is shared. Temperatures are copied directly from the thermal analysis nodes to the structural analysis nodes. This is the result:

The Outline in Workbench Mechanical shows both environments when the above direct link is employed:

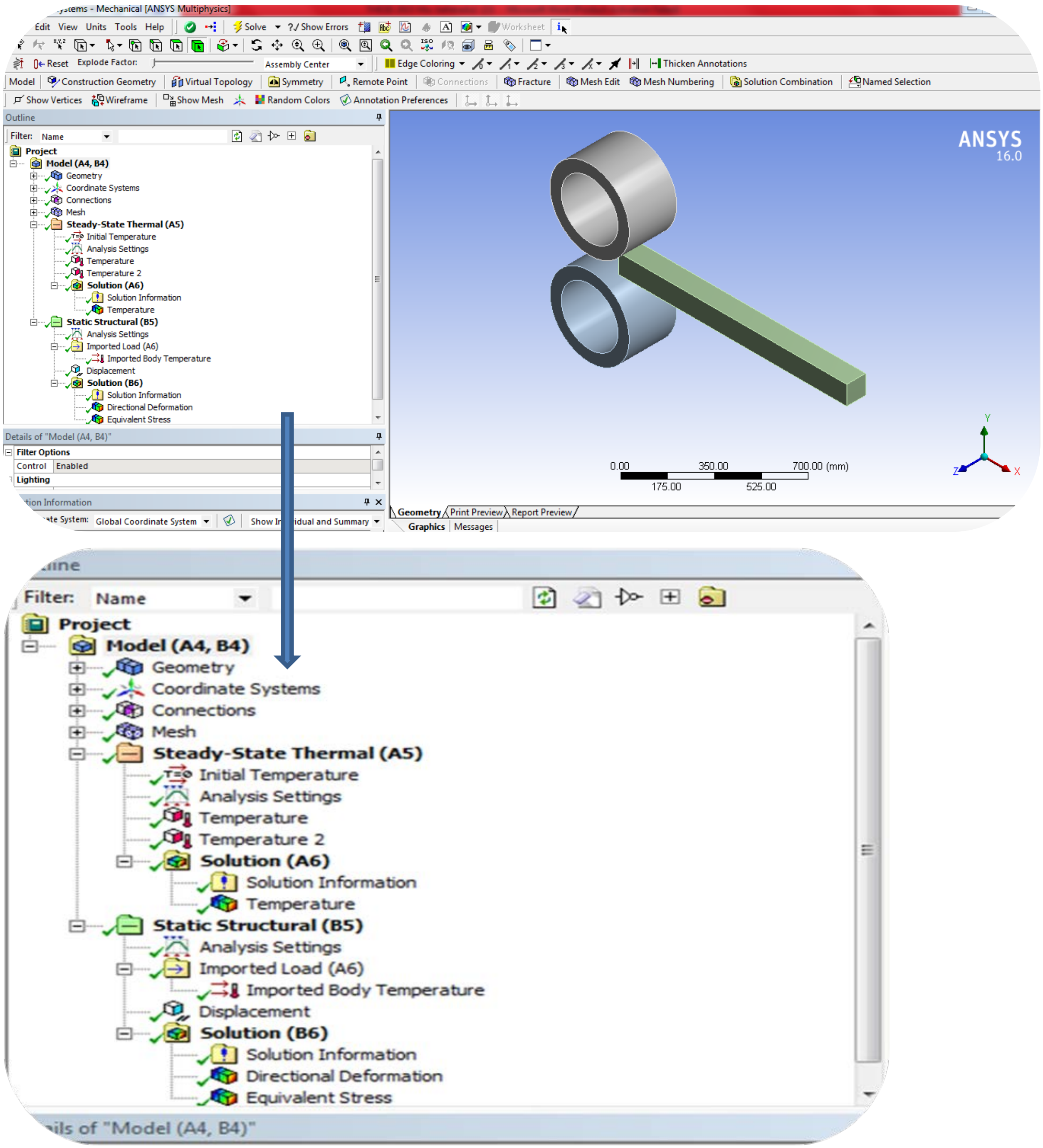

Figure3.18 Outline with Two Linked Environments

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Step 4: Mesh

Mesh generation is one of the most critical aspects of engineering simulation. The mesh influences the accuracy, convergence and speed of the analysis.

Structural mechanics simulations need to use the mesh efficiently as run times can be impaired with high element counts. ANSYS Meshing has a physics preference setting ensuring the right mesh for each simulation.

After the proper model is finished, the computational mesh that is used as a basis of solution procedure should be generated. The mesh consists of discrete elements located throughout the computational domain. A good computational mesh is an essential ingredient for a successful and accurate solution. If the overall mesh is too coarse, the resulting solution may be inaccurate. If the overall mesh is too fine, the computational cost may become prohibitive. So the mesh was fine near the contact and course away from the contact surfaces as it is seen in Figure 3.19.

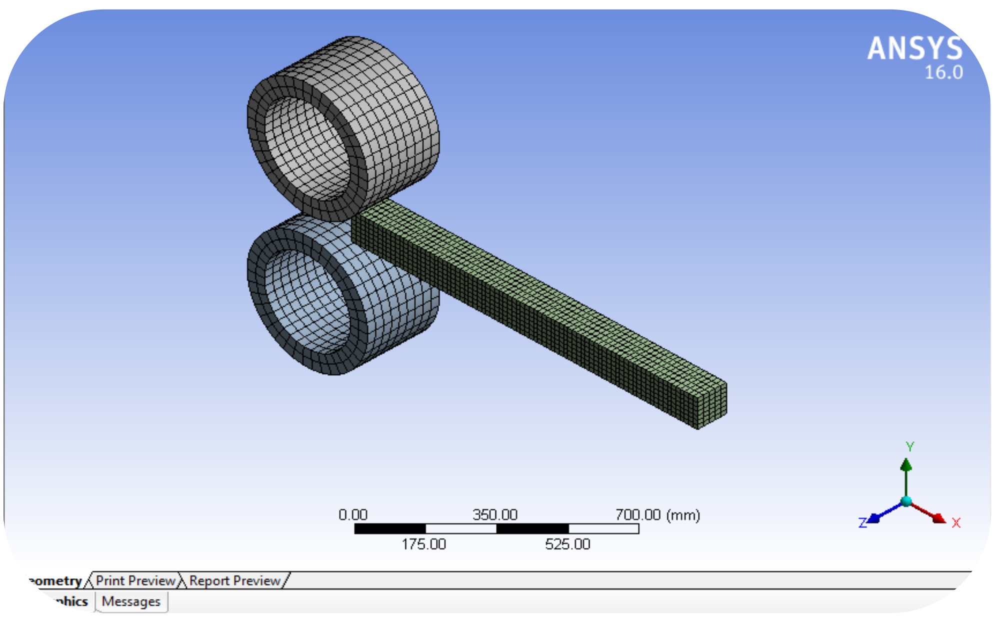

Figure3.19 Mashed model of billet and rolls assembly

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Step 5: The boundary conditions

The boundary conditions for the Rolls and billet were taken as follows: the inner part of the roll given Joint rotation support and the bearing of the rolls support is given a fixed support as shown in Figure 3.20. Displacement boundary condition applied as it is seen in Figure 3.20. And finally rolling temperature was applied on the billet as it is seen in Figure 3.20. The details of temperature application are shown in Figure 3.22.

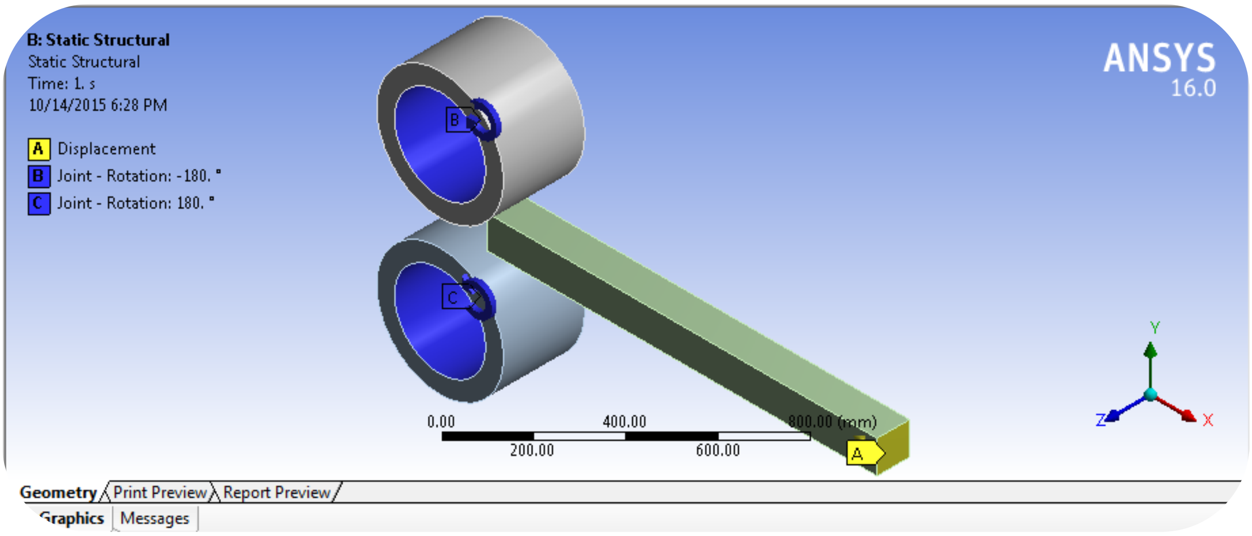

Figure3.20 All boundary conditions of Rotation applied on the Model

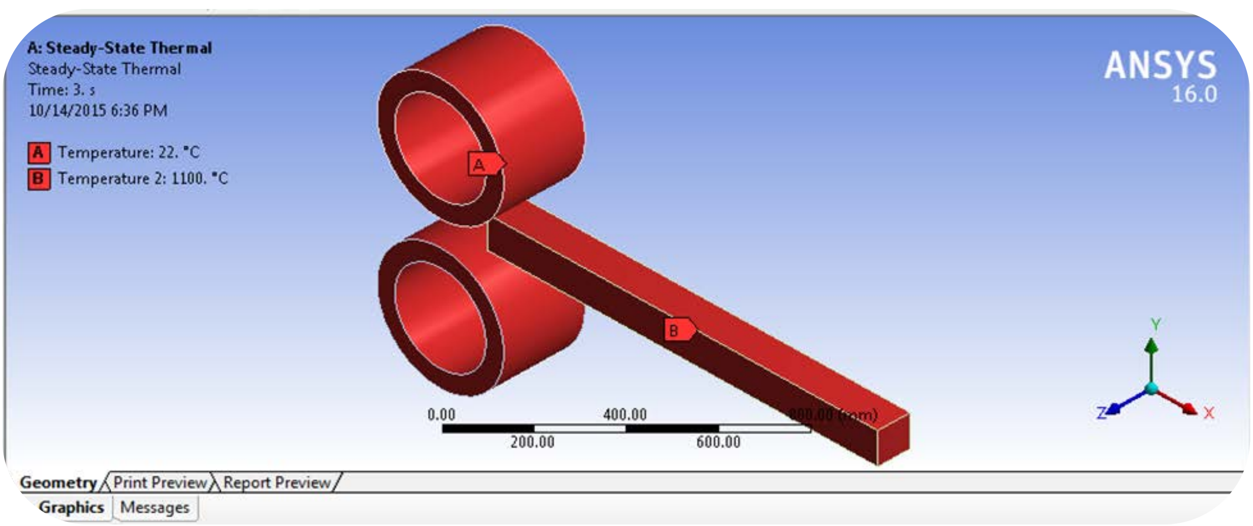

Figure3.21 All boundary conditions of steady state thermal Temperature applied on the Model

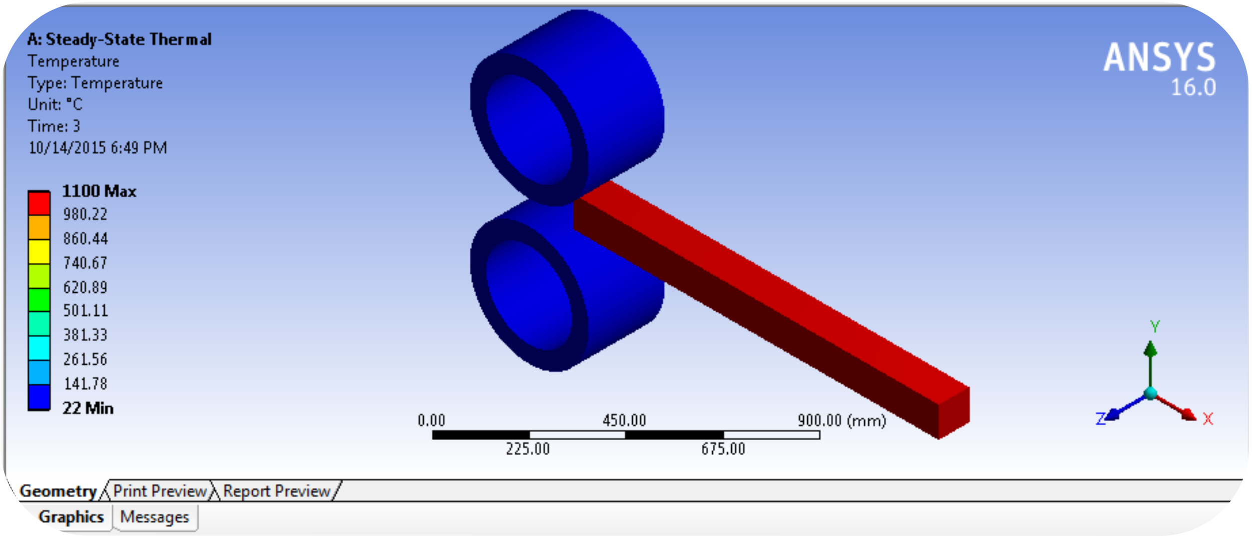

Figure3.22 All boundary conditions of steady state thermal Billet Rolling Temperature applied on the Model

Defined Analysis Solution Options

After setting of all the boundary conditions for Rolls and Billet then initiating the solver to compute the required results.

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Chapter Four

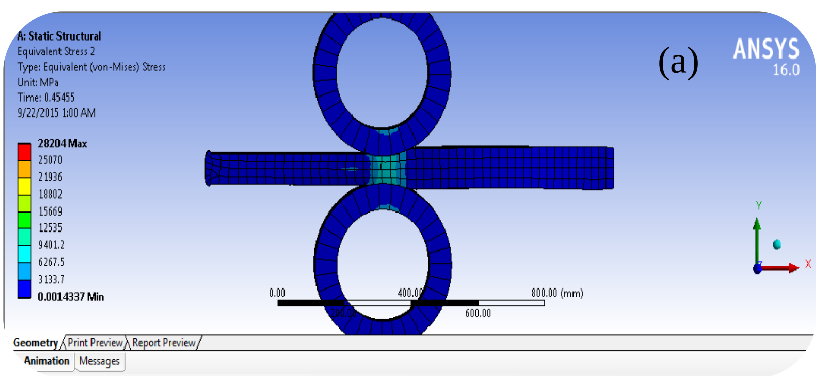
4. Result and Discussions

4.1. Deformation Analysis

In the previous chapter, steps and input parameters that are used in the analysis of the rolls and billets deformation and temperature effect discussed briefly. Analysis types are selected in terms of expected result. Finite Element Method is preferable for Deformation of billet in the first pass of Roughing mill (ZuSRoM) analysis of hot rolling process of Billet and Rolls. The deformation on the deformation zone developed in the area of contact of the Rolls and Billet was analyzed by Finite Element Method by using ANSYS workbench release 16.0. Static analysis is carried out for determining the distribution of deformation and stresses on the rotating rolls and processed billet with required rolling temperature due to rolling load.

In chapter three, steps and input parameters that are used in the analysis of the Deformation of billet on the deformation zone discussed briefly. Results from the analysis in relation to input parameters will be discussed.

The initial and predicted deformed geometries for both stress and strain cases are shown in Figure below:



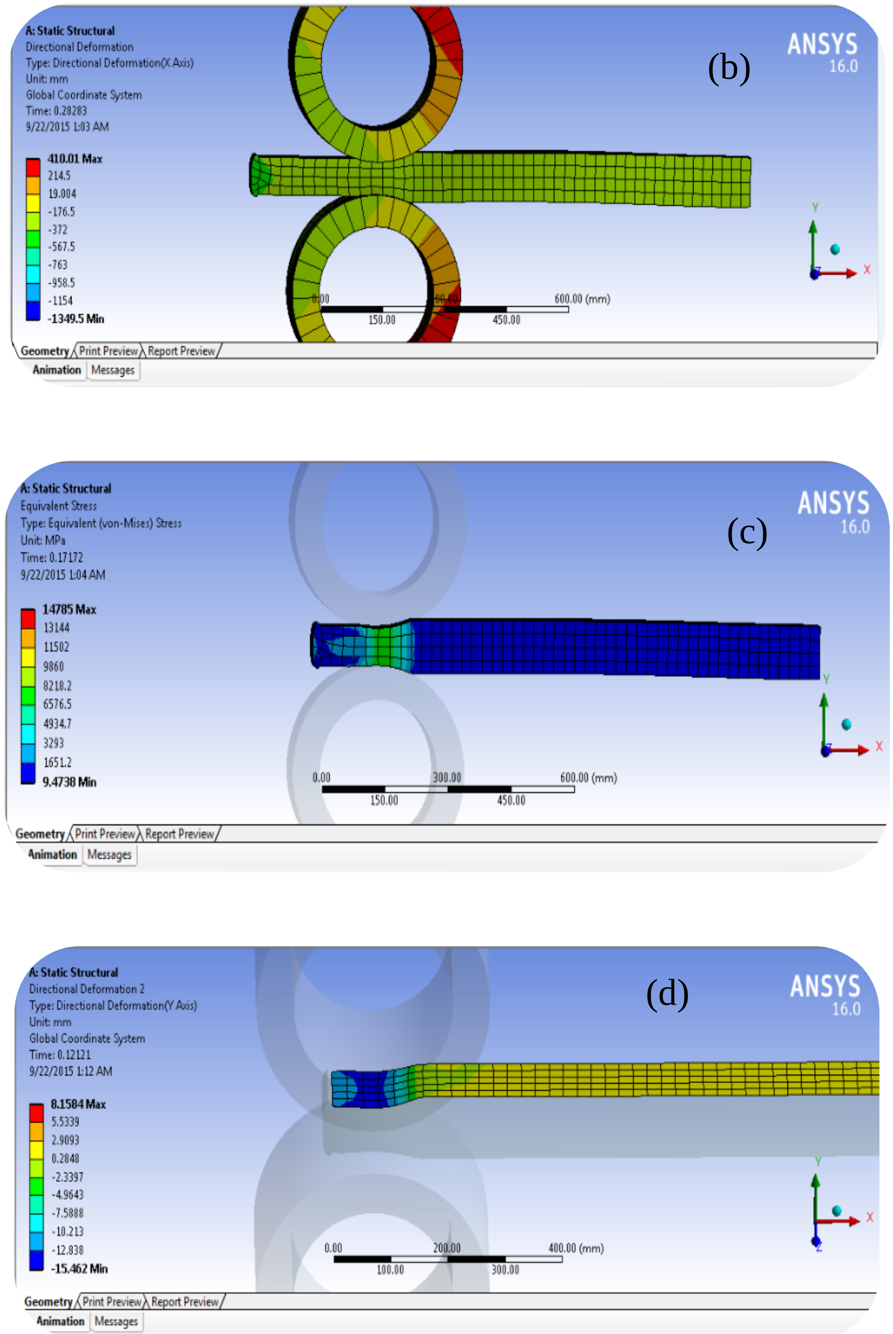


Figure 4.1 Mode shapes of the rolls and billet deformation on the 1st pass of 3-high roughing mill as per the roll pass design parameters (a) to (d).

The process normally starts with heating of the billet, followed by rolling in a roughing mill, which is commonly reversible, rolling in an intermediate mill and in a finishing mill.
The strain distributions of the two cases are shown in Fig.4.1. It is noted that strain is concentrated in the direction of rolling of the deforming region in the first case. In the stress case, the stress distribution is relatively close to design range. As the billet enters the roll gap it is first deformed elastically. It speeds up; the relative velocity between the roll and the billet is such that friction draws the metal in.

The criterion of plastic flow governs the manner in which the transformation from elastic to plastic happens in what is known as the elastic-plastic interface. The billet proceeds through the roll gap and more plastic flow occurs until finally at the exit roll pressure is removed. The billet is unloaded and it returns, through an elastic state to the original, load free condition. It is observed that during rolling, the relative velocities of the roll and the billet change and as the billet is accelerating forward it reaches the roll surface velocity at the no-slip or neutral point. From then on, as further compression occurs, the billet speeds up and the direction of friction changes in such a way that it now retards motion. Exit velocity of the billet is often larger than that of the roll and the difference between the two velocities is determined by the forward slip.

Roll-pass design, which decides the shape, size and combination of the grooves, is a complex work. However, using an optimal roll-pass design will result in defect free products with correct dimension. In the work of improving the roll-pass design finite element simulations are a useful tool. Using FEM can provide a picture of the deformation of the billet and risks for defects could possibly be detected. A drawback of FE is, however, that the simulations generally are quite time consuming.

Table 4.1 Comparison of ASTM experimental and FEM methods

ANSYS		EXPERIMENTAL(ASTM)	
Strain (mm)	Stress (Mpa)	Strain (mm)	Stress (Mpa)
0.01	205	0.01	200
0.015	311	0.015	300
0.12495	385	0.1042	450
0.16354	444	0.1134	450
0.22142	515	0.1225	520
0.32778	565	0.2933	570
0.32878	569	0.2948	575
0.32988	573	0.2963	582
0.33098	577	0.2978	589

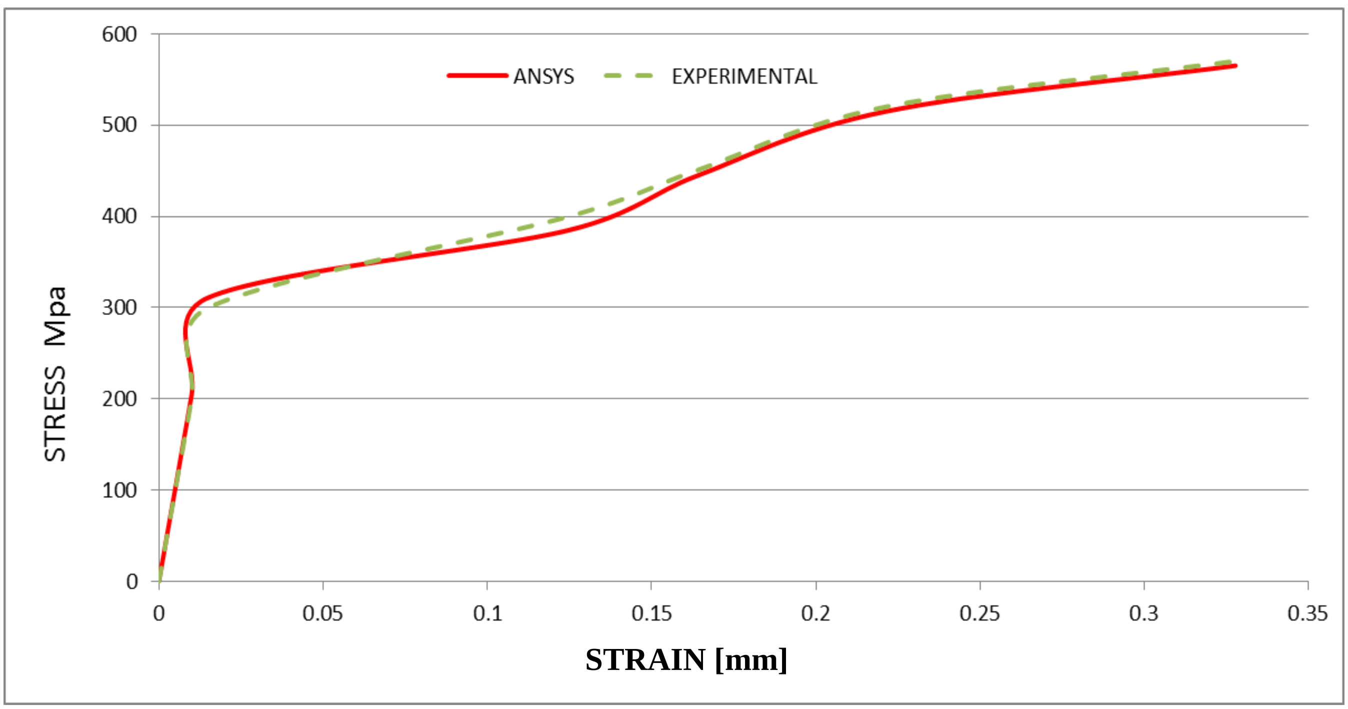


Figure 4.2 Stress vs. Strain curve ASTM from FEM

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Chapter Five

5. Conclusion and Recommendation

5.1. Conclusion

The ultimate goal in this thesis hot roll Deformation analysis is to manufacture the correct size and shape of a rolled product with a defect free surface and the required mechanical properties. In addition, economic condition must be achieved, for example:

- maximum output and lowest cost,
- easy working conditions for the rolling crew and minimum roll wear.
- Improvement in the quality and reliability of rolled products can only be achieved through a thorough understanding of the rolling process.

Taking in to account what it has been found from literature and results from this thesis study, the conclusions that we reached with are discussed below.

This paper reviews key aspects of deformation:-

- roll material properties,
- roll pass design, and system factors such as temperature, loads and sliding velocity.

As the results of the modal analysis confirm, the stress and strain curve shows that,

- In the rolling process for useful deformation work done on the billet and roll,
- that means, **the roll gap, the bite angle, the rolling temperature**, and **the entry and exit guide alignment** is as per the roll pass design and the result is defect free and the production process goes smoothly.

As in hot roll working processes, rolling involves a number of process and material variables that should be controlled in order to roll products having:

- high quality,
- properties,
- surface finish, and dimensional accuracy.

These variables include **rolling deformation**, **temperature** and **speed**, **cooling system**, and **the condition of the rolls.**

`

As explain on the statement of the problem, the main target of this analysis is to reduce the losses on **the first pass of 3-high roughing mill** and to make the factory production process defect free. Therefore, in ZuSRoM these parameters not kept in the process, some data shows from the performance report that in the first pass of roughing mill 2-2.5% of cobbles occurs from the total production, the rolls changes before it gives its design life time.

The roll life for first pass of roughing mil should rolls above 5000ton before the first machining or dismounting, but in the existing mill ≈3000ton billet processed in one pass.

In this paper, it was presented a method to determinate the appropriate adjustment for deformation control, considering three possible control parameters:

- roll gap,
- temperature,
- front tension and back tension. The analysis and simulation results show that the proposed structure has results that are acceptable for rolling processes.

The temperature influence

The temperature affects substantially the mechanical properties of metals and alloys. The influence of temperature of metal heating is explained by the increase of amplitude of atoms' thermal oscillation, which causes the weakening of their ties and facilitates the process of plastic sliding. Besides that the rate of recrystallization process increases at higher temperatures and contributes to the metal softening. The resistance to deformation decreases due to increasing of metal heating temperature within the range of temperatures of hot metal forming, and the plasticity increases. Steel that is too hot must be rolled slowly in order to prevent surface melting. Steel that is too cool will crack. Steel that is not uniformly heated will result in poor shape and size control. ***The product speed and the amount of reduction at each stand can be optimized through precise temperature control.***

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5.2. Recommendation

The development of the Rolling technology is at its infant stage in Ethiopia. Now a day the rolling mill technology is boosting up. As a professional we have to work on this area.

This study has been conducted with deformation of billets on hot rolling process the cracked FEM analysis software and it was done by an ordinary computer. The research has to be done using high computational facility.

5.3. Future work

Proper deformation of billet has been a very important issue to engineering hot rolling mill sectors for minimizing cobles and equipment damage as well as for maintenance cost. In order to improve more effectiveness of current condition of the factory, the following research areas are recommended for future studies:

- Optimization of working roll cooling system in hot rolling

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