DESIGN AND ANALYSIS OF TWO PASS ROLLING DIES

A project report submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

Submitted by

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ABSTRACT

In general, Roller Conveyors are designed by taking a set of elements into considerations like to reduce cost, ease of assembly and manufacturability etc. In addition to this, one also needs to address stress issues at the contact regions between any two elements; stress is induced when a load is applied to two elastic solids in contact. If it is not considered, the stresses which are generated can cause serious flaws within the mechanical design and the end product may fail to qualify. In order to avoid the failure of rollers one has to calculate and estimate the maximum stresses that are produced and design the rollers by taking these into consideration. The roller bearing assembly is an example where the assembly undergoes fatigue failure due to contact stresses. High stresses are generated in this case as the total load acts through this line of contact.

The project aims to analyze the contact stress distribution along the length and surface of roller of different materials of metal billets which is of constant length is passed through a two pass roller by varying the speeds of rollers. The 3D modelling of two pass rollers and the metal billet is carried out using SOLID WORKS and the analysis of two pass roller and billet assembly is to carry out using static structural module in ANSYS 2022R1 student version by taking the speeds and materials as variants.

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NOMENCLATURE

A	Area, mm2
Al	Aluminium
Cu	Copper alloy
D,d	Diameter, mm
Mn	Manganese
p	Pressure, N/mm2
rad	Radians
s	seconds
T	Temperature
ss	Stainless steel

CHAPTER I
INTRODUCTION

Metal forming is a very important manufacturing operation. It enjoys industrial importance among various production operations due to its advantages such as cost effectiveness, enhanced mechanical properties, flexible operations, higher productivity, considerable material saving.

The objects and articles that we use in our daily life are man-made, engineered parts, which are obtained from some raw material through some manufacturing process. All these objects are made of a number of small components assembled into finished product. An automobile is supposed to be an assembly of more than 15000 parts, produced through various manufacturing operations. Manufacturing of finished parts and components from raw materials is one of the most important steps in production.

Production encompasses all types of manufacturing processes. Manufacturing refers to the conversion of raw materials into finished products employing suitable techniques. There are several methods of manufacturing such as metal casting, metal forming, metal machining, metal joining and finishing.

Some of the modern methods of manufacturing include micro machining, Nano fabrication, ultra-precision manufacturing etc. In order to fulfil the requirements of the ever-increasing demands of various types of industries, the manufacturing engineer has to choose the right type of material and the right type of equipment for manufacture so that the cost of production and the energy consumption are minimum.

The selection of suitable manufacturing process should also include concerns for environmental impacts such as air pollution, waste disposal etc.

Computers and robots play important role in modern manufacturing techniques, today. Modelling and simulation of the process prior to mass production helps the manufacturing engineer fix up the best operating parameters and hence achieve the finished product to the utmost level of quality and cost-effectiveness.

Materials are converted into finished products though different manufacturing processes. Manufacturing processes are classified into shaping [casting], forming, joining, and coating, dividing, machining and modifying material property.

Fig 1.1 Classification of manufacturing

Of these manufacturing processes, forming is a widely used process which finds applications in automotive, aerospace, defence and other industries. Wrought forms of materials are produced through bulk or sheet forming operations. Cast products are made through shaping – molding and casting. A typical automobile uses formed parts such as wheel rims, car body, valves, rolled shapes for chassis, stamped oil pan, etc.

Forming is the process of obtaining the required shape and size on the raw material by subjecting the material to plastic deformation through the application of tensile force, compressive force, bending or shear force or combinations of these forces

1.1 Classification of metal forming:

Typically, metal forming processes can be classified into two broad groups. One is bulk forming and the other is sheet metal forming.

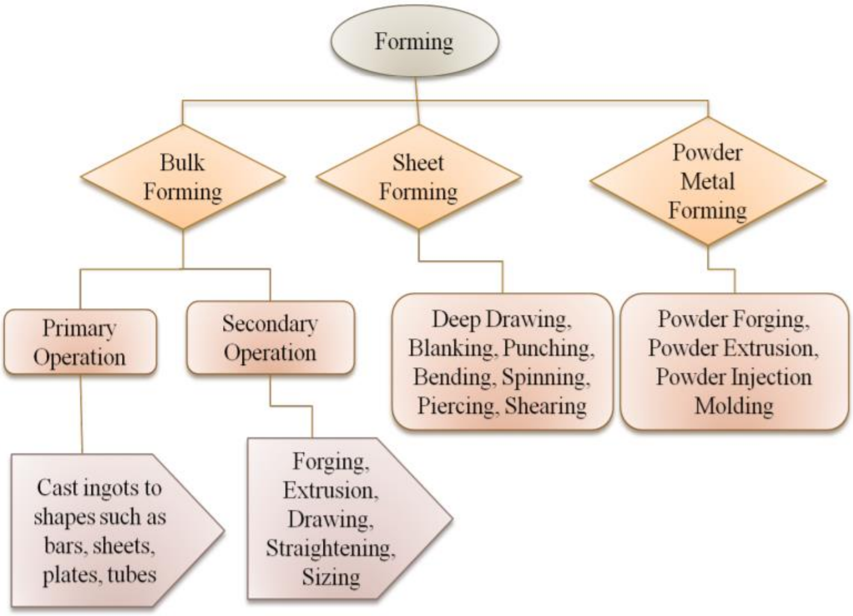


Fig 1.2 Classification of forming process

1.1.1 Bulk deformation

It refers to the use of raw materials for forming which have low surface area to volume ratio. Rolling, forging, extrusion and drawing are bulk forming processes. In bulk deformation processing methods, the nature of force applied may be compressive, compressive and tensile, shear or a combination of these forces. Bulk forming is accomplished in forming presses with the help of a set of tool and die. Examples for products produced by bulk forming are: gears, bushed, valves, engine parts such as valves, connecting rods, hydraulic valves, etc.

1.1.2 Sheet metal forming

It involves application of tensile or shear forces predominantly. Working upon sheets, plates and strips mainly constitutes sheet forming. Sheet metal operations are mostly carried out in presses – hydraulic or pneumatic. A set of tools called die and punch are used for the sheet working operations. Bending, drawing, shearing, blanking, punching are some of the sheet metal operations.

1.1.3 Powder forming

A new class of forming process called **powder forming** is gaining importance due to its unique capabilities. One of the important merits of powder forming is its ability to produce parts very near to final dimensions with minimum material wastage. It is called near-net-shape forming. Material compositions can be adjusted to suit the desirable mechanical properties. Formability of sintered metals is greater than conventional wrought materials. However, the challenge in powder forming continues to be the complete elimination or near-complete elimination of porosity. Porosity reduces the strength, ductility and corrosion resistance and enhances the risk of premature failure of components.

1.2 Types of processes

1.2.1 Rolling:

In this process, the workpiece in the form of slab or plate is compressed between two rotating rolls in the thickness direction, so that the thickness is reduced. The rotating rolls draw the slab into the gap and compresses it. The final product is in the form of sheet.

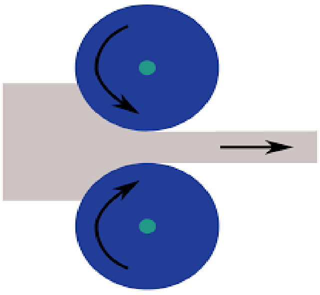


Fig 1.3 Rolling

1.2.2 Forging:

The workpiece is compressed between two dies containing shaped contours. The die shapes are imparted into the final part.

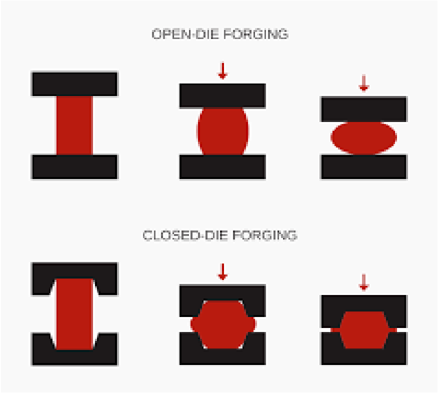


Fig 1.4 Forging

1.2.3 Extrusion:

In this, the workpiece is compressed or pushed into the die opening to take the shape of the die hole as its cross section.

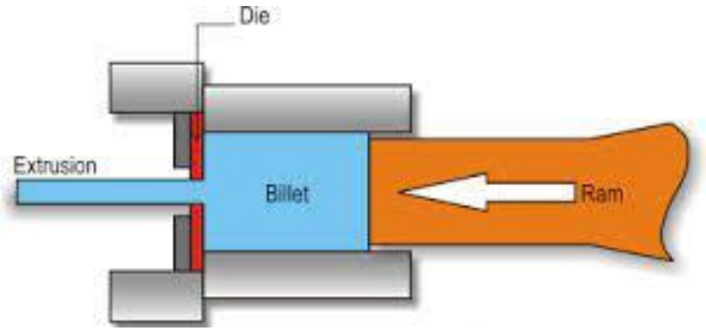


Fig 1.5 Extrusion

1.2.4 Wire or rod drawing:

Similar to extrusion, except that the workpiece is pulled through the die opening to take the cross-section.

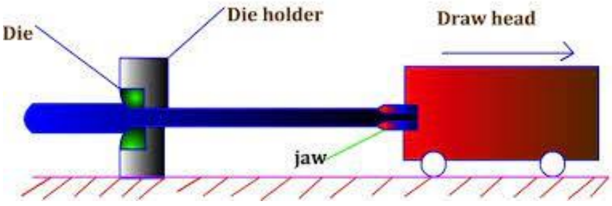


Fig 1.6 Wire or Rod drawing

1.2.5 Bending:

It is a process by which metal can be deformed by plastically deforming the material and changing its shape. The material is stressed beyond the yield strength but below the ultimate tensile strength. The surface area of the material does not change much. Bending usually refers to deformation about one axis.

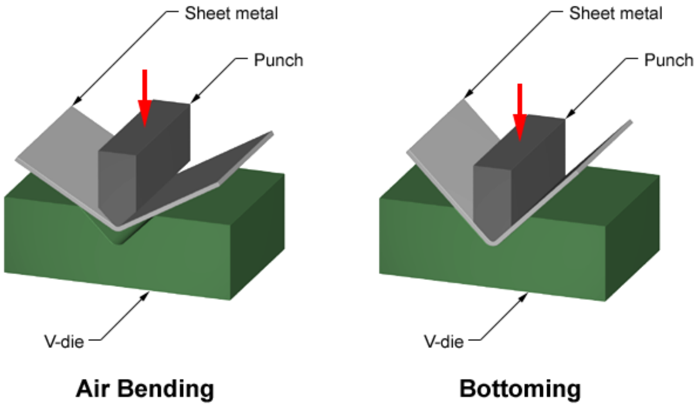


Fig 1.7 Bending

1.2.6 Shearing:

The term "shearing" by itself refers to a specific cutting process that produces straight line cuts to separate a piece of sheet metal. Most commonly, shearing is used to cut a sheet parallel to an existing edge which is held square, but angled cuts can be made as well. For this reason, shearing is primarily used to cut sheet stock into smaller sizes in preparation for other processes.

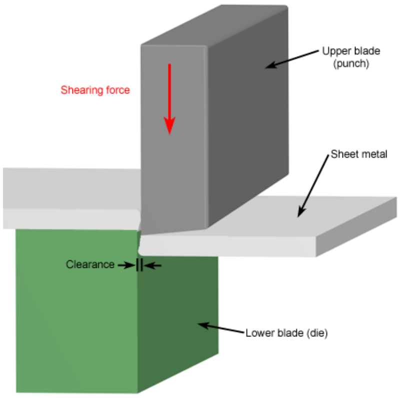


Fig 1.8 Shearing

1.2.7 Drawing:

It is a metal working process that uses tensile forces to stretch (elongate) metal, glass, or plastic. As the metal is drawn (pulled), it stretches to become thinner, to achieve a desired shape and thickness. Drawing is classified into two types: sheet metal drawing and wire, bar, and tube drawing. Sheet metal drawing is defined as plastic deformation over a curved axis. For wire, bar, and tube drawing, the starting stock is drawn through a die to reduce its diameter and increase its length. Drawing is usually performed at room temperature, thus classified a cold working process, however, drawing may also be performed at elevated temperatures to hot work large wires, rods or hollow sections in order to reduce forces.

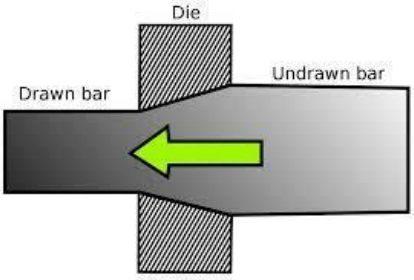


Fig 1.9 Drawing

1.3 Hot and cold working process:

Hot working refers to the process where metals are deformed above their recrystallization temperature and strain hardening does not occur. Hot working is usually performed at elevated temperatures. Lead, however, is hot-worked at room temperature because of its low melting temperature. At the other extreme, molybdenum is cold-worked when deformed even at red heat because of its high recrystallization temperature.

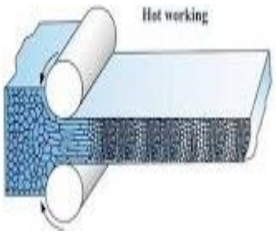


Fig 1.10 Hot working

Plastic deformation which is carried out in a temperature region and over a time interval such that the strain hardening is not relieved is called **cold work**. Considerable knowledge on the structure of the cold-worked state has been obtained. In the early stages of plastic deformation, slip is essentially on primary glide planes and the dislocations form coplanar arrays. As deformation proceeds, cross slip takes place. The cold-worked structure forms high dislocation density regions that soon develop into networks. The grain size decreases with strain at low deformation but soon reaches a fixed size. Cold working will decrease ductility.

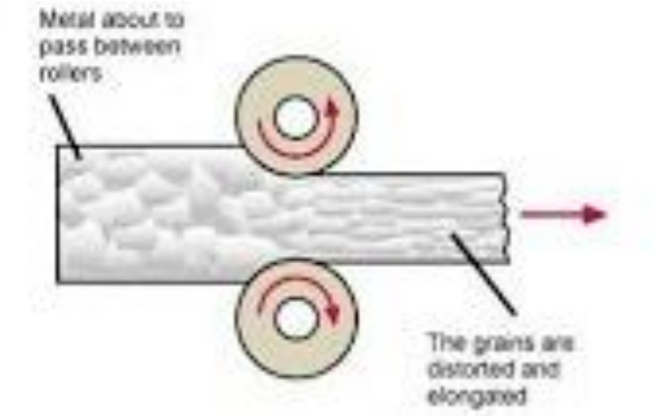


Fig 1.11 Cold working

The resistance of metals to plastic deformation generally falls with temperature. For this reason, larger massive sections are always worked hot by forging, rolling, or extrusion. Metals display distinctly viscous characteristics at sufficiently high temperatures, and their resistance to flow increases at high forming rates. This occurs not only because it is a characteristic of viscous substances, but because the rate of recrystallization may not be fast enough.

1.4 Rolling

Rolling is defined as a process to form metals where the metal strip is pressed by two or multiple rollers, thus the uniform thickness is formed. To do this, the temperature is essential.

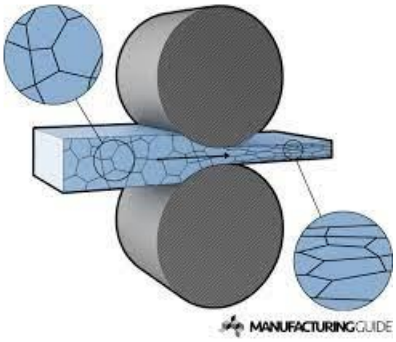


Fig 1.12 rolling

There are two types of processes. One is hot rolled and another is Cold Rolled. If the strip is rolled after heating the strip above the re-crystallization temperature then it is termed as Hot rolled and if that done in room temperature then it is termed as the Cold rolled. Rolling is a process that is widely used and has very high production.

Blooms are rolled into structural shapes like rails for railroad tracks.

Billets are rolled into bars, rods. They become raw materials for machining, wire drawing, forging, extrusion etc.

Slabs are rolled into plates, sheets, and strips. Hot rolled plates are generally used in shipbuilding, bridges, boilers, welded structures for various heavy machines, and many other products.

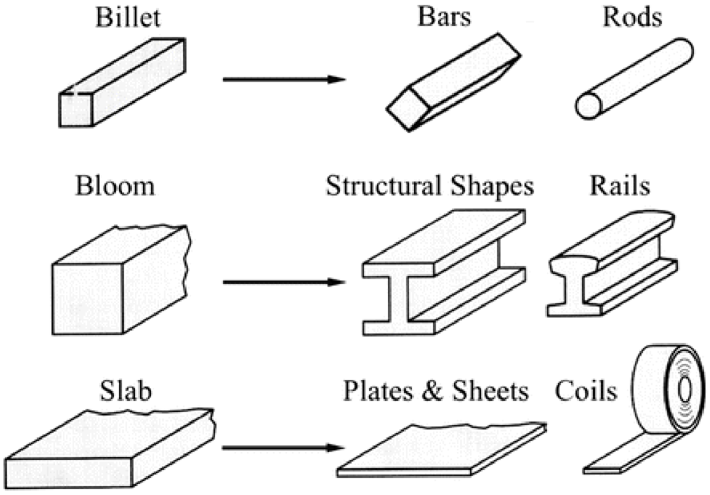


Fig 1.13 Blooms, Billets, Slabs

1.4.1 Working Principle:

The rolling process is a metal forming process, in which stock of the material is passed between one or more pairs of rollers in order to reduce and to maintain the uniform thickness.

This process is mainly focused on the cross-section of the ingot or the metal which is forming. Mainly by this process, we reduce the thickness of the metal workpiece.

Now, the rolling processes are mainly focused on the increasing length and the decreasing thickness without changing the width of the workpiece.

There are certain types of the rolling process, whereas, in the hot rolling process, the metal is heated at its desirable temperature, when the metal is properly heated then the metal should be passed between the one or more rolling mills to gain the proper desirable shape.

This process is vastly used in respect of any other rolling process. In this process, the metal is heated above the recrystallization temperature. In the hot working process, the metal is changing its grain structure because of the heat, now there were a new set of strain-free grains in the metal and this process needs less amount of force which correspondingly reduces the quality of the surface finish, of that metal.

Now there is another rolling process, which is a cold rolling process. This rolling process is done below the recrystallization temperature of the metal it varies upon the metal, room temperature can also be a below recrystallization temperature.

In this process, the force is much more required than the hot working process to pass the metal from the rollers and this process offers good surface finish.

1.4.2 Types of rolling mills:

There are most commonly used five types of rolling mills basing on the number of dies used to reduce the cross section of the metal.

They are

1. Two-High Rolling Mills
2. Three-High Rolling Mills
3. Four High Rolling Mills
4. Tandem Rolling Mills
5. Cluster Rolling Mills
6. Thread rolling

1.4.2.1 Two-High Rolling Mills:

In this rolling mill, there are two rolls used and the roll diameters are in the range 0.6 to 1.4 m

In this reversing type of mill, the rollers are both adjustable. In these mills, rotation of those two rolls is made in two different directions. In this operation, the metal is passed between two rollers that rotate at the same speed but it is in the opposite direction.

It is used in slabbing, plumbing, rail, plate roughing work and many other areas. As there is the need for a reversible drive, this mill is cheaper compared to the others.

In in reversing type of mills, two rolls continuously revolve in the same direction and we can’t reverse the direction of the rollers. In this operation, the motive power is less costly.

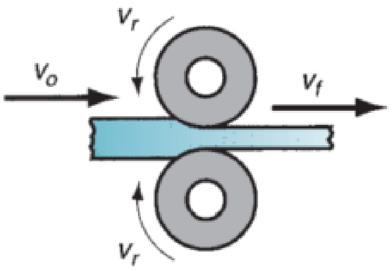


Fig 1.14 Two pass rolling mill

1.4.2.2 Three-High Rolling Mills:

In this mill, the three rolls stand in parallel one by others. The rolls are rotating in opposite directions. In this mill, between the first and the second rolls, the material passes. If the second roll rotates in a direction then the bottom roll rotates in another direction. The material is rolled both in forward and return in three high rolling mills.

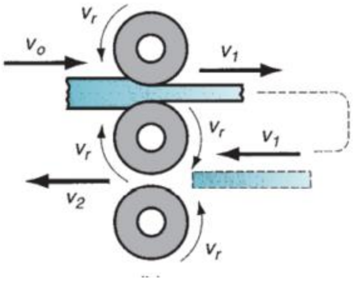


Fig 1.15 Three pass rolling mill

At first, it passes forward through the last and second roller and then comes back through the first and second roller. In that mill, the thickness of the material is reduced and being uniform by each pass. Here transition system and a motor are needed which is less powerful.

1.4.2.3 Four High Rolling Mills:

In this type of mill, there are four parallel rolls one by another. In this operation, the rotation of the first and the fourth rolls take place in the opposite direction of the second and the third rolls. The second and third rolls are smaller to provide rigidity in necessity. So those are known as back up rolls. It is used in the hot rolling process of the armor and in the cold rolling process of sheets, strips, and plates.

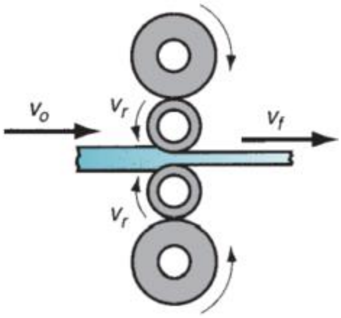


Fig 1.16 Four high rolling mill

1.4.2.3 Tandem Rolling Mills:

In this type of rolling mill, there are two or more sets of rolls in the parallel alignment which make the continuous passes and successively decrease the thickness and make that uniform.

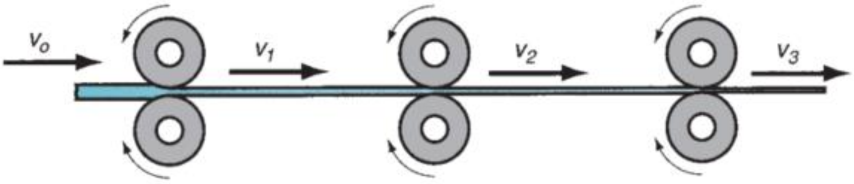


Fig 1.17 Tandem rolling mill

1.4.2.4 Cluster Rolling Mills:

In this type of rolling mill, there are two basic roles that are backed up by two or more rolls which are bigger than those two basic rolls. These backed up rolls give more pressure to the basic rolls to heavily press the strip.

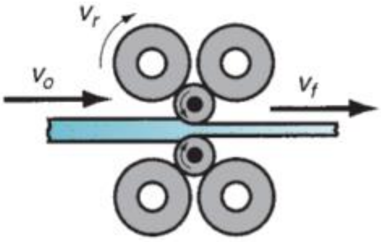


Fig 1.18 Cluster rolling mill

1.4.2.5 Thread rolling:

Thread rolling is used to create threads on cylindrical parts by rolling them between two dies as shown in figure. It is used for mass production of external threaded parts like bolts and screws.

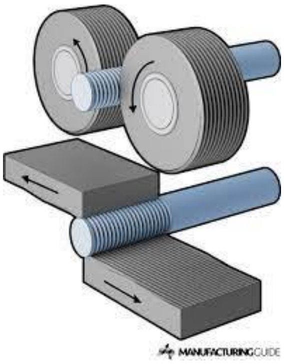


Fig 1.19 Thread rolling

1.4.2.6 Ring rolling:

Ring rolling is a forming process in which a thick walled ring part of smaller diameter is rolled into a thin walled ring of larger diameter. As the thick walled ring is compressed, the deformed material elongates, making the diameter of the ring to be enlarged. Application: ball and roller bearing races, steel tires for railroad wheels, rings for pipes, pressure vessels, and rotating machinery

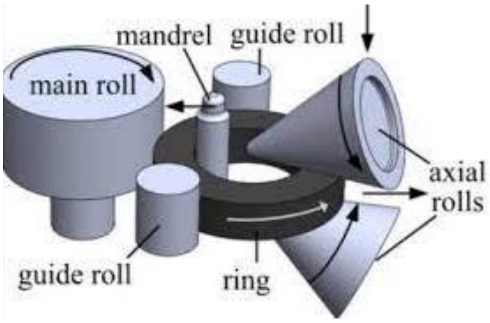


Fig 1.20 Ring rolling

1.4.3 Advantages of Rolling Process:

- By rolling, uniform dimensions of the components can be obtained.
- It uses the same tool in the sense, the same rollers are responsible for the production of various components.
- Close tolerance is possible for the components in the rolling.
- High-speed production takes place in the rolling.

1.4.4 Disadvantages of Rolling Process:

- The cost of equipment is high.
- It is suitable for large scale production only.
- Poor surface finish and thereby we need to secondary operations like finishing etc.

1.4.5 Application of Rolling:

The rolling operation used in various industries such as:

- Rods, seamless hollow tubes are made by rolling.
- Rolling is used to producing cross-section of large sections.
- Rolling is used to cutting the gears on the gear blank.
- The threaded parts, bolts, screws, etc. which have mass production is made by the rolling process.
- In automotive industries, various parts are manufactured by the rolling process.
- The rolling process is used to made plates, steel sheets, etc.
- Bearing, Turbines rings are rolling products.

1.4.6 Defects of Rolling:

The most common defects we can see in the rolling process are listed below,

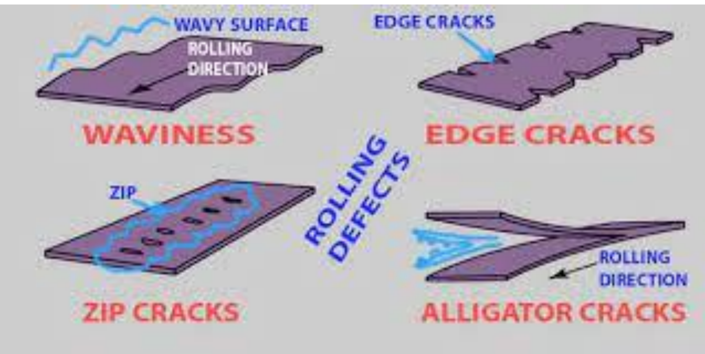


Fig 1.21 Defects of rolling

1.4.6.1 Wavy Edges:

One of the most common rolling defects is the occurrence of fibers at the edge, which are longer than those at the centre. This occurs when concave rolls bend leading to elastic deformations. Thickness at the centre implies that the edges are more elongated.

Fig 1.22 Waviness or wavy edges

Wavy edges can be prevented by the use of hydraulic jack’s works well in instances where wavy edges occur. These jacks control the elastic deformation of rolls as per the requirements. Also, the use of small diameter rolls works efficiently.

1.4.6.2 Zipper Cracks:

The occurrence of small cracks in the middle of the metal sheet explains this phenomenon. Mostly, zipper cracks occur due to the bending of rolls under the high rolling pressure. It causes compressive stress in the edges and tensile stress in the centre. It’s this tensile stresses induced at the work piece by homogeneous deformation that leads to the formation of zipper cracks.

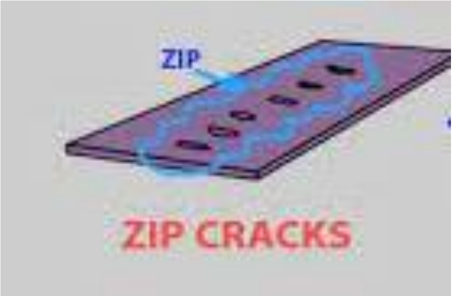


Fig 1.23 Zipper cracks

Cambering of rolls has proven effective when it comes to preventing zipper cracks. Camber provides a slightly large diameter at the centre than on the edges.

1.4.6.3 Edge Cracks:

During both hot and cold rolling, the metal might show some cracks on the edges. This phenomenon occurs from secondary tensile stresses induced at the work piece surfaces. These cracks result from factors such as uneven heating, uneven rolling, or excess quenching.

Fig 1.24 Edge cracks

A trimming operation can remove edge cracks. Also, stretch and roller levelling under tension might work against edge cracks. Using edge rolls might help in achieving uniform rolls without any cracks.

1.4.6.4 Alligator Cracks

During rolling, layers of the metal stock might separate, leading to the opening of slabs resembling alligator cracks. The sheet metal adheres to the rolled surface and follows the path of respective rolls causing sheets to appear on the in the plane. Alligator cracking is majorly due to the non-homogeneous flow of materials across the sheet thickness. Greater spreading of materials occurs at the centre of the material, thus metallurgical weakness.

Fig 1.25 Alligator cracks

Cambering of rolls is one of the most common solutions to alligator cracking. By applying the camber on rolls in the opposite direction, the surface in contact with the sheet becomes flat after a deflection.

1.4.6.5 Center Buckling

This defect occurs due to the self-equilibrating residual stresses that result from the rolling process. During centre buckling, fibers at the centre of the metal piece are longer than those at the edges. In an event where hot or cold mills have too much crown, mills roll out at the centre. Sideways deflection of a structural member perfectly explains centre buckling.

Use crowned rolls is a solution to centre buckling. The roll’s parabolic curvature is sufficient to cover the problems of material, temperature, and deformation.

CHAPTER II
LITERATURE REVIEW

2.1 Details of work conducted by various authors,

Alexander Schowtjak, et.al [1], the authors analyze the evolution of damage and voids in the sequence of caliber rolling to cold forward rod extrusion. The analysis is performed with the help of a variant of the Lemaitre model, microstructural analysis of the void area fraction and density measurements. The numerical analysis of this process chain makes use of a fully three-dimensional simulation approach. Even though the damage distribution is non-axisymmetric in caliber rolling, the distribution is almost axisymmetric after cold forward extrusion. The shoulder opening angle in extrusion is varied to compare model predictions with experiments. The decrease in density is largest for the largest shoulder opening angle and smallest for the smallest shoulder opening angle. The simulations agree qualitatively well with the experiments in term of the measured void area fraction and the density changes. The quantitative comparison reveals differences of one to two orders of magnitude.

Andre Lim, et.al (2016) [2], examined and studied the residual stress distributions caused by the deep cold rolling (DCR) process, with a focus on the distributions at the boundary of the treatment zone. A three-dimensional finite-element (FE) model, validated with experimental residual stress data, is used to study the effect of the process. Other factors that cause a difference between the steady state and the transient zone of the burnished area are also investigated. It is shown that the net material movement causes larger plastic deformation in the boundary zone between the burnished and unburnished region of DCR.

A k ray, et.al [3], focused on the failures that occur due to improper manufacturing and operational parameters. Prematurely failed roll samples are collected from a reputated steel plant were examined for their chemistry, indusion content, microstructures, hardness, and retained austenite content. The residual stresses are also measured on the inner and outer surfaces of the rolls. The higher content of retained austenite is highly responsible for the spalling of the indigenous rolls for which sub-zero treatment has been recommended.

D.Muruganandam, et.al [4], Developed 3D model of the slab and roller using finite element approach for the contacting leads thermal & mechanical behaviour of the roll and slab in the hot rolling. The article simulated the hot rolling of aluminium slab under different reduction, different speed and temperature to shows the effects of the above parameters on hot rolling process.

The strain rate, and develops greater effective strain and temperature rise due to high reduction increases the rolling force. Increasing rolling speed affects the strain rate and roll pressure but increases the temperature of the slab. The amount of initial temperature of work piece is another parameter, while Increasing the slab temperature, its leads to decreases pressure, and effective strain

Dr. Ravi Goyal, et.al [5], has focussed on to highlight those reasons which are responsible for the breakage. The parameters considered during the manufacturing and during the regular use of rolls in cold rolling in the past researches and the effect of these parameters to increase the life of a roll. These are based upon the various factors and summarize the effect of parameters responsible for the deformation concluded by the various researchers in the past history of cold rolling mill.

Huiping Hong [6], Reasonable design of roll pass schedule is the prerequisite for a successful shape rolling process. In this paper three dimensional elastoplastic finite element simulation with thermal mechanically coupled analysis is applied to study the roll pass design of the hot continuous rolling of Φ100mm alloy steel round bar from 200mm×200mm square cast bloom. Due to the larger plastic strain occurring at the corner of the workpiece, the method of bias meshing for the cross section is adopted to fine the elements of surface and corner area. The stress, strain, temperature distribution, rolling force and rolling moment of the hot continuous rolling are simulated to analyze the plastic deformation and the position and cause of possible rolling defects in order to confirm the roll pass design. The simulated results of cross section sizes of rolled steel at the exit of each pass are in good agreement with the measured values.

Kaixiang Peng [7], studied constant and reproducible production conditions of modern steel grades both in the hot strip mill and in the cooling section to achieve constant material properties along the entire strip length and from strip to strip. Finite element model is constructed for the temperature field in a rolling process. The temperature field of strip steel is modelled with a 3-D finite element analysis (FEA) structure, simultaneously considering the distribution of the work roll temperature.

Kun shi, et.al [8], aimed at the complex changes of the working rollers and rolled pieces in the rolling process of a cold rolling mill, this paper built a finite element model of the working rollers and rolled pieces based on ANSYS, and analyzed the rolling process of working rollers by using the transient algorithm of structural dynamic equation. The stress-strain situation and rolling force curve of working rollers and rolling pieces were obtained, The results revealed the characteristic change process of working rollers and rolled pieces in the rolling process, which laid the foundation for further realizing the precise control of the rolling process of cold rolling mill.

Kondapalli Siva Prasad, M. Lalitha Kavya [9], Made an attempt is made to summarize the various works reported by earlier researchers on certain specific areas of rolling like Finite Element Analysis (FEA), die and rolling material and summarize the results , so that the gaps can be identified, which in turn helps the researchers to carry their research in rolling.

Mesay Alemu Tolcha, et.al [10], The central concern of numerical modelling is used in this work to indicate a set of equations, derived from the contact principle, that transfer the physical event into the mathematical equations. Continuum rolling contact phenomena is considered to explain how a contact region is formed between rolling die and slab and how the tangential force is distributed over the contact area with coefficient of friction. At the end, elasticity stress behaviour of rolling die contact with the slab for a number of cyclic loads is modelled. The model includes new proposed constitutive equations for discontinuity of the velocity–pressure distribution in rolling contact from the entry side to exit side of the neutral point.

O.A. Gasiyarova, et.al [11],The paper deals with the methods to increase the accuracy of determination of roll torque on the motor shaft of the hot plate mill. Experiments are carried out by rolling of different steel grads eat the hot plate mill 5000. Thus, as a result of the carried out research it is obtained the experimental dependence to calculate angle of resultant roll force at hot plate mill, consequently it is possible to determine roll torque on the motor shaft of the rolling stand of the hot plate mill 5000 more accurately.

O.M. Ikumapayi, et.al [12], rolling operation in metal forming and equipment has been conducted. The present article aimed to access rolling techniques in metal forming operation, or as part of the industrial manufacturing process. Comparison in performance of different rolling methods, while analysing their defects, and areas of application of rolled products or components is presented. Hence, the functionality and working principle of Rolling as manufacturing, or shaping process are discussed, and prospect for future industrialization suggested. The research is ascensive of the relationship between human, and machine handling, equipment handling, material handling and understanding of the type of defect in rolling to meet the increase in operational performance, even as the processes become more advanced.

Santhosh kumar et.al [13], analysed on reducing or minimizing the defects of rolling process. The analysis has been carried out for different temperature i.e. 100°C, 150°C, 200°C and 250°C. As the temperature goes on increasing correspondingly the residual stresses decreases. Hot rolling process helps in reduced residual stresses at high temperature & helps in formation of smooth granular structure of product. Due to the symmetry of the rolling components, half the model is built & the analysis is carried out with 4 roller sizes varying from 8mm to 20mm with 4mm increment & the results were tabulated by using ANSYS. This will helps in estimation of residual stresses.

Shaibu [14], investigated three dimensional heat equations and temperature fields of a roll using finite element method (FEM). For the estimation of thermal field on the work roll, mathematical modelling of moving heat sources approach is executed. The differences in the surface temperature of the roll during hot rolling process were illustrated. The effect of orientations of the water jets, heat transfer coefficient at roll surface and hot strip entry temperature also been deliberated by this model, and their effect on roll temperature has been analyzed. The change of angle of jet has shown that the effect of heat transfer coefficient is reduced. The computational dynamics of fluid flow with heat transfer variation and its characteristic are analytically modelled using the Finite volume Method (FVM).

Wang, et.al [15], analyzed some key technologies and gave out related solution schemes, in which the LS DYNA code and its mass scaling function is adopted to reduce the compute time, and a user-defined ANSYS Parametric Design Language program is developed to control the complex movements of the guide rolls and axial rolls. And this paper created the three-dimensional simulation models of a rear axle bevel gear blank, an aero-engine turbine casing blank and a great conical ring of the 600MW nuke reactor shell, and realized the entry virtual rolling process of these profile rings, respectively.

Yavtushenko A.V, et.al [16], The possibility of application of the program complex called Mathcad Prime 5 for calculation of normal contact stresses in the centre of deformation during cold rolling of the strips is considered. The algorithm, the block-scheme and the computer program of calculation of the normal contact stresses during rolling of the strips on the re-verse mill 1680 PJSC “Zaporizhstal” are developed. The epures were constructed and a comparative analysis of the formulas used to calculate the normal contact stresses in the deformation centre was carried out. Received calculation data in Mathcad Prime 5 coincides with the literary data, which has practical value for both educational process and research and design work. Based on the analysis of the contact stress epures, it can be concluded that the most accurate calculation of the total metal pressure on the rolls during cold rolling is possible only when the formulas used ещ consider the change in the forced yield strength in the deformation centre by the law of a straight line or the parabolic law.

Yingxiang Xiaa, et.al [17], Aiming at the existing problems, e.g. cracking, many forming passes, difficult control of dimensional accuracy, in thin-walled pipe fittings hot extrusion forming process, an innovative forming on thinning and thickening of thin-walled pipe fittings by three-roll skew rolling with a pair of molds is being proposed in this paper. Based on the analysis of the movement principle of the three-roll skew rolling hollow reduction process, the three-roll diameter reducing and end-thickening forming of thin-walled pipe blank with 1.5mm wall thickness is simulated by Simufact Finite Element software. The law of metal flow, strain field and rolling force are analysed, and the forming mechanism is clarified. The product meeting the production specifications is obtained by comparing the simulation results of the end wall thickness distribution and the wall thickness of pipe forming. The results show that the diameter reducing and end-thickening forming process of thin-walled pipe fittings by three-roll skew rolling is feasible. This study lays a theoretical foundation and new idea for the diameter reducing and end-thickening high efficiency precision forming of thin-walled pipe fittings such as aircraft control rods.

2.2 Summary of works

The following points are summarized based on the survey conducted

1. Few studies suggested the new factors including the material to be used for the design of rollers which improves the life of rollers.
2. Some of the studies focussed on the failures that are occurred during the process and stated the corrections to be made.
3. Some papers used aluminium as slab or billet material because aluminium is widely used in this process across industries.
4. Few studies are conducted by changing the temperatures, as the temperature goes on increasing the residual stresses are decreasing.
5. Some studies stated that performance of rollers can be increased by manufacturing the rollers by using composites rather than pure metals.
6. Most of studies are conducted by taking air as medium with constant temperature by changing the materials of billets.
7. Some studies used Mathcad and ANSYS and have developed a 3d model and compared the results with the theoretical values have shown accurate values for stress distribution and deformation.
8. Few studies suggested that the low speeds of rollers have stress distribution is less thus the life of rollers will increase.

CHAPTER III
MODELLING AND FEA

3.1 Formulation of problem

Consider a roller and billet assembly of dimensions as 50mm and 40mm as diameter and width of the roller and 100mm, 15mm, 10mm as length, input width and output width respectively. The rollers are made to rotate at 4 different speeds i.e. 0.24rad/s, 0.3rad/s, 0.46rad/s, 0.6rad/s and billet is made to move between the rollers. The temperatures are considered to be constant throughout the process.

The contact stress between the roller and the billet , maximum equivalent stress and directional deformation can be found out. Simultaneously the material of the billet is changed. We have considered 4 different materials which are commonly used in the industry. Aluminium alloy, copper alloy, magnesium alloy and stainless steel are 4 different materials.

3.2 Mechanical parameters of roller and billet

Dimensional Accuracy of Work Roll – The manufacturing of work roll consist of Forged bar of particular material is to be sized as per the requirement and after that roughing work is to be started. Lot of care to be taken at this stage as if the work roll is run out by its own axis then it’s not possible to recover it. The main course of action is final finishing stage is called as grinding. Usually Cylindrical Grinding machine is used of varying capacity. Skill and high accuracy is highly required to achieve dimensional accuracy of a roll and need to be inspected at every stage of finishing operation. Rat tails, marks and surface defects may give negative impression on sheet.

Hardness – It’s one of the important parameter which needs to be proper checked while manufacturing. Its impact on quality of rolling is very high. Suppose there are two work rolls in a rolling mill and a sheet of metal like aluminium, copper or mild steel. If the hardness of both the rolls are deviated by a substantial amount the roll will not be able to withstand against load applied by screw down, this will be result in poor rolling quality.

Surface Finish – Surface finishing of work roll and other rolls are dependent of various parameters. These are hardness stability, machine conditions, and skill of operator, support gauges and inspection. Hardness process is having its role as before hardness poor surface finish is very common and if after hardening operation the surface finish enhances. The chemical composition is such that % of Silicon also pays vital role in surface finishing. Machine conditions such as condition of grinding wheel, availability of coolant, coolant condition are factors which effects surface finish. The higher side of the diameter of roll always give good surface finish as machine speed has to be moderated while is small diameter rolls ranging from 50 to 70 mm moderated surface finishing noticed.

Chemical Composition of Material – Right chemical composition always has it effects on roll quality. The correct percentage of carbon, silicon, manganese, chromium, Nickel, Sulphur and Phosphorus have its effects. The increased quantity of S and P is highly restricted for the roll quality. The incorrect composition will tend to unexpected cracks and breaks at the corners of the rolls. This composition of materials make steel usable or in sometimes pre-mature failure. For work roll usually Hi Carbon Hi Chromium tool steel is deployed. This is available in D2, 9H, C105W1 and others.

3.2.1 Properties of roller material used

Table 3-1 composition of D2 steel (weight %)

Steel Grade	carbon	Mn	silicon	Cr	Nickel	S	P	Hardness HRC
D2	1	0.25	0.25	1	0.2	0.005	0.003	60-62

Young’s modulus	2.09×10^11 pa
Poisson’s ratio	0.3
Bulk modulus	1.7417×10^11 pa
Shear modulus	8.038×10^10 pa
Coefficient of thermal expansion	1.04 ×10^-5 /c
Density	7700 kg/m^3
Tensile ultimate strength	2.4×10^9

3.2.2 Properties of billet materials used

3.2.2.1 Aluminium alloy

Young’s modulus	7.1×10^10 pa
Poisson’s ratio	0.33
Bulk modulus	6.960×10^10 pa
Shear modulus	2.669×10^10 pa
Tangent modulus	5×10^8 pa
Density	2770 kg/m^3
Yield strength	2.8×10^8 pa

3.2.2.2 Copper alloy

Young’s modulus	1.1×10^11 pa
Poisson’s ratio	0.34
Bulk modulus	1.1458×10^11 pa
Shear modulus	4.10×10^10 pa
Tangent modulus	1.15×10^9 pa
Density	8300 kg/m^3
Yield strength	2.8×10^8 pa

3.2.2.3 Magnesium alloy

Young’s modulus	4.5×10^10 pa
Poisson’s ratio	0.35
Bulk modulus	5×10^10 pa
Shear modulus	1.667×10^10 pa
Tangent modulus	9.2×10^8 pa
Density	1800 kg/m^-3
Yield strength	1.93×10^8 pa

3.2.2.4 Stainless steel

Young’s modulus	1.93×10^11 pa
Poisson’s ratio	0.31
Bulk modulus	1.693×10^11 pa
Shear modulus	7.366×10^10 pa
Tangent modulus	1.8×10^9 pa
Density	7750 kg/m^3
Yield strength	2.1×10^8 pa

3.3 Introduction to finite element method

The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It is also referred to as finite element analysis (FEA). It subdivides a large problem into smaller, simpler parts. The simple equations that model these finite elements are then assembled into a large system of equations that models the entire problem. FEM then uses variation methods from the calculus of variations to approximate a solution by minimizing an associated error function.

The sub-division of a whole domain into simpler parts has several advantages:

- Accurate representation of complex geometry
- Inclusion of dissimilar metal properties
- Easy representation of total solution
- Capture of local effects

Most often it is not possible to ascertain the behaviour of complex continuous system without some form of approximations. For simple members like uniform beams, plates etc., classical solutions can be sought by forming differential or integral equations through structures like machine tool frames, pressure vessels, automobile bodies, ships, air craft structures, domes etc., need some approximate treatment to arrive at their behaviour, be it static deformation, dynamic properties or heat conducting property. Indeed these are continuous systems with their mass and electricity being continuously distributed.

The classical differential equation solution approach leads to intractability. To overcome this, engineers and mathematicians have from time to time proposed complex structures, which are defined using a finite number of well-defined components. Such systems are then regarded as discrete systems.

3.4 Historical background

The method originated from the need to solve complex elasticity and structural density problems in civil and aeronautical engineering. Its development can be traced back to work by A. Hrennikoff and R. Courant. In china, in the later 1950s and early 1960s, based on the computations of dam constructions, K. Feng proposed a systematic numerical method for solving partial differential equations. The method was called finite difference method based on variation principle, which was another independent invention of finite element method. Although the approaches used by these pioneers are different, they share one essential characteristic: mesh discretization of a continuous domain into set of discrete sub-domains, usually called elements.

Hrennikoff's work discritizes the domain by using a lattice analogy while Courant's approach divides the domain into finite triangular sub regions to solve second order elliptical partial differentiation equations (PDEs) that arise from the problem of torsion of a cylinder. Courant's contribution was evolutionary, drawing on a large body of earlier results for PDEs developed by Rayleigh, Ritz, and Galerkin.

The finite element method obtained its real impetus in the 1960s and 1970s by the developments of J. H. Argyris with the co-workers at the University of Stuttgart, R. W. Clough with the co-workers at UC Berkeley, O. C. Zienkiewicz with the co-workers Ernest Hinton, Bruce Irons and others at the university of Swansea, Philippe G. Ciarlet at the University of Paris 6 and Richard Gallagher with co-workers at Cornell University.

3.5 Need for finite element method

To predict the behaviour of stricter the designer adopts three tools such as analytical, experimental and numerical methods. The analytical method is used for the regular sections of known geometric entities or primitives where the component geometry is expressed mathematically. The solution obtained through the analytical method is exact and takes less time. This method cannot be used for irregular sections and the shapes that require very complex mathematic equations. On the other hand the experimental method is used for finding the unknown parameters of interest. But the experimentation requires the testing equipment and a specimen for each behaviour of requirement. This in turn, requires a high initial investment to procure the equipment and to prepare the specimens.

The solution obtained is exact by the time consumed to find the results and during the preparation of specimens also. There are many numerical schemes such as finite difference methods, Finite element method, Boundary element and volume method, Finite strip and volume method and Boundary Integral methods etc., are used to estimate the approximate solutions of acceptably tolerance.

3.6 The process of finite element method

A typical work out of the method involves (1) dividing the domain of problem into a collection of sub-domains, with each sub-domain represented by a set of element equations to the original problem, followed by (2) symmetrically recombining all sets of element equations into a global system of equations for final calculations. The global system of equations has the known solution techniques, and can be calculated from the initial values of the original problem to obtain a numerical answer.

In the first step above, the element equations are simple equations that locally approximate the original complex equations to be studied, where the original equations are often partial differential equations (PDE). To explain the approximation in the process, FEM is commonly introduced as a special case of Galerkin method. The process, in the mathematical language, is to construct an integral of the inner product of residual and the weight functions and set the integral to zero. In simple terms, it is a procedure that minimizes the error of approximation by fitting the trial function into the PDE. The residual is error caused by the trial function into the PDE. The residual is the error caused by trial functions, and the weight functions are polynomial approximation functions that project the residuals. The process eliminates all the spatial derivates from the PDE, thus approximating the PDE locally with

- A set of algebraic equations for steady state problems and
- A set of ordinary differential equations for transient problems.

These equation sets are the element equations. They are linear if the underlying PDE is linear, and vice versa. Algebraic equations sets that rise in the steady state problems are solved using numerical linear algebraic methods, while ordinary differential equation sets that rise in the transient problems are solved by the numerical integration using standard techniques such as Euler method and Runge-Kutta method.

In step (2) above, a global system of equations is generated from the element equations through the transformation of coordinates from the sub-domains local nodes to the global domain nodes. This spatial transformation includes approximate orientation adjustments as applied in relation to the reference condition system. The process is often carried out by FEM software using co-ordinate data generated by sub-domains.

3.7 Field and boundary conditions

The field variables such as displacements, strains and stresses must satisfy the governing conditions, which can be mathematically expressed in the form of differential equations.

For structure mechanic problems the boundary conditions may be kinematic i.e., where the displacements (and slopes i.e., derivative of displacement) may be prescribed. Initial values are given to problems where time is involved. The specified temperature or heat flow/heat flux or convections may be specified in thermal analysis.

3.8 Steps involved in finite element modelling

The steady state thermal analysis is used to determine temperature, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary with time. A steady state thermal analysis calculates the effects of steady thermal loads on a system or component. In this method the structure is assumed to be build of numerous connected tiny elements. From this comes the name “Finite Element Method“. Extremely complex structures can also be simulated by proper arrangement of these elements. The most commonly used elements are beams, solids, plates, prismatic shapes etc. The points interconnecting the elements are called nodes. The broad steps in the finite element method when it is applied to thermal analysis are as follows:

1. Divide the continuum into a finite number of sub regions of simple geometry such as line segments, triangles, quadrilaterals. (Square and rectangular elements are subsets of quadrilateral), tetrahedrons and hexahedrons (cubes) etc.
2. Nodes are assigned to location in the element at which unknown function, such as stresses are to be determined. Nodes are often placed at corners of elements, but additional nodes can be placed internally or along the element boundaries
3. A shape function is assumed within each element so that stress at desired nodes can be found
4. Satisfy the stress distribution within a typical element
5. Develop equilibrium equations for nodes of the discretized continuum in terms of element contributions
6. Solve the equilibrium for the nodal elements

7. Calculate the stress distribution, directional deformation at selected points within the element.

3.9 Applications of finite element method

Since early 1960s there has been much progress in the method. The method requires a large number of computations requiring a fast computer. Infact digital computer advances have been responsible for expanding usage of finite element method. A rigorous mathematical basis to the finite element method was provided in 1973 with the publication by Strang and fix. The Finite element method was initially developed to solve structural steel problems. Its use, of late, has been rapidly extended to various fields. The method has since been generalized for the numerical modelling of physical systems in a wide variety of engineering disciplines, e.g., electromagnetism, heat transfer, fluid dynamics.

NASA sponsored the original version of NASTRAN, and UC Berkeley made the finite element program SAP IV widely available. In Norway the ship classification society Det Norske Veritas (now DNV GL) developed Sesam in 1969 for use in analysis of ships.

3.10 3D Modeling of roller and billet

The 3D modelling of pin fin is performed in SOLIDWORKS modelling software.

3.10.1 Introductions to solid works

SOLIDWORKS is a solid modelling computer aided design (CAD) and computer aided engineering (CAE) computer program that runs on Microsoft windows. SOLIDWORKS is published by DASSAULT SYSTEMS.

SOLIDWORKS uses sketch entities and tools to facilitate the creation of parts. While sketch entities have specific geometries (line, rectangle, parallelogram, slot, polygon, circle, arc, ellipse, parabola, spline, etc.), some of the sketch tools (fillet, chamfer, offset, convert entities, intersection curves, trim, extend, split, jog line, constructive geometry, mirror, stretch, move, rotate, scale, copy, pattern, etc.) are used to modify the shapes of sketch entities. Entities are grouped to define the boundary or profile, which are closed regions needed for creating extruded or revolved parts. SOLIDWRKS sketch entities and tools can be accessed by clicking the tools bar.

Sketch entities include line, rectangle (2-opposite vertices, centre, 2-opposite vertices, 3-point corner,3-point centre), parallelogram, slot (straight, centre-point straight, 3-arc, centre-point arc), polygon, circle (centre-1-point,3-points on perimeter), arc(center-2-point, tangent, 3-point arc), ellipse(full, partial), parabola, and spline.

Sketch tools include fillet, chamfer, offset, convert entities, intersection curves, trim, extend, split entities, jog line, construction geometry, make path, mirror (straight, dynamic), stretch entities, move entities, rotate entities, scale entities, copy entities, and pattern (linear, circular).

3.10.2 Steps involved in modelling

The modelling is done by following three steps

Table 3-2 geometry of roller and billet

	Volume (mm^3)	**Surface area (mm^2)**	**Dimensions (mm)**
Roller	74895.57	11787.26	Dia=50mm Width= 40mm
billet	24892.41	7014.22	Input=15mm Output=5mm

3.10.2.1 Creation of roller

The body is created by the sketch entities and feature entities with the available dimensions of the roller and billet. A sketch of side view of roller is generated and is extruded to required depth or thickness. Another sketch is developed in the side view and use extruded cut to the required depth. Extruded cut feature of this sketch creates a hole in the body. The parts are saved in standard format of '.SLDPRT' for the assembly operation.

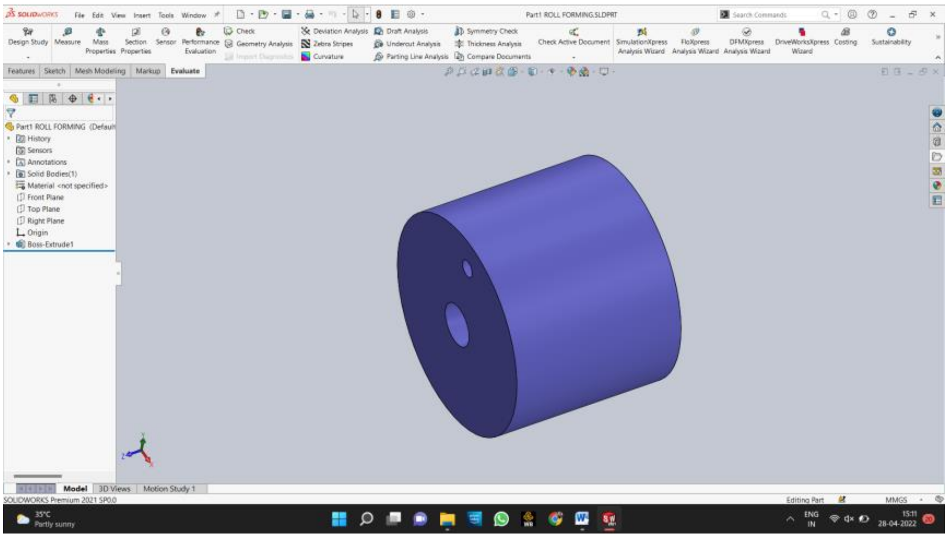


Fig 3.1 Roller 3D model

3.10.2.2 Creation of billet

The body is created by sketch entities and feature entities with the available dimensions of billet. A sketch of side view of the billet is generated and is extruded to required depth or thickness. The part is saved in standard format of '.SLDPRT' for the assembly operation.

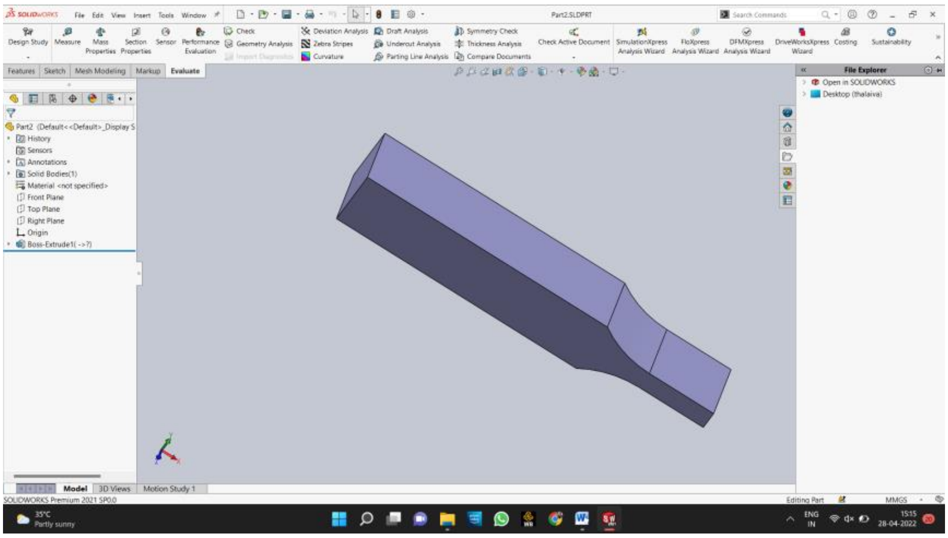


Fig 3.2 Billet 3D model

3.10.2.3 Assembling the roller and billet

The assembly of the roller and billet was prepared in the assembly file of SOLIDWORKS. The two part files are imported into the assembly file. The roller and the billet are connected together by the use of mate option eight mating are given for the complete assembly. The mating can be given in many ways. Here the curved surface area of billet and matching surface area of the billet are selected. The assembled roller and billet is as shown in the figure. It is saved in the '.igs ' format to be used in the ANSYS WORKBENCH for the analysis work.

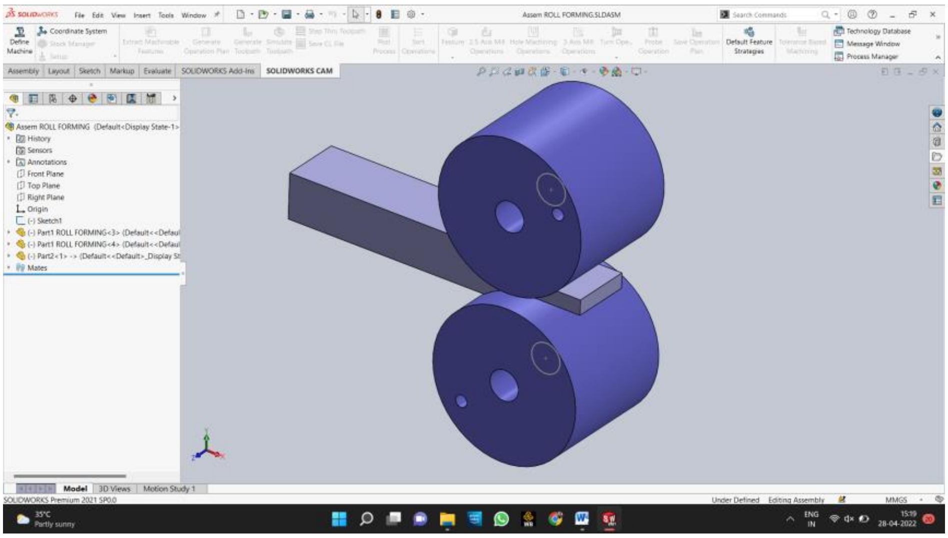


Fig 3.3 Roller and Billet assembly

3.11 Analysis

Analysis of the fin is done in ANSYS MECHANICAL WORKBENCH software considering the designing conditions and material properties of aluminium, copper, brass, bronze, stainless steel, polymers etc.,

3.11.1 History of ANSYS

ANSYS, Inc. is an American computer aided engineering software developer headquartered south of Pittsburgh in Cecil Township, Pennsylvania, and United States. ANSYS publishes engineering analysis software across a range of disciplines including finite element analysis, structural analysis, computational fluid dynamics, explicit and implicit methods, and heat transfer.

The company was founded in 1970 by John A. Swanson as *Swanson Analysis Systems, Inc.* (SASI). Its primary purpose was to develop and market finite element analysis software for structural physics that could simulate static(stationary), dynamic (moving) and thermal (heat transfer) problems. SASI developed its business in parallel with the growth in computer technology and engineering needs. The company grew by 10 percent to 20 percent each year, and in 1994 it was sold to TA associates. The new owners took SASI's leading software, called ANSYS, as their flagship product and designated ANSYS, Inc. as the new company name.

3.11.2 Introduction to ANSYS mechanical

ANSYS Mechanical is a finite element analysis tool for structural analysis, including linear, non-linear and dynamic studies. This computer simulation product provides finite element to model behaviour, and supports material models and equation solvers for wide range of mechanical design problems. ANSYS Mechanical also include thermal analysis and coupled physics, capabilities, involving acoustics, piezoelectric, thermal-structural and thermoelectric analysis.

This type of analysis involves is typically used for design and optimization of a system far too complex to be analyzed by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges. ANSYS is also used in Civil and Electrical Engineering, as well as Physics and Chemistry Departments.

ANSYS provides a cost-effective way to explore the performance of the products or process in a virtual environment. This type of product development is termed virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimize the product long before the manufacturing is started. This enables a reduction in level of the risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effects of design on the whole behaviour of the product, be it electromagnetic, thermal, mechanical etc.

3.11.3 Steps involved in the analysis of the model

1. Save the 3d solid assembly of roller and billet created using SOLIDWORKS in “.igs” format
2. Static structural analysis module is selected from the Analysis system toolbox menu of ANSYS WORKBENCH 2021 R1, so as to perform a static structural analysis on the roller and billet for determination stress distribution, directional deformation and contact stresses.

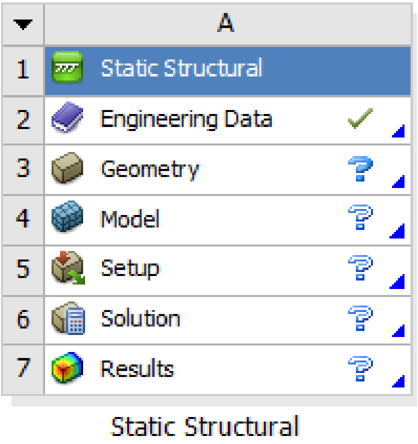
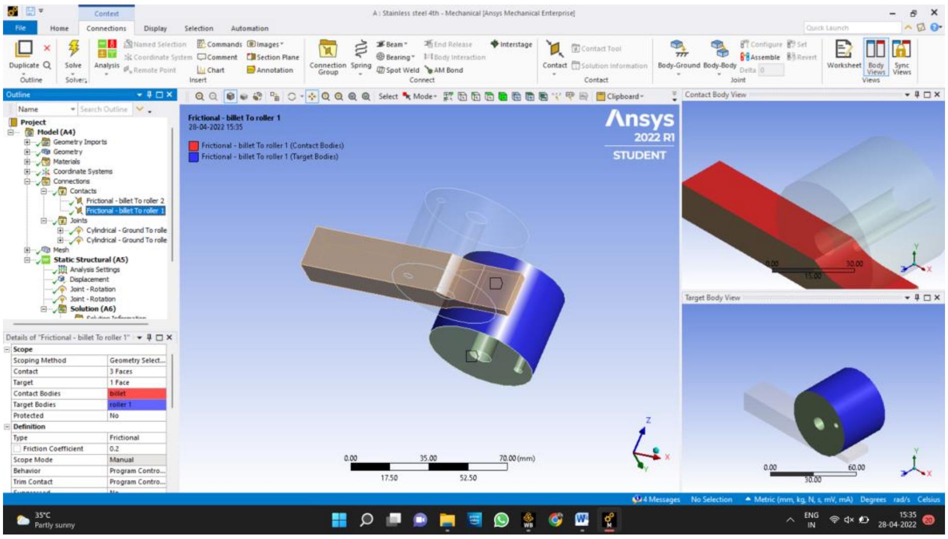


Fig 3.4 Static structural project module

3. The static structural module is placed on the project schematic window of WORKBENCH. All the material properties of the materials required for the analysis are entered in engineering data section of static structural module
4. The ‘.igs’ file is imported into the Geometry (Design Modular) section of static structural module, and the 3D solid assembly is generated in order to work under ANSYS environment. The 3D solid’s surface is divided into the sections for facilitating the loading points during analysis.
5. The process of FEA is done in the MECHANICAL MODEL window.
6. The materials are assigned in the geometry sections of mechanical model window.

7. Contact regions are given as the 3D solid assembly consists of a roller and billet. A solid-solid bonded contact was given at the region as the bond strength of roller and billet and joints are given to the ground and roller.



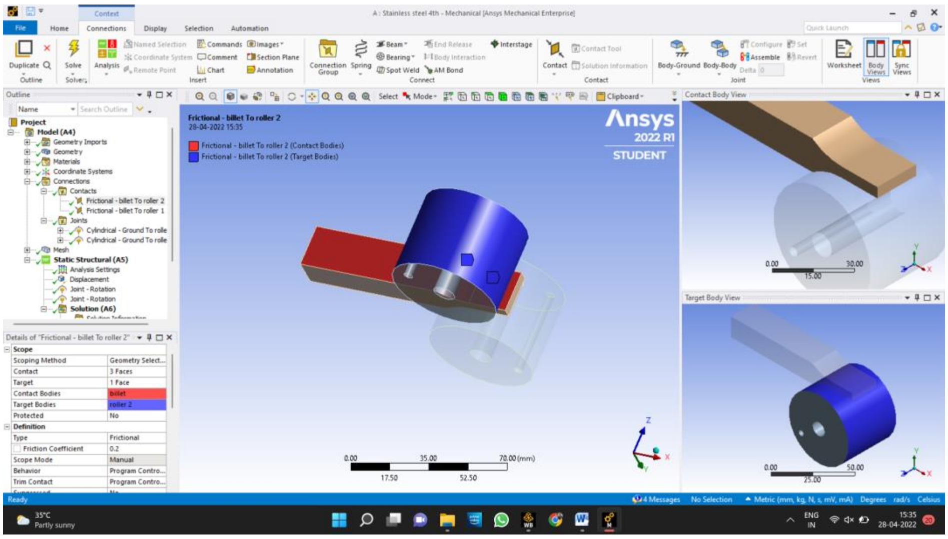
Frictional - billet To roller 1
28-04-2022 15:35

🟥 Frictional - billet To roller 1 (Contact Bodies)
🟦 Frictional - billet To roller 1 (Target Bodies)

Details of "Frictional - billet To roller 1"

Scope	
Scoping Method	Geometry Select...
Contact	3 Faces
Target	1 Face
Contact Bodies	billet
Target Bodies	roller 1
Protected	No
Definition	
Type	Frictional
☐ Friction Coefficient	0.2
Scope Mode	Manual
Behavior	Program Contro...
Trim Contact	Program Contro...

Fig 3.5 Contact between the lower roller and the billet surface



Frictional - billet To roller 2
28-04-2022 15:35

🟥 Frictional - billet To roller 2 (Contact Bodies)
🟦 Frictional - billet To roller 2 (Target Bodies)

Details of "Frictional - billet To roller 2"

Scope	
Scoping Method	Geometry Select...
Contact	3 Faces
Target	1 Face
Contact Bodies	billet
Target Bodies	roller 2
Protected	No
Definition	
Type	Frictional
☐ Friction Coefficient	0.2
Scope Mode	Manual
Behavior	Program Contro...
Trim Contact	Program Contro...

Fig 3.6 Contact between the upper roller and the billet surface

8. Meshing of the 3D solid assembly is performed with a sweep method with an automatic sizing for the roller and the elements are divided in quad/tri method and body sizing with a size of 3mm for the billet.

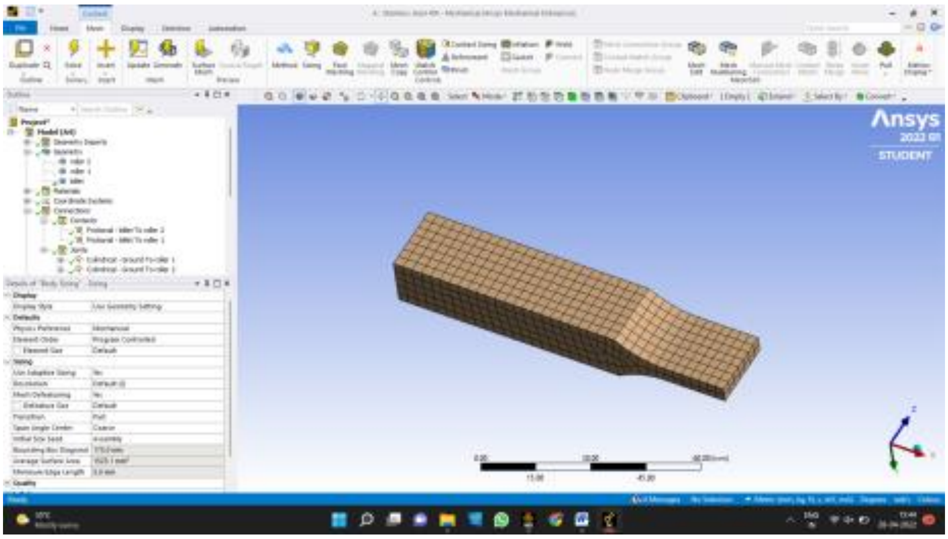


Fig 3.5 Billet Mesh

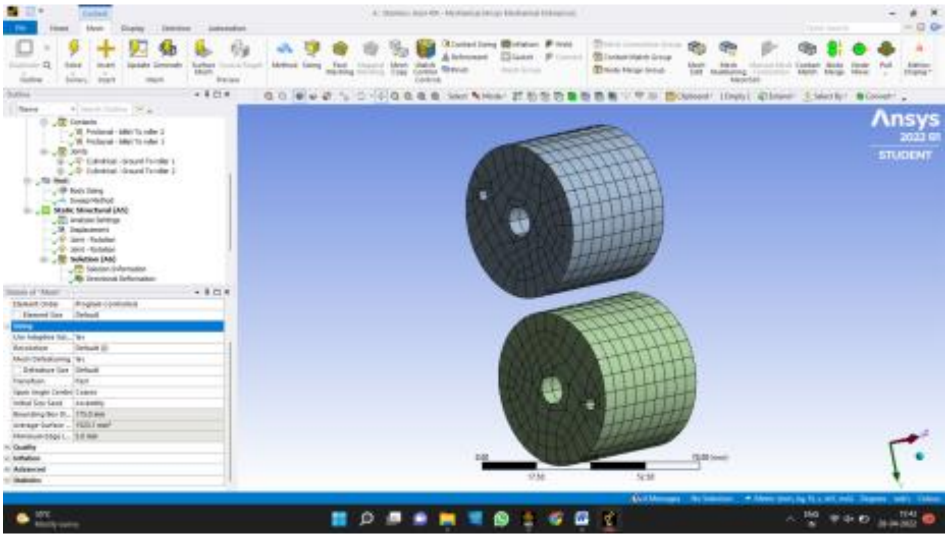


Fig 3.6 Roller Mesh

9. The load setup is given to the model as below. Rotation of rollers is given by selecting the joint rotation in the z-axis. Four different speeds are considered for the entire analysis.

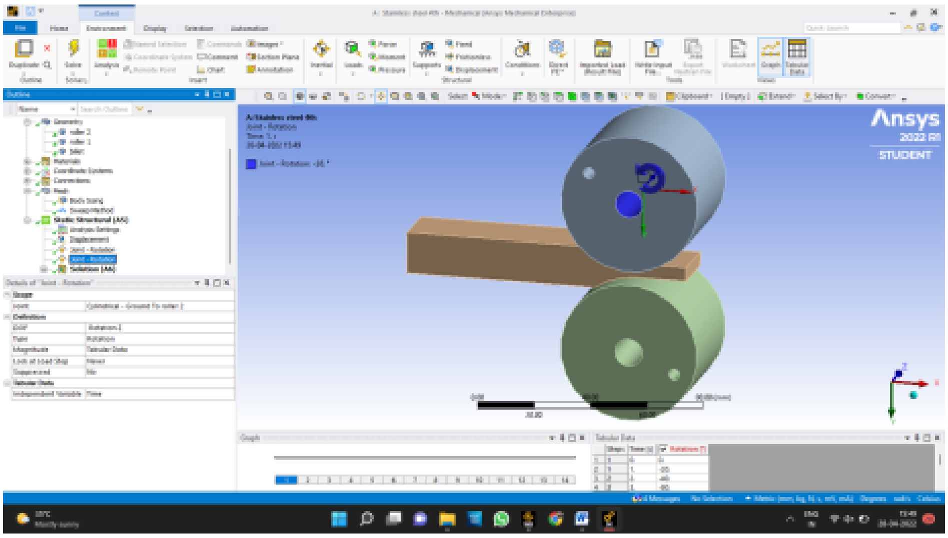


Fig 3.7 Rotational direction of upper roller

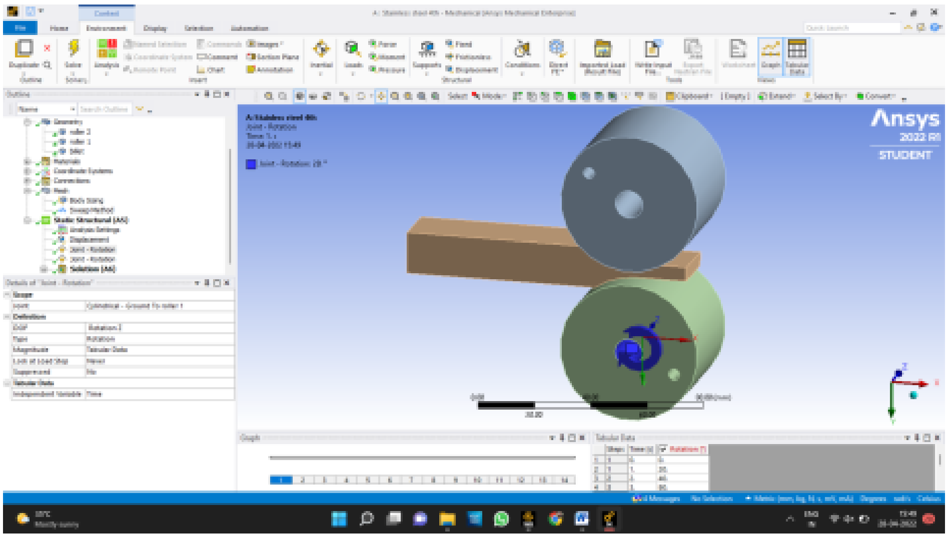


Fig 3.8 Rotational direction of lower roller

10. The solver module is used to obtain the solution for the given boundary conditions to the model. The required stress distribution and contact stress are evaluated for given loading conditions.

CHAPTER IV
RESULTS AND DISCUSSIONS

The contact stress, equivalent stress distribution and directional deformation for the 3d model have been evaluated in static structural with 4 different speeds are tabulated below

4.1 Tabular data of the results obtained

Table 4-1 Contact stresses

Speed (rad/s)	Aluminium alloy	Copper alloy	Magnesium alloy	Stainless steel
0.24	911.38	1738.4	1303.2	2640.1
0.3	814.2	1544.9	1197.1	2245.1
0.48	815.72	1560.1	1169.2	2296
0.6	815.75	1548.3	1169.3	2406.1

Table 4-2 Directional deformation

Speed (rad/s)	Aluminium alloy	Copper alloy	Magnesium alloy	Stainless steel
0.24	6.339	5.8974	5.6377	4.4164
0.3	3.7001	3.9951	3.8693	4.4539
0.48	4.0962	4.3762	4.224	4.6514
0.6	4.2245	4.5054	4.3644	3.587

Table 4-3 Equivalent stress

Speed (rad/s)	Aluminium alloy	Copper alloy	Magnesium alloy	Stainless steel
0.24	1377.3	2411.76	1712.6	4019.8
0.3	1136.7	1809.4	1407.3	2564.9
0.48	1019	1704.7	1266.1	2344.5
0.6	1079.8	1793.7	1335.4	3183.2

4.2 Finite element solved models

Below figures are the results obtained at 0.24 rad/s for aluminium alloy

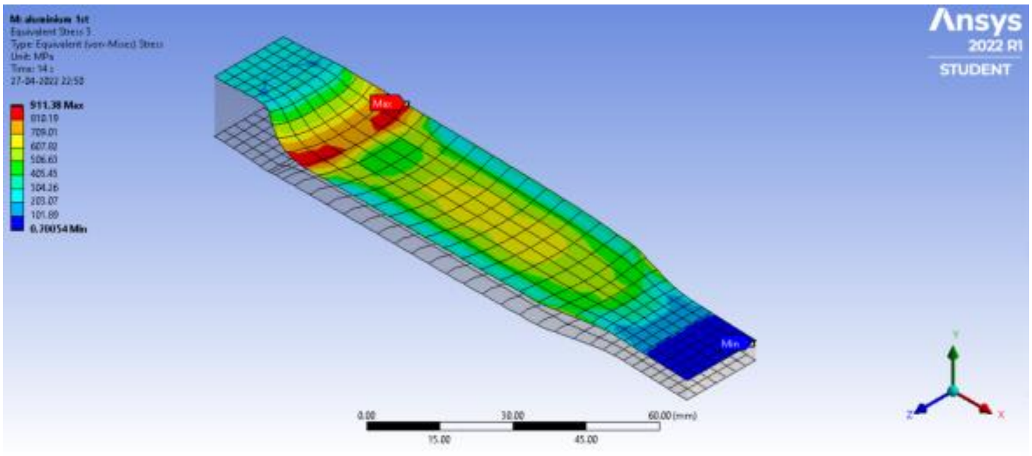


Fig 4.1 Contact stress for aluminium alloy

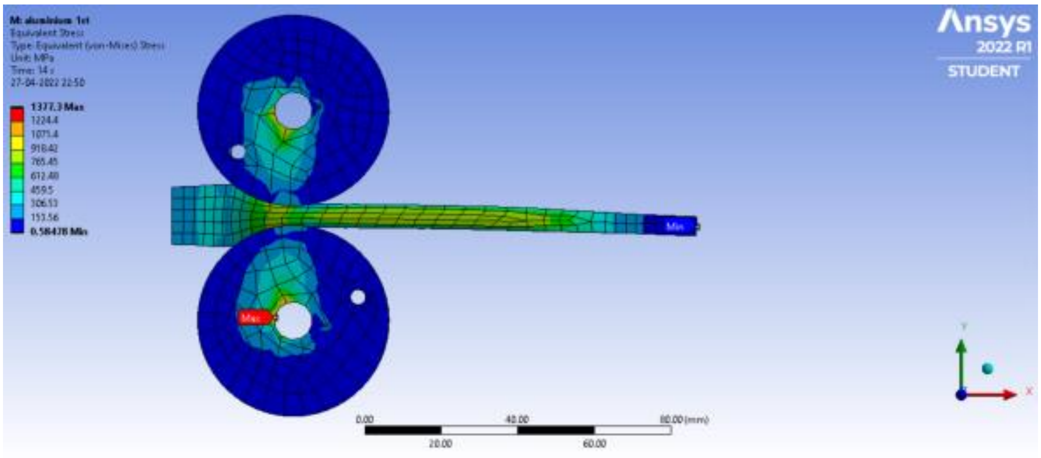


Fig 4.2 Equivalent stress distribution for aluminium alloy

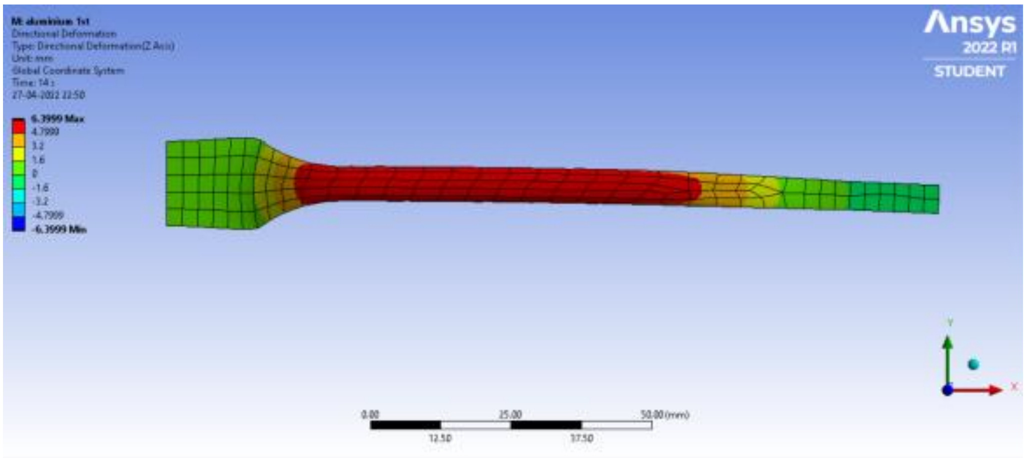


Fig 4.3 Directional deformation for aluminium alloy

Below figures are the results obtained at 0.24 rad/s for copper alloy

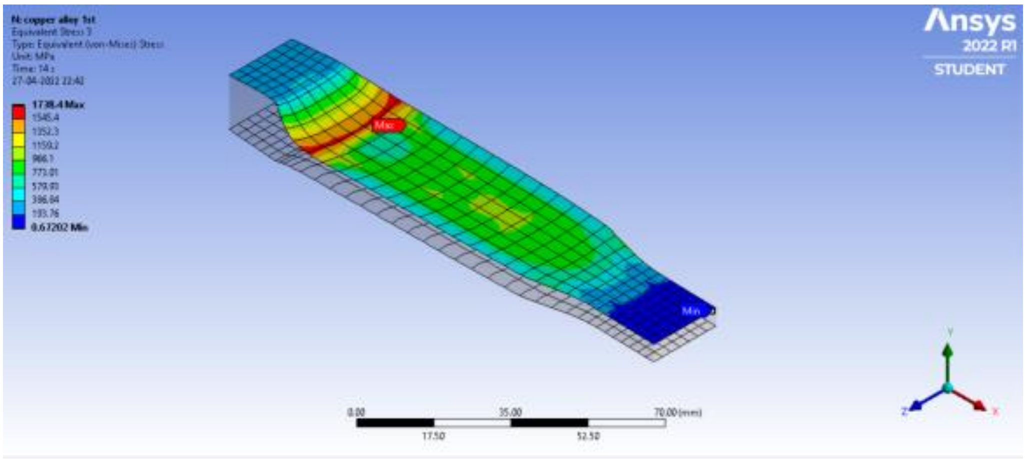


Fig 4.4 Contact stress for copper alloy

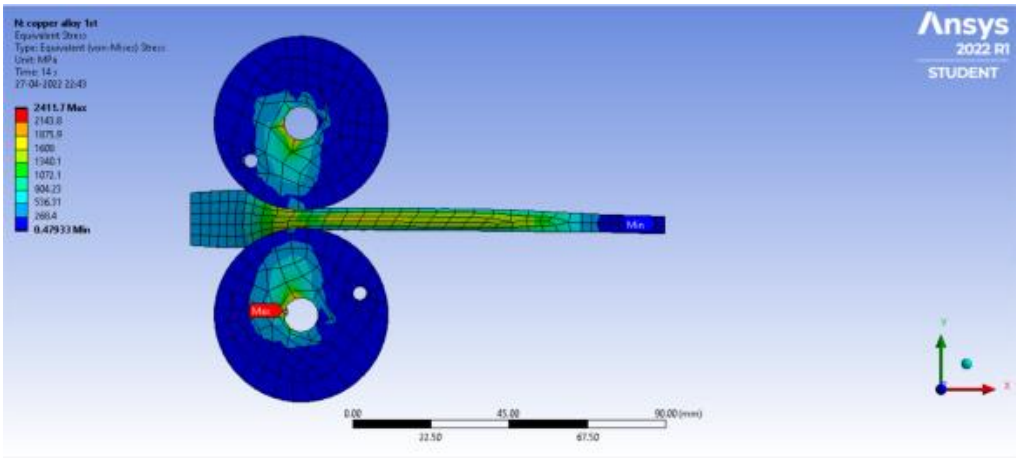


Fig 4.5 Equivalent stress for copper alloy

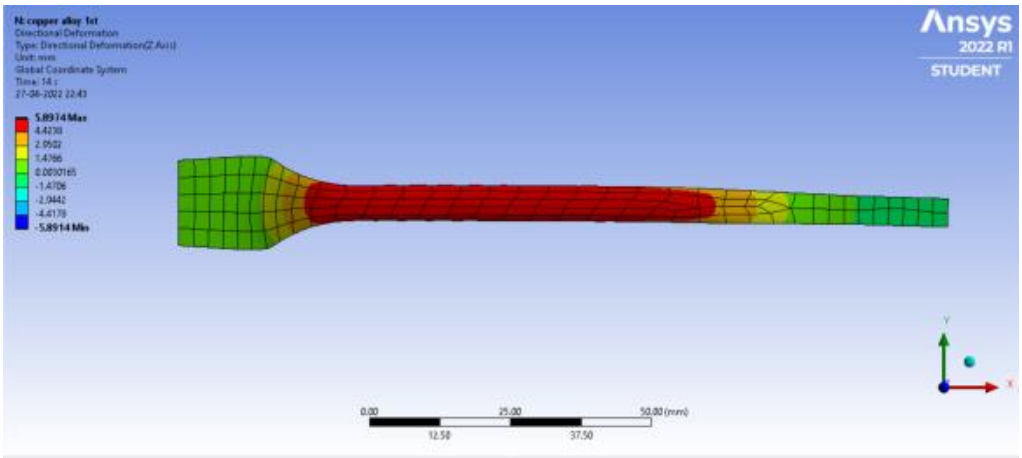


Fig 4.6 Directional deformation for copper alloy

Below figures are the results obtained at 0.24 rad/s for magnesium alloy

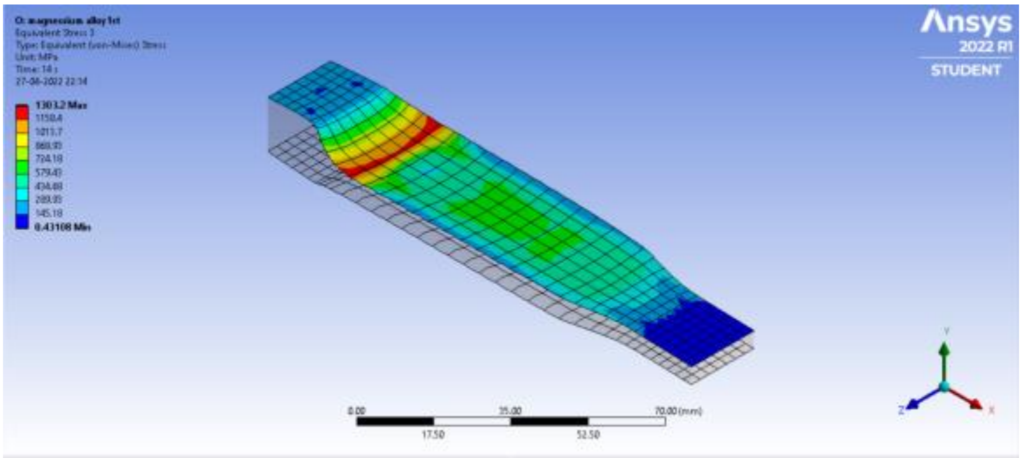


Fig 4.7 Contact stress for magnesium alloy

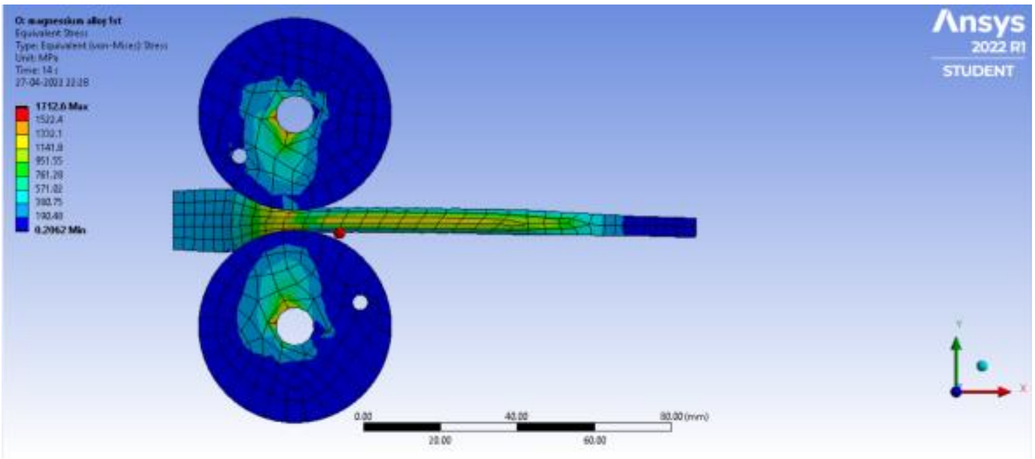


Fig 4.8 Equivalent stress for magnesium alloy

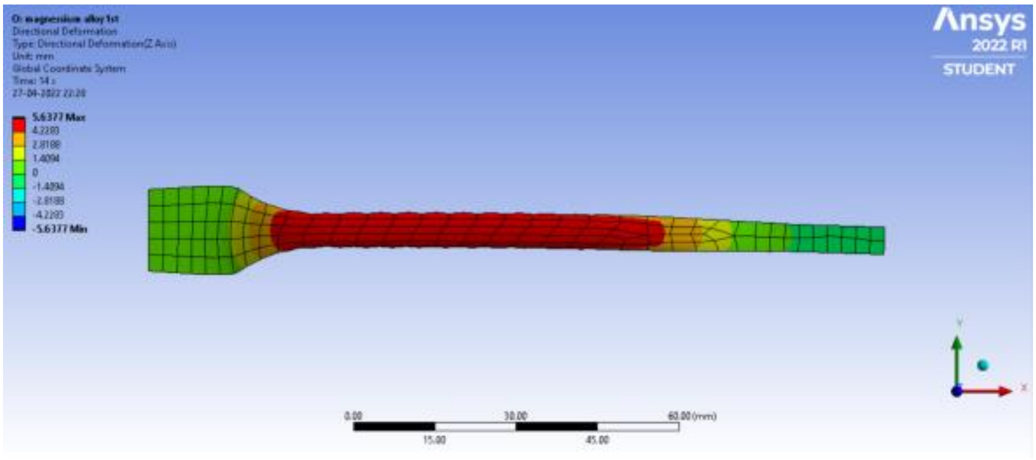


Fig 4.9 Directional deformation for magnesium alloy

Below figures are the results obtained at 0.24 rad/s for stainless steel

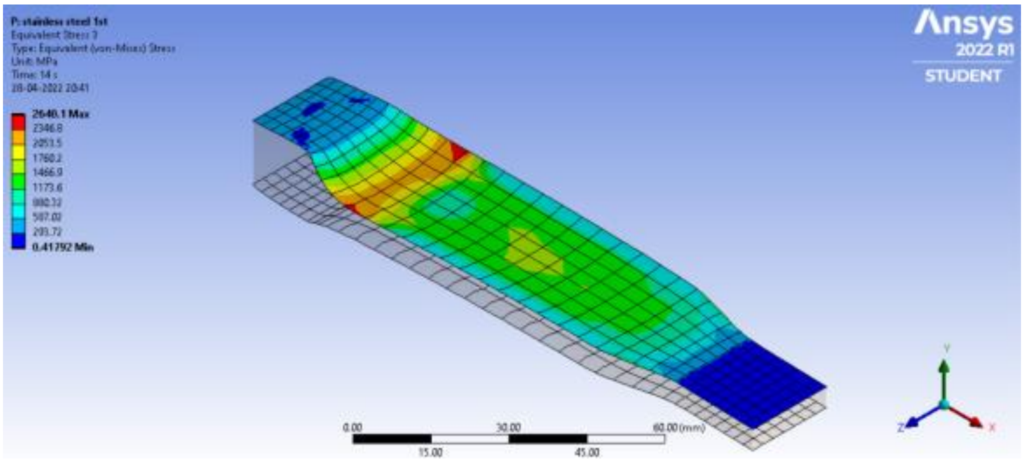


Fig 4.10 Contact stress for stainless steel

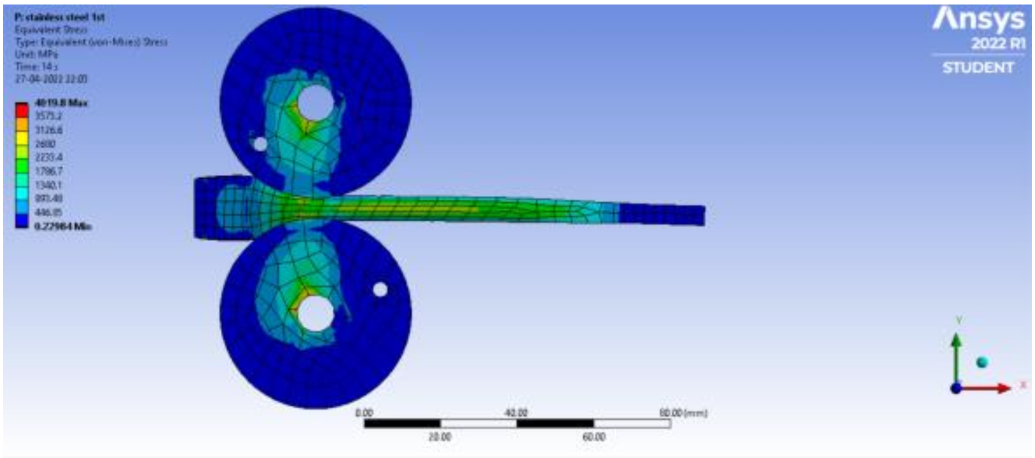


Fig 4.11 Equivalent stress for stainless steel

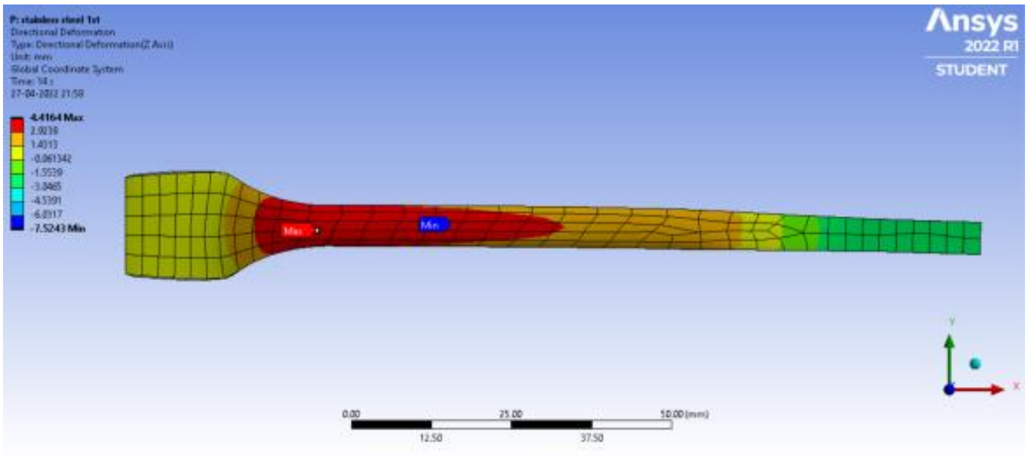


Fig 4.12 Directional deformation for stainless steel

Below figures are the results obtained at 0.3 rad/s for aluminium alloy

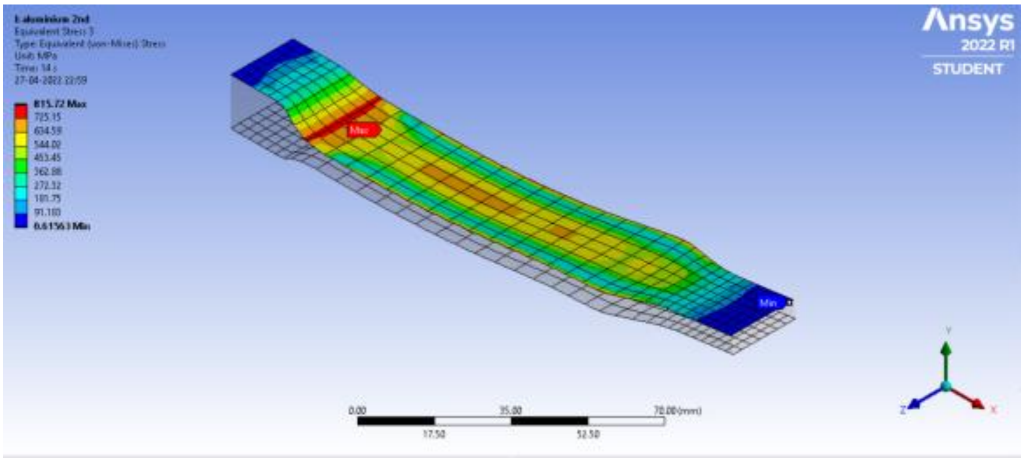


Fig 4.13 Contact stress for aluminium alloy

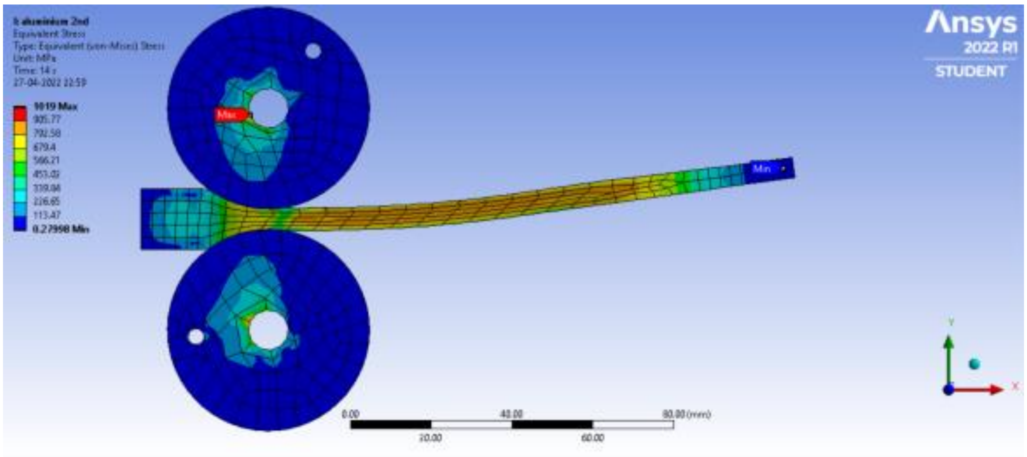


Fig 4.14 Equivalent stress distribution for aluminium alloy

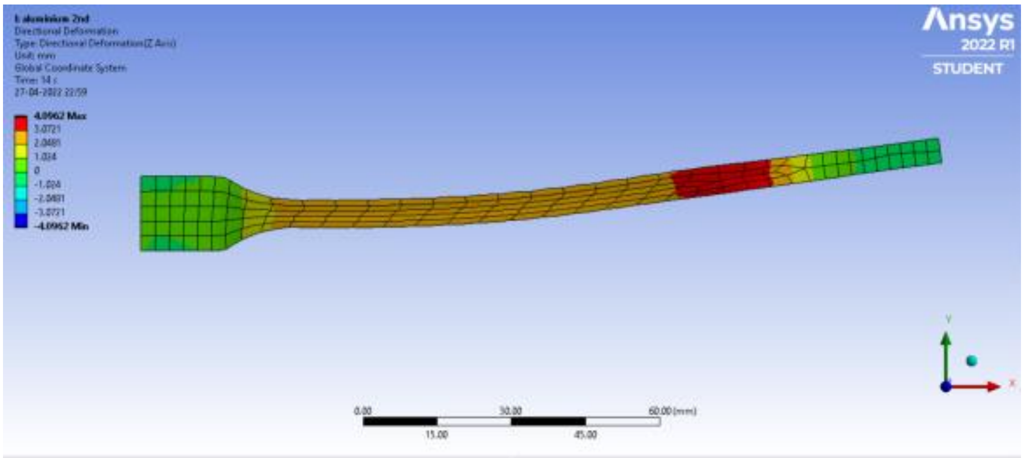


Fig 4.15 Directional deformation for aluminium alloy

Below figures are the results obtained at 0.3 rad/s for copper alloy

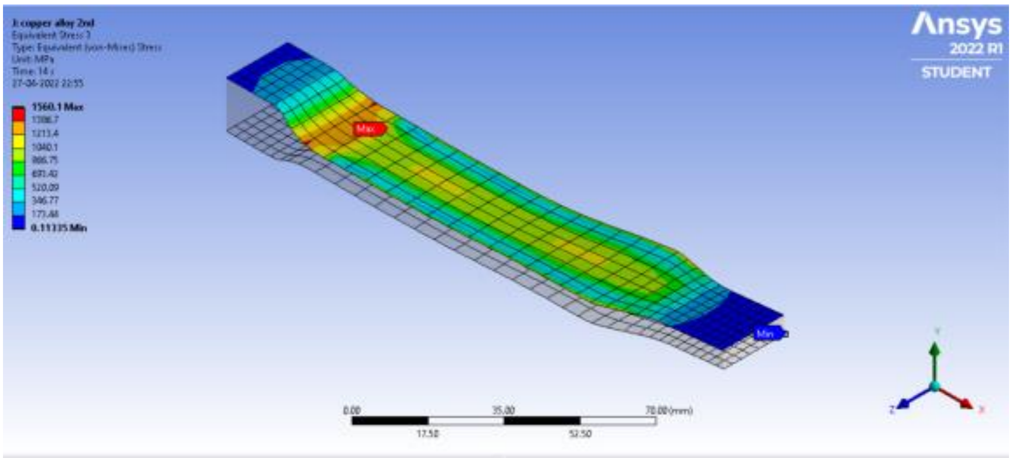


Fig 4.16 Contact stress for copper alloy

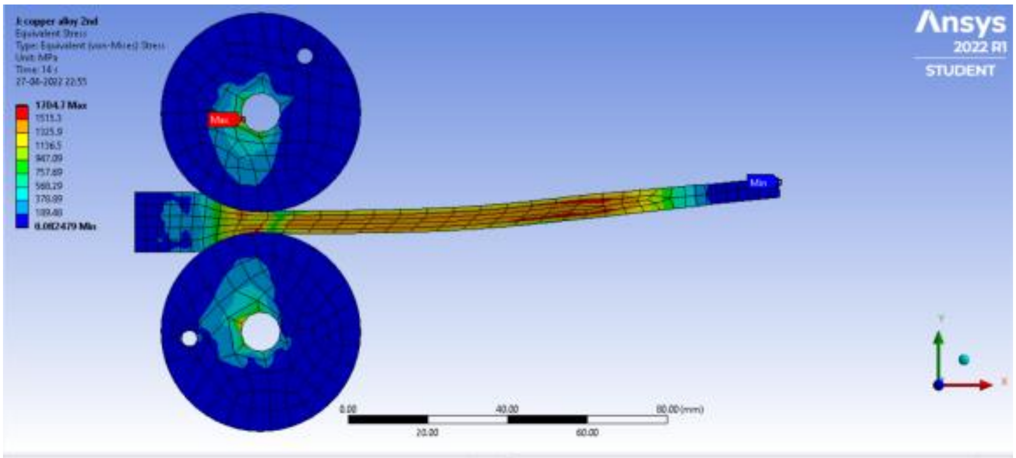


Fig 4.17 Equivalent stress for copper alloy

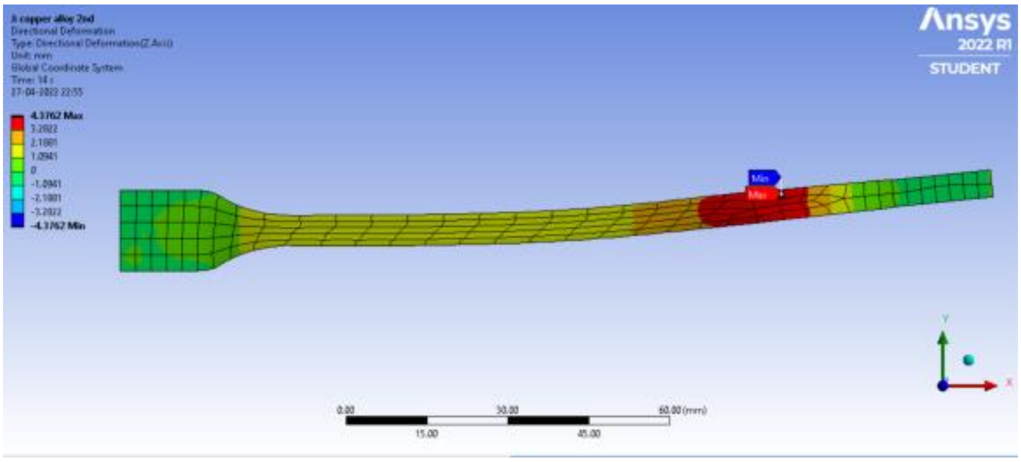


Fig 4.18 Directional deformation for copper alloy

Below figures are the results obtained at 0.3 rad/s for magnesium alloy

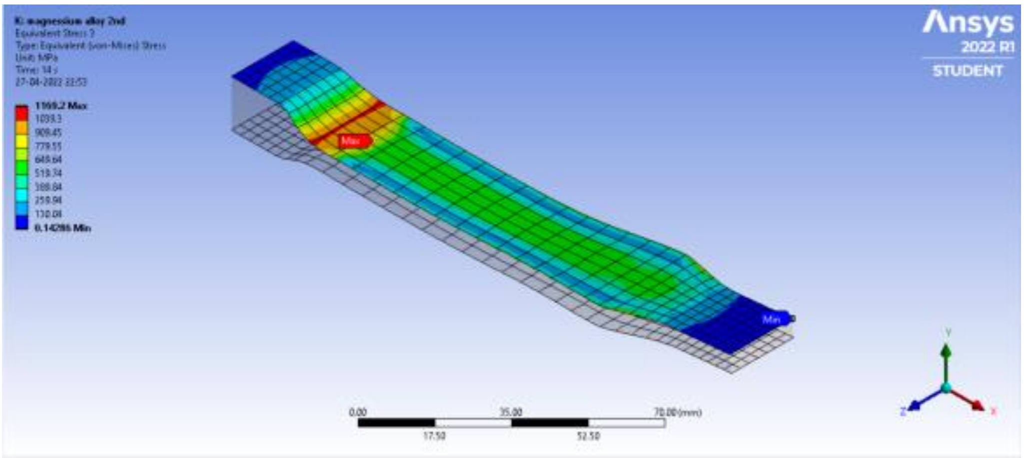


Fig 4.19 Contact stress for magnesium alloy

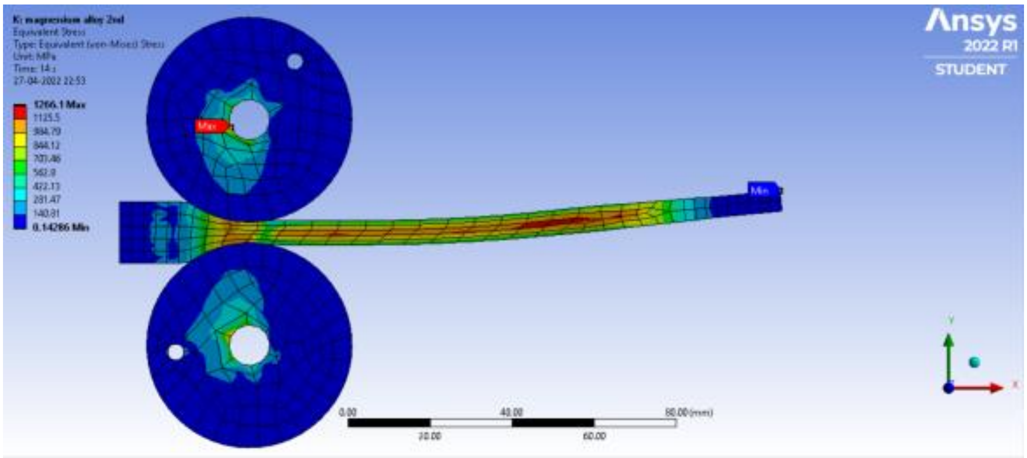


Fig 4.20 Equivalent stress for magnesium alloy

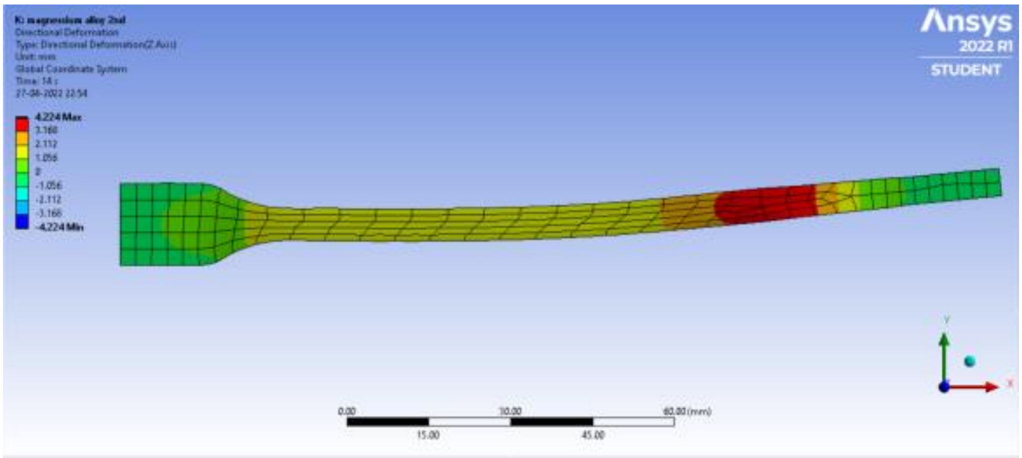


Fig 4.21 Directional deformation for magnesium alloy

Below figures are the results obtained at 0.3 rad/s for stainless steel

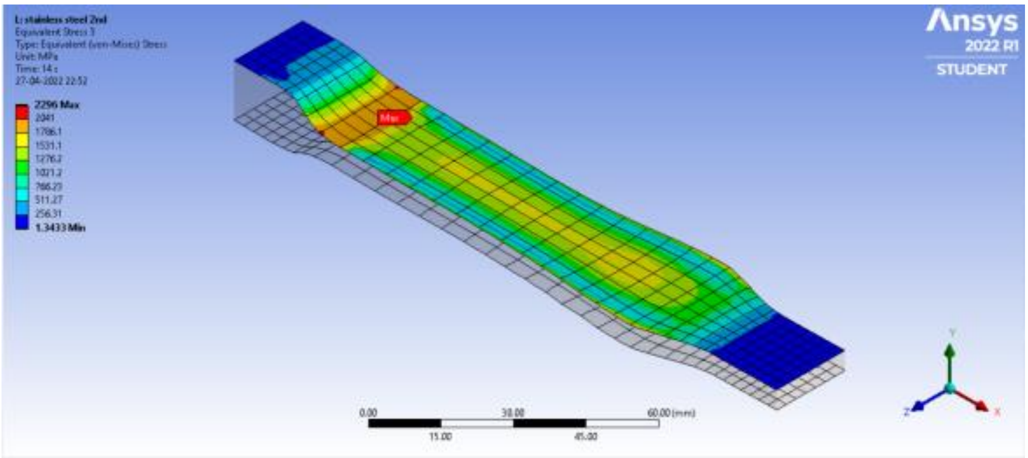


Fig 4.22 Contact stress for stainless steel

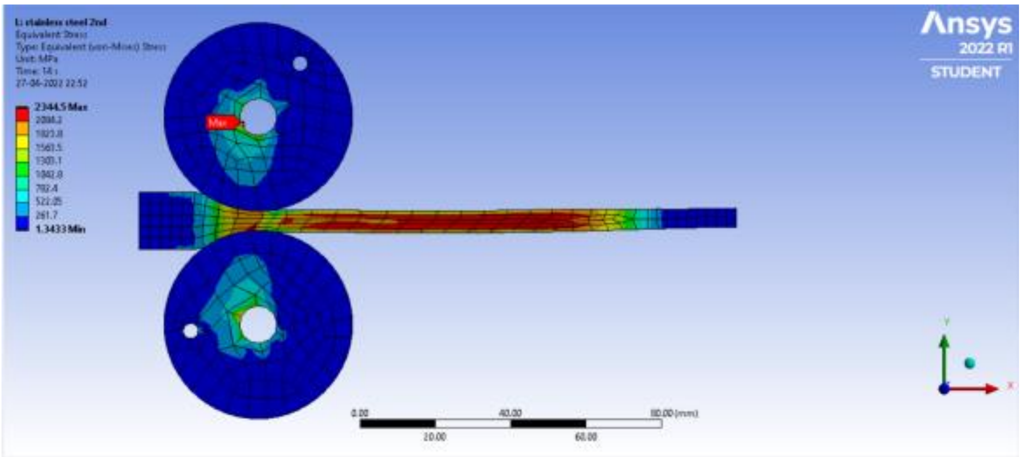


Fig 4.23 Equivalent stress for stainless steel

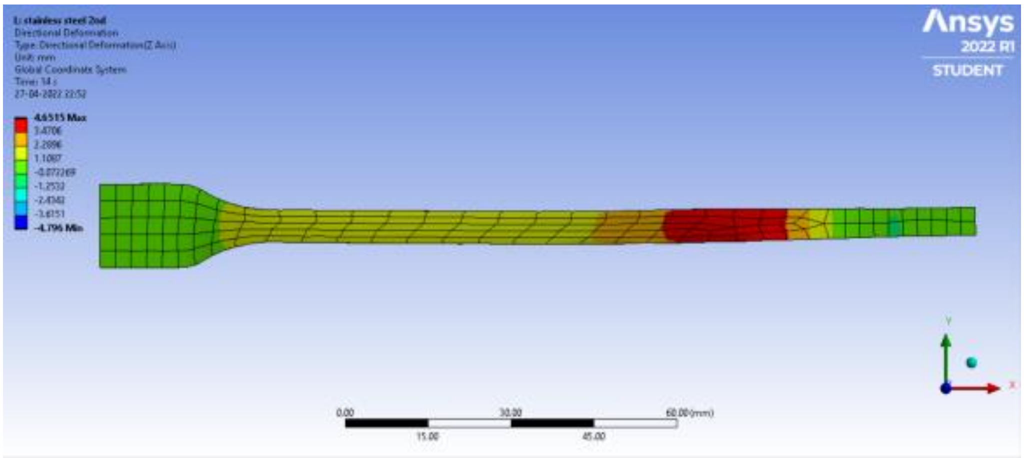


Fig 4.24 Directional deformation for stainless steel

Below figures are the results obtained at 0.48 rad/s for aluminium alloy

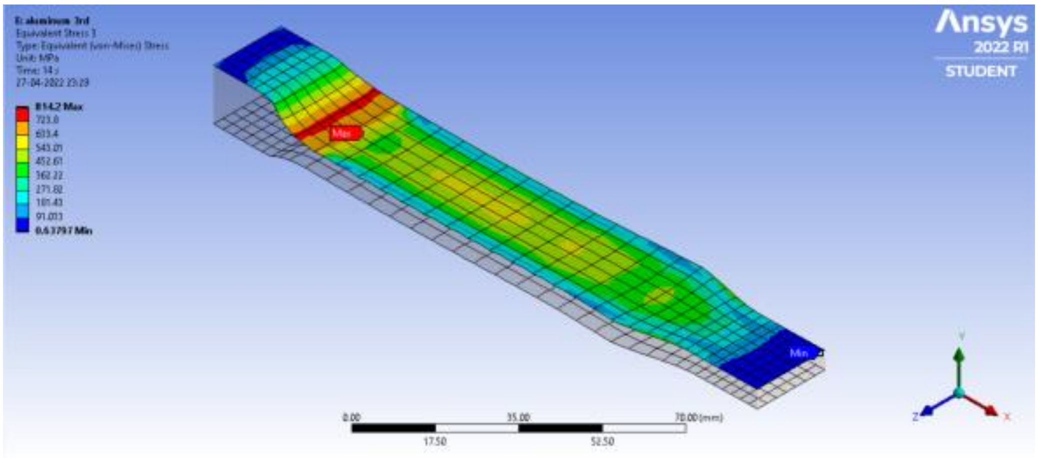


Fig 4.25 Contact stress for aluminium alloy

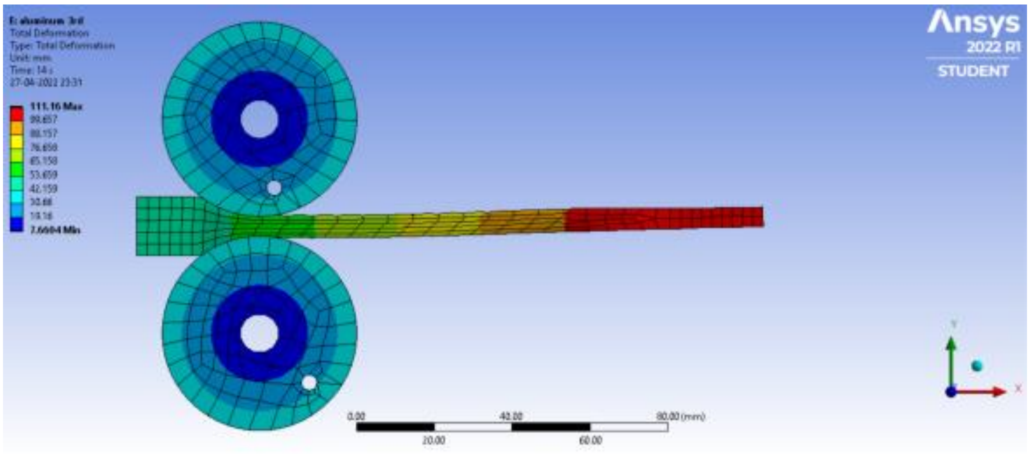


Fig 4.26 Equivalent stress distribution for aluminium alloy

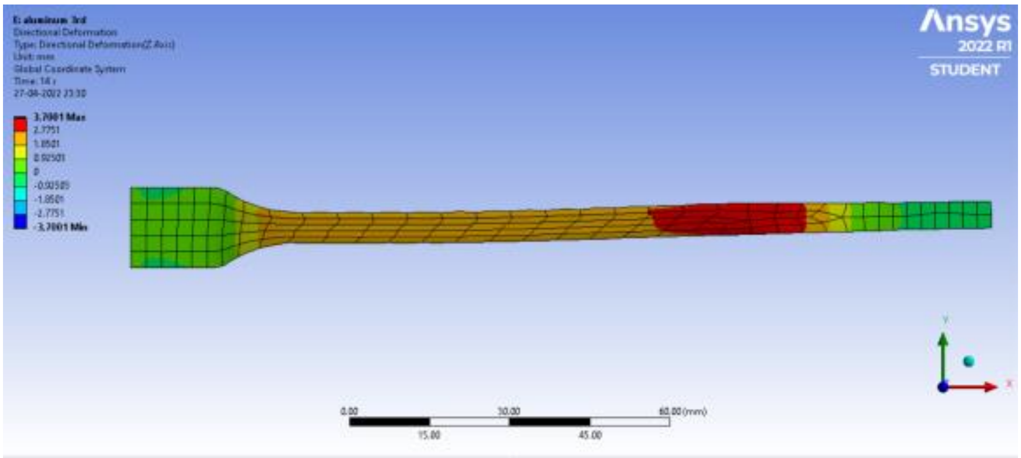


Fig 4.27 Directional deformation for aluminium alloy

Below figures are the results obtained at 0.48 rad/s for copper alloy

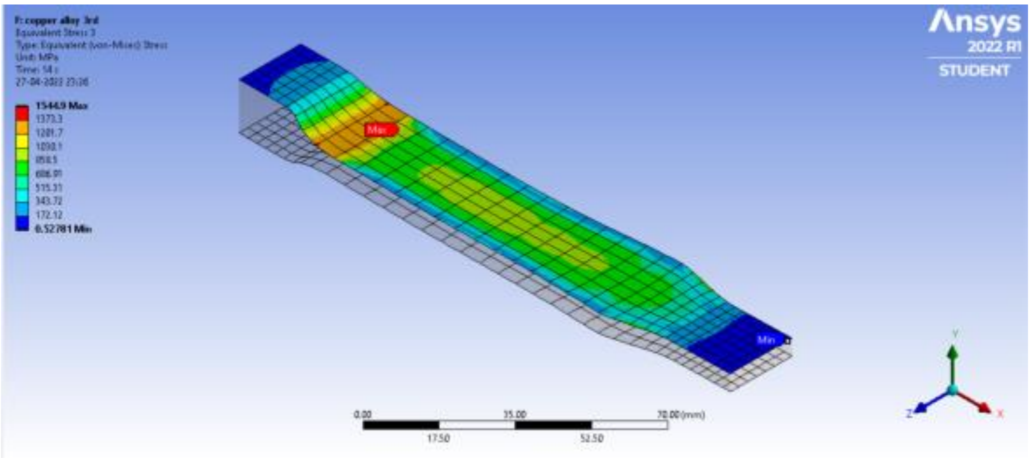


Fig 4.28 Contact stress for copper alloy

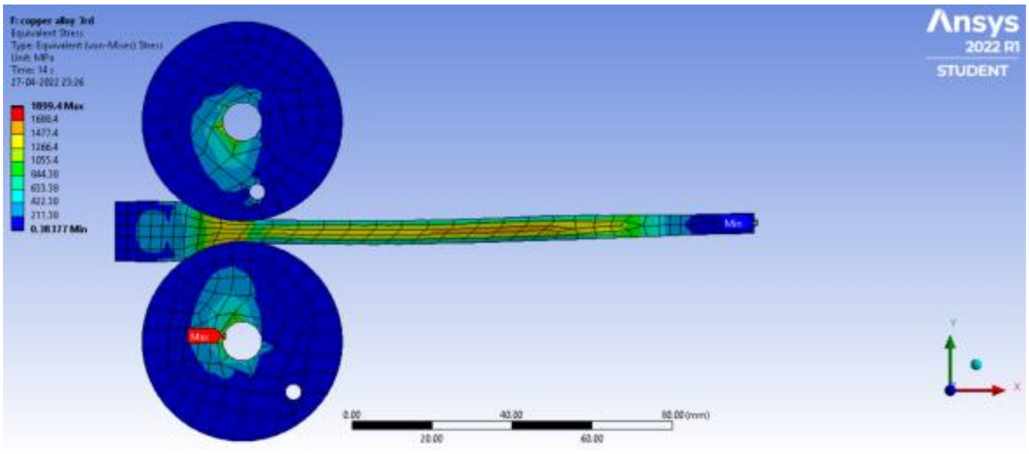


Fig 4.29 Equivalent stress for copper alloy

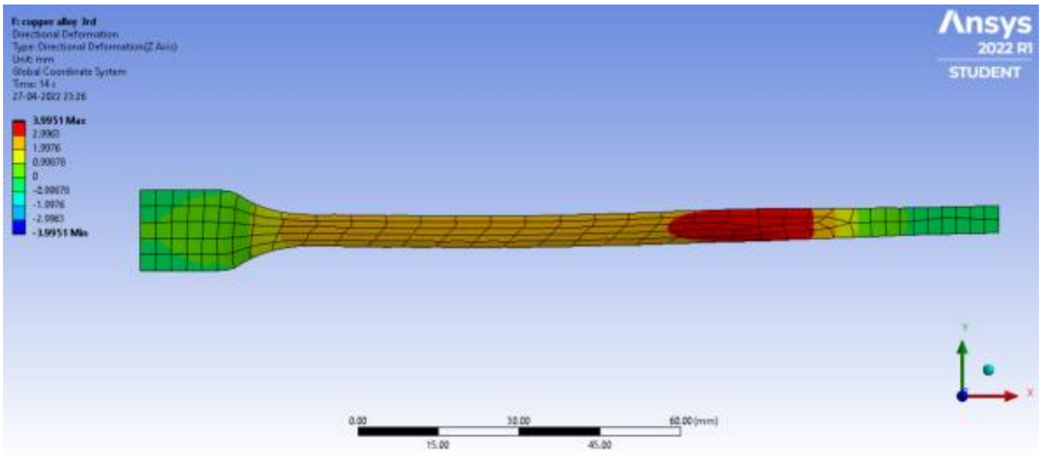


Fig 4.30 Directional deformation for copper alloy

Below figures are the results obtained at 0.48 rad/s for magnesium alloy

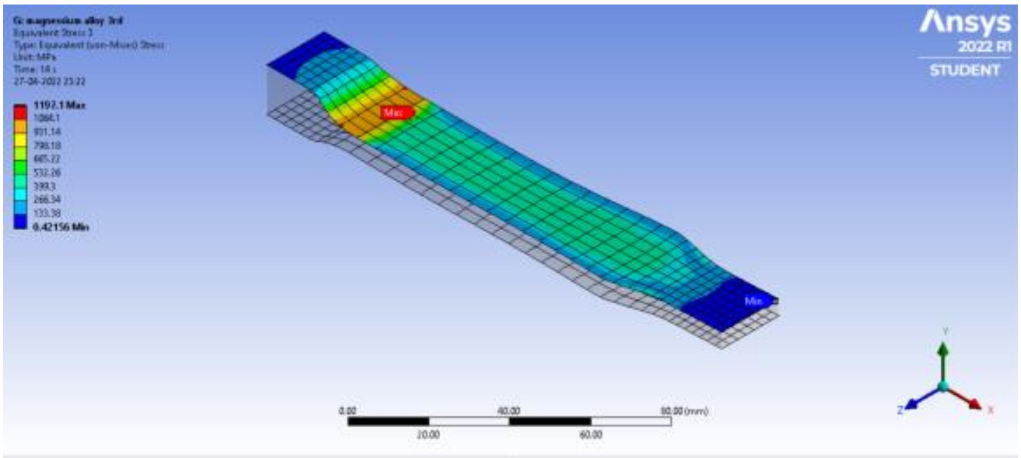


Fig 4.31 Contact stress for magnesium alloy

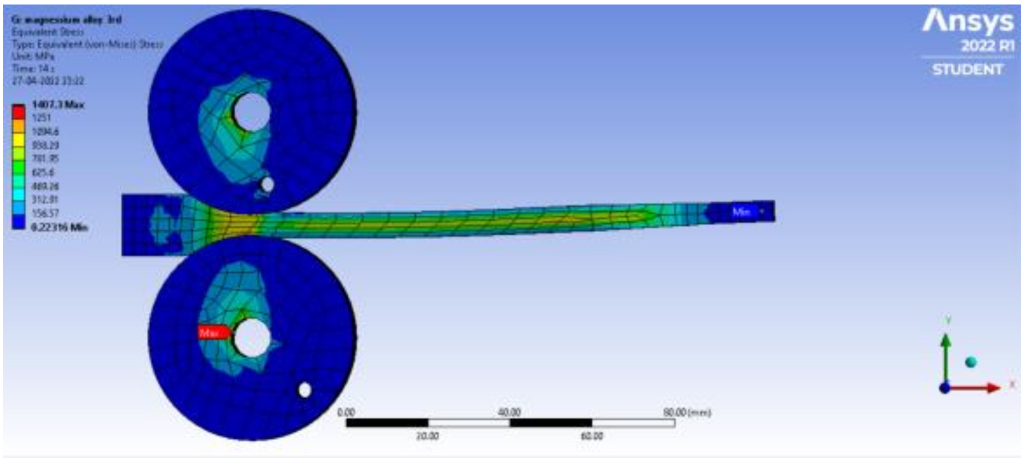


Fig 4.32 Equivalent stress for magnesium alloy

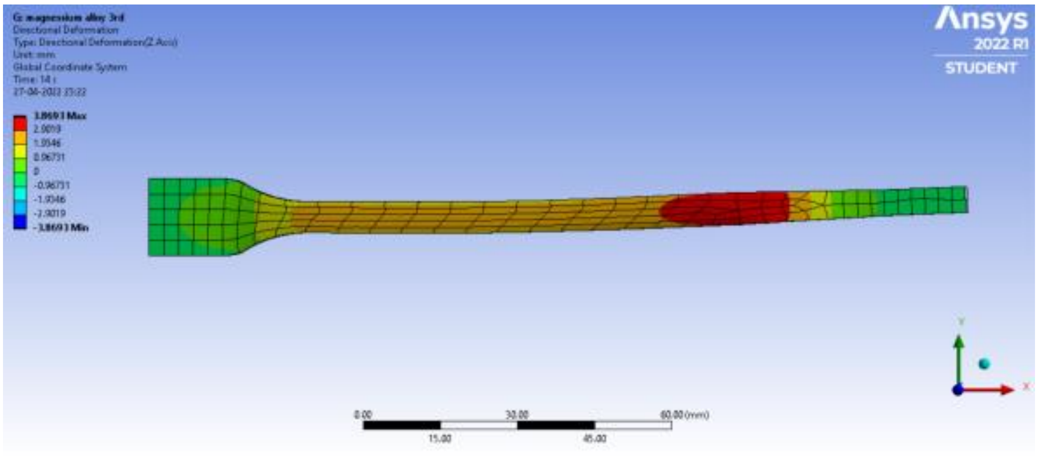


Fig 4.33 Directional deformation for magnesium alloy

Below figures are the results obtained at 0.48 rad/s for stainless steel

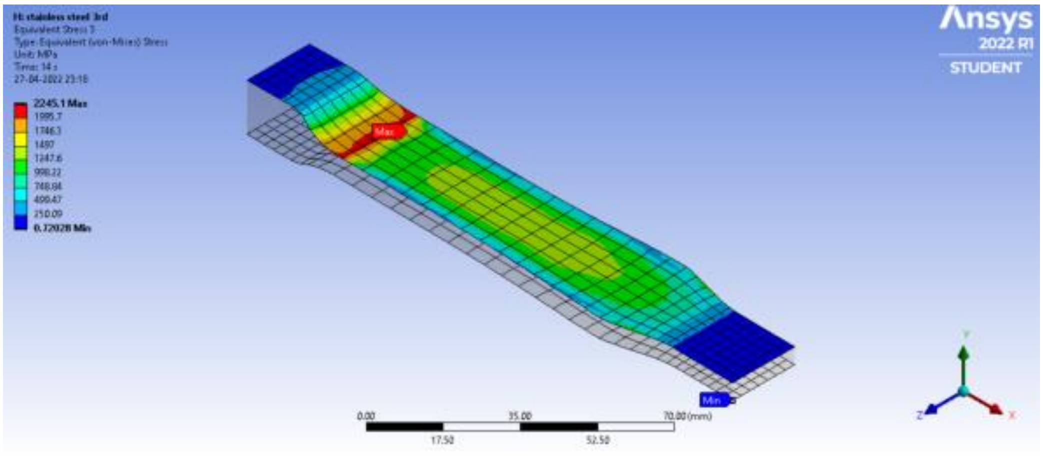


Fig 4.34 Contact stress for stainless steel

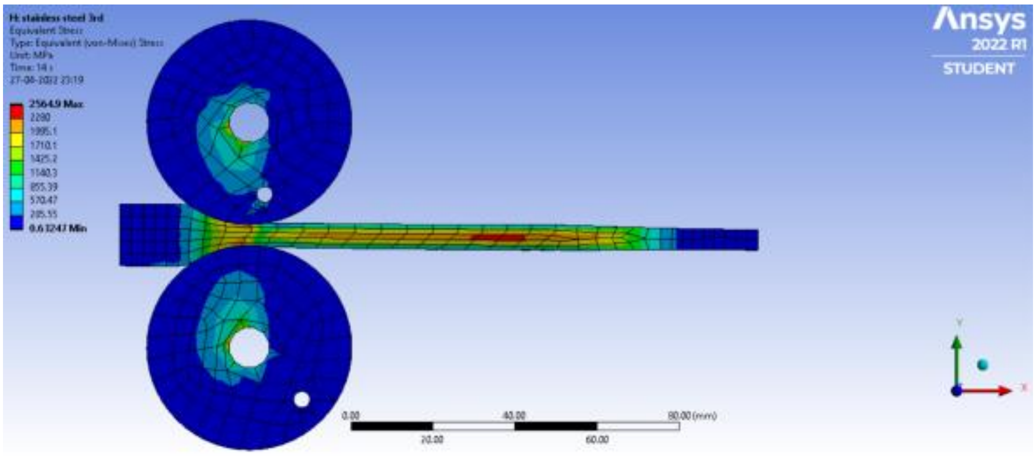


Fig 4.35 Equivalent stress for stainless steel

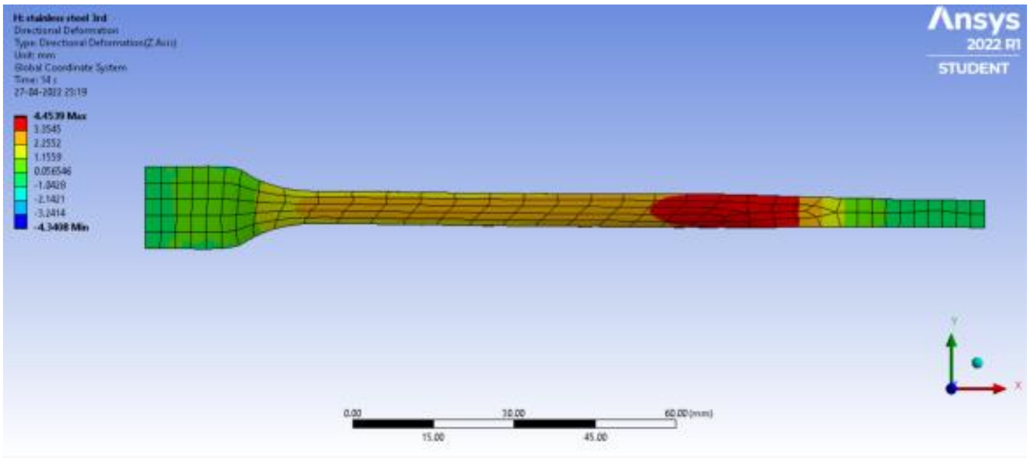


Fig 4.36 Directional deformation for stainless steel

Below figures are the results obtained at 0.6 rad/s for aluminium alloy

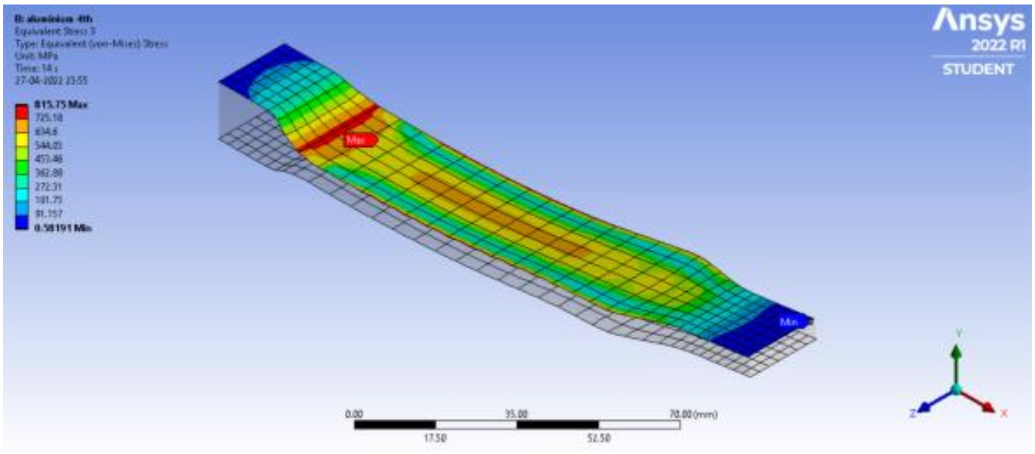


Fig 4.37 Contact stress for aluminium alloy

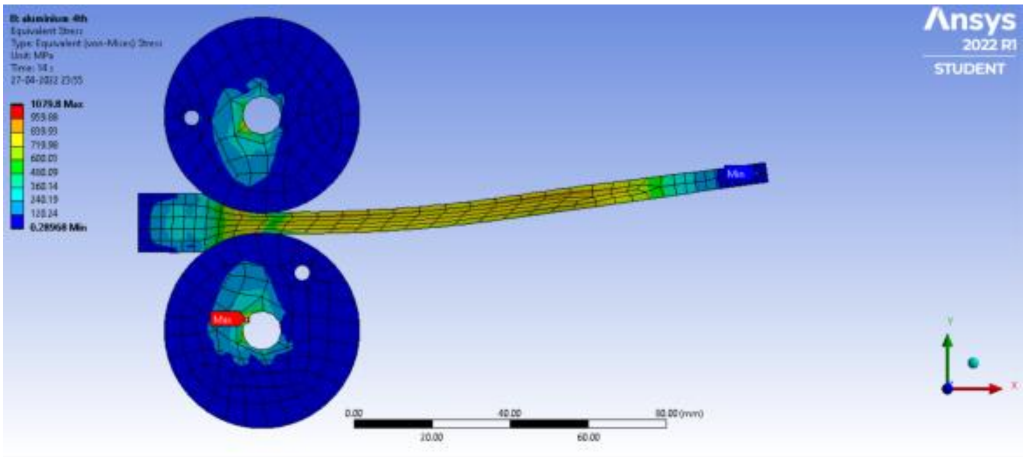


Fig 4.38 Equivalent stress distribution for aluminium alloy

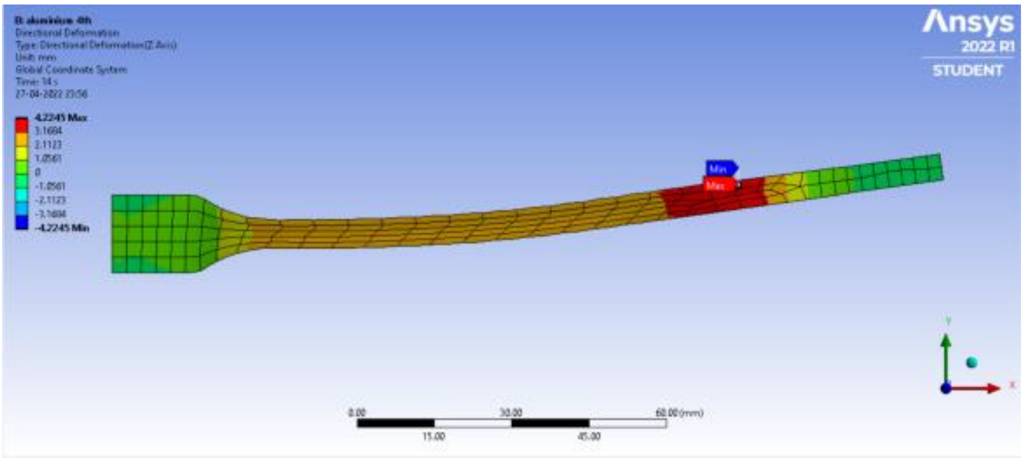


Fig 4.39 Directional deformation for aluminium alloy

Below figures are the results obtained at 0.6 rad/s for aluminium alloy

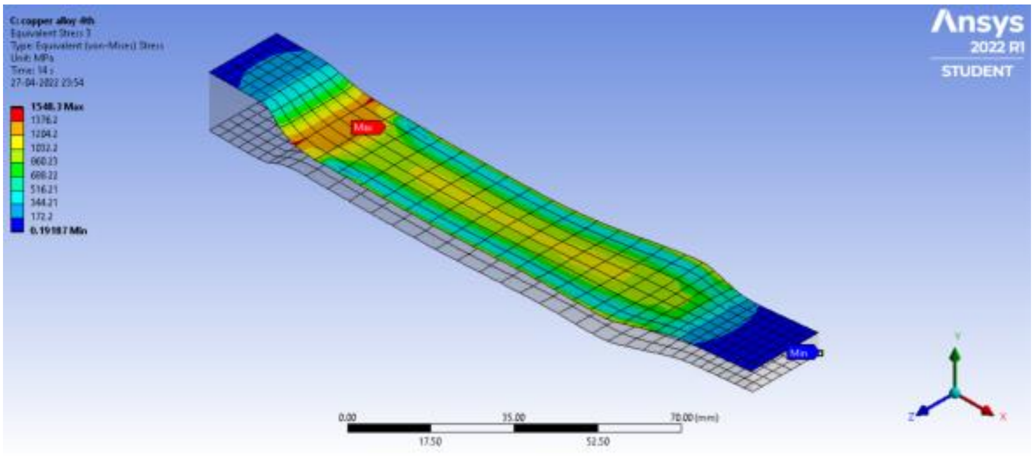


Fig 4.40 Contact stress for copper alloy

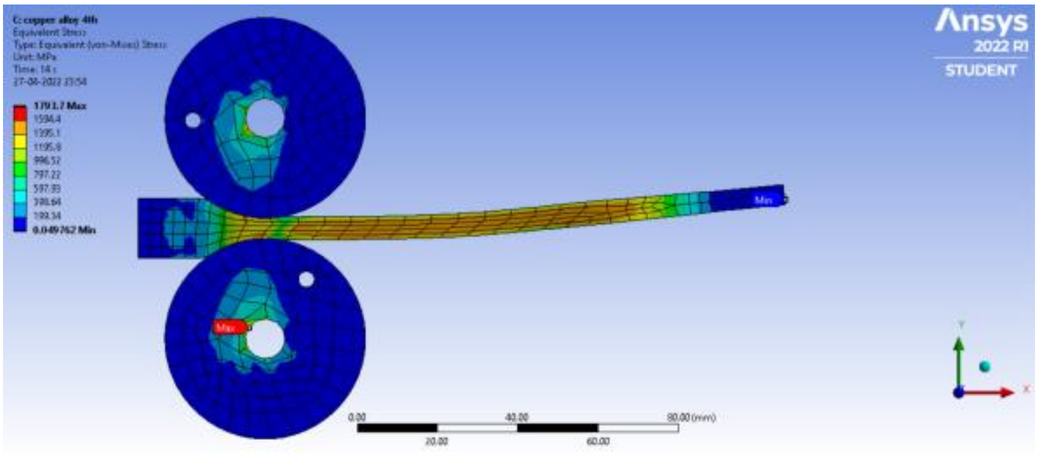


Fig 4.41 Equivalent stress for copper alloy

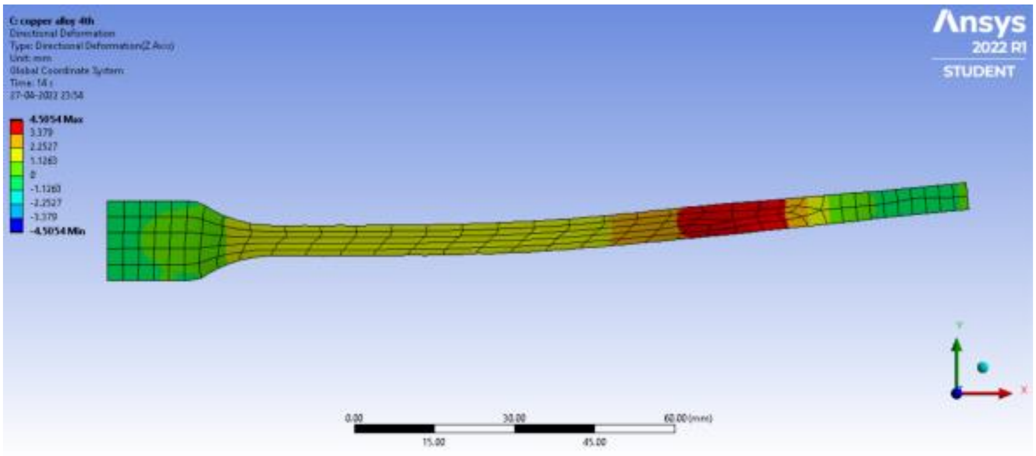


Fig 4.42 Directional deformation for copper alloy

Below figures are the results obtained at 0.6 rad/s for aluminium alloy

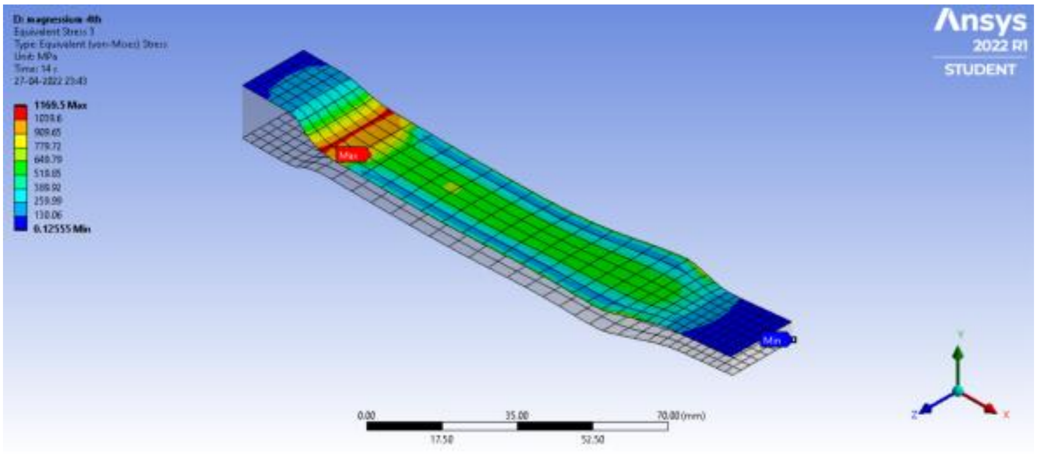


Fig 4.43 Contact stress for magnesium alloy

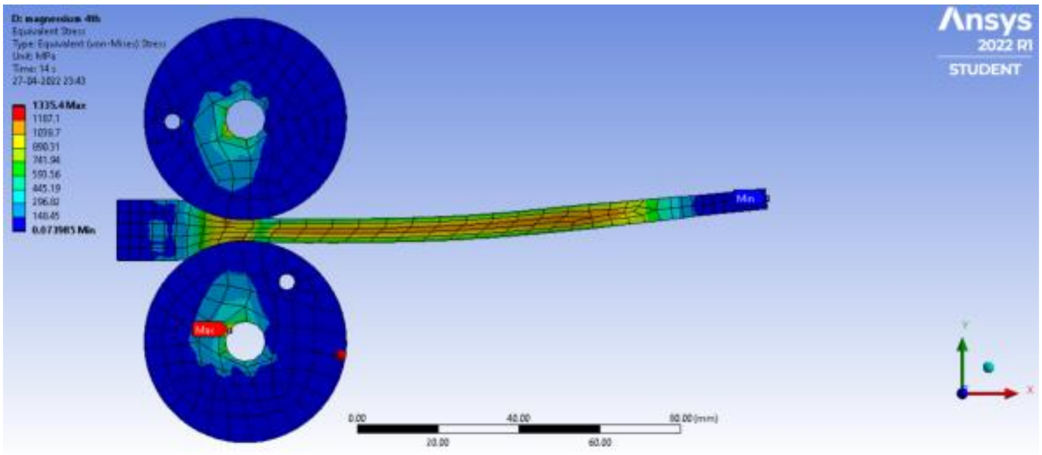


Fig 4.44 Equivalent stress for magnesium alloy

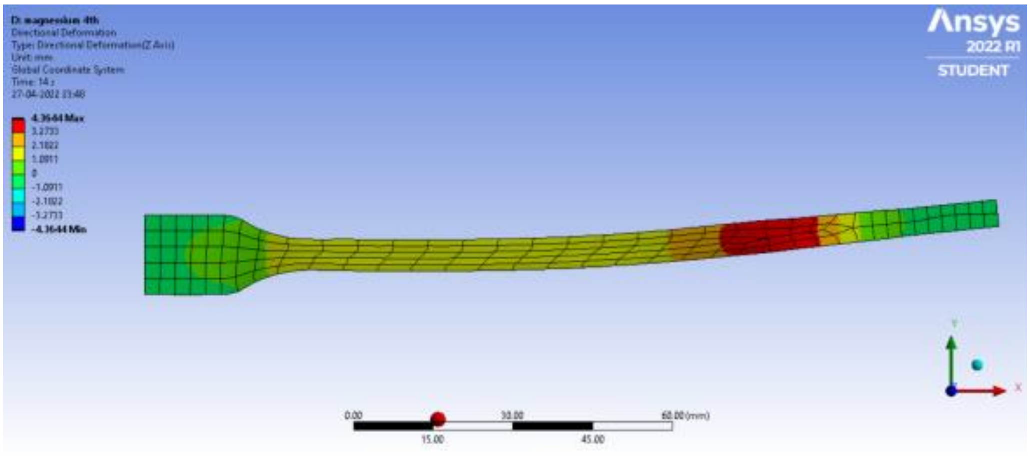


Fig 4.45 Directional deformation for magnesium alloy

Below figures are the results obtained at 0.6 rad/s for aluminium alloy

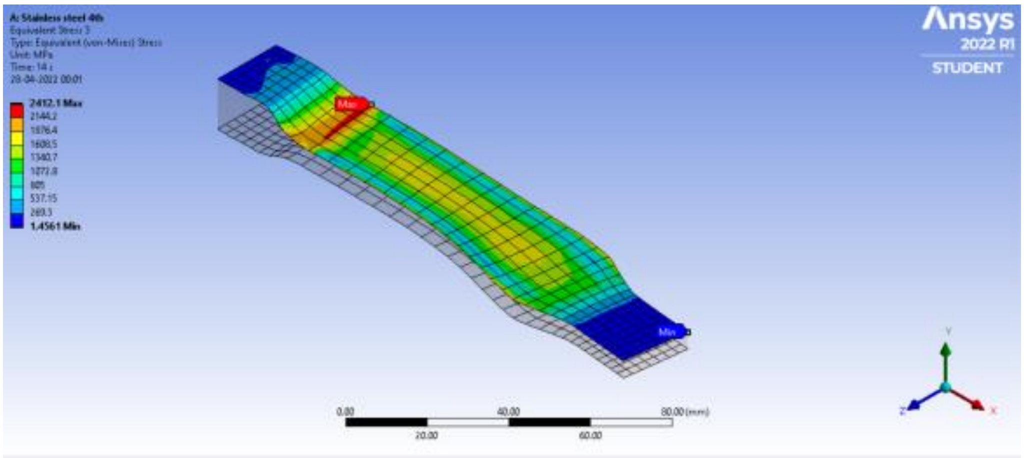


Fig 4.46 Contact stress for stainless steel

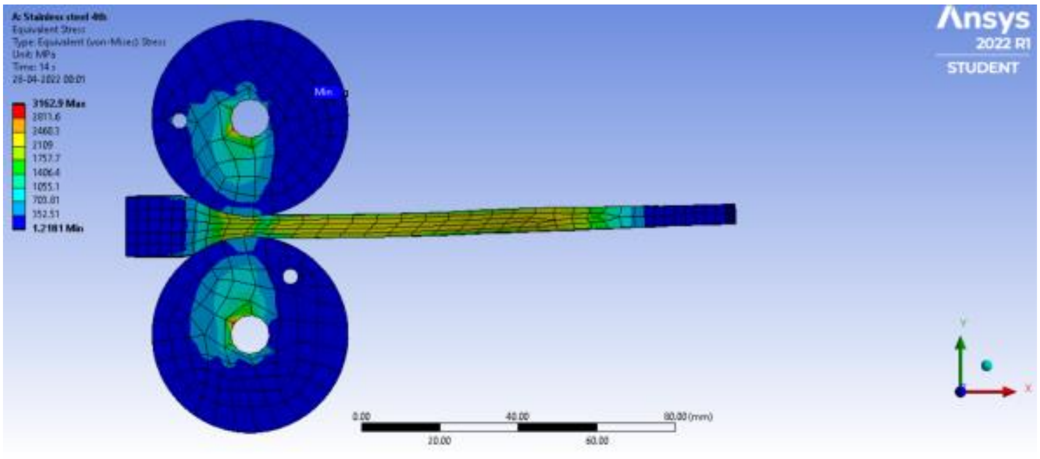


Fig 4.47 Equivalent stress for stainless steel

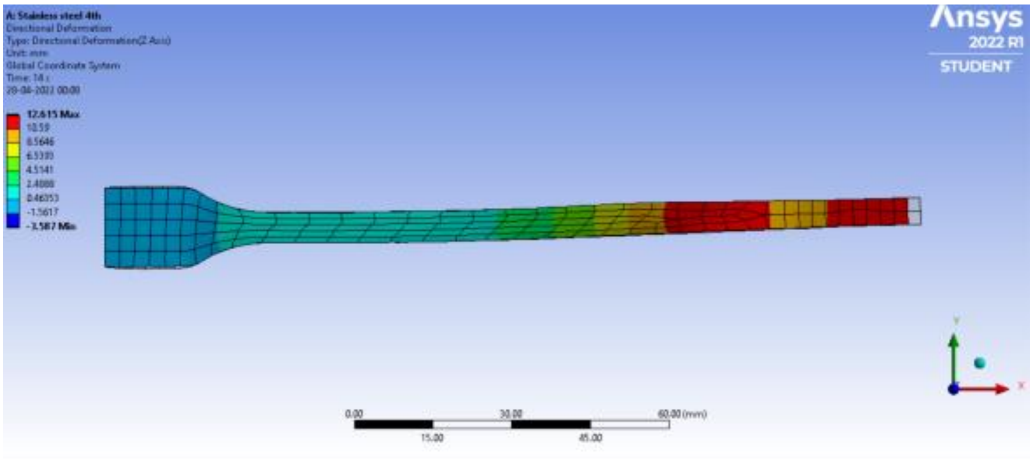


Fig 4.48 Directional deformation for stainless steel

4.3 Graphs for solved models

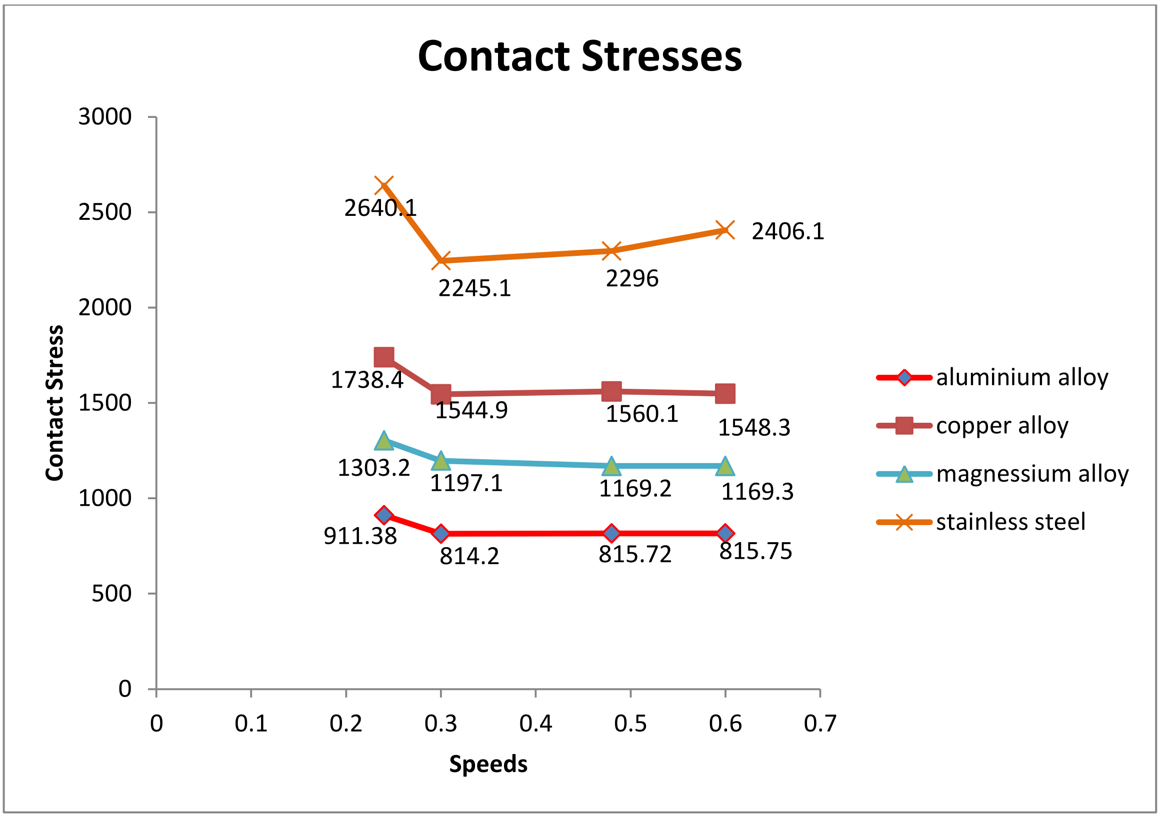


Fig 4.49 Contact Stresses

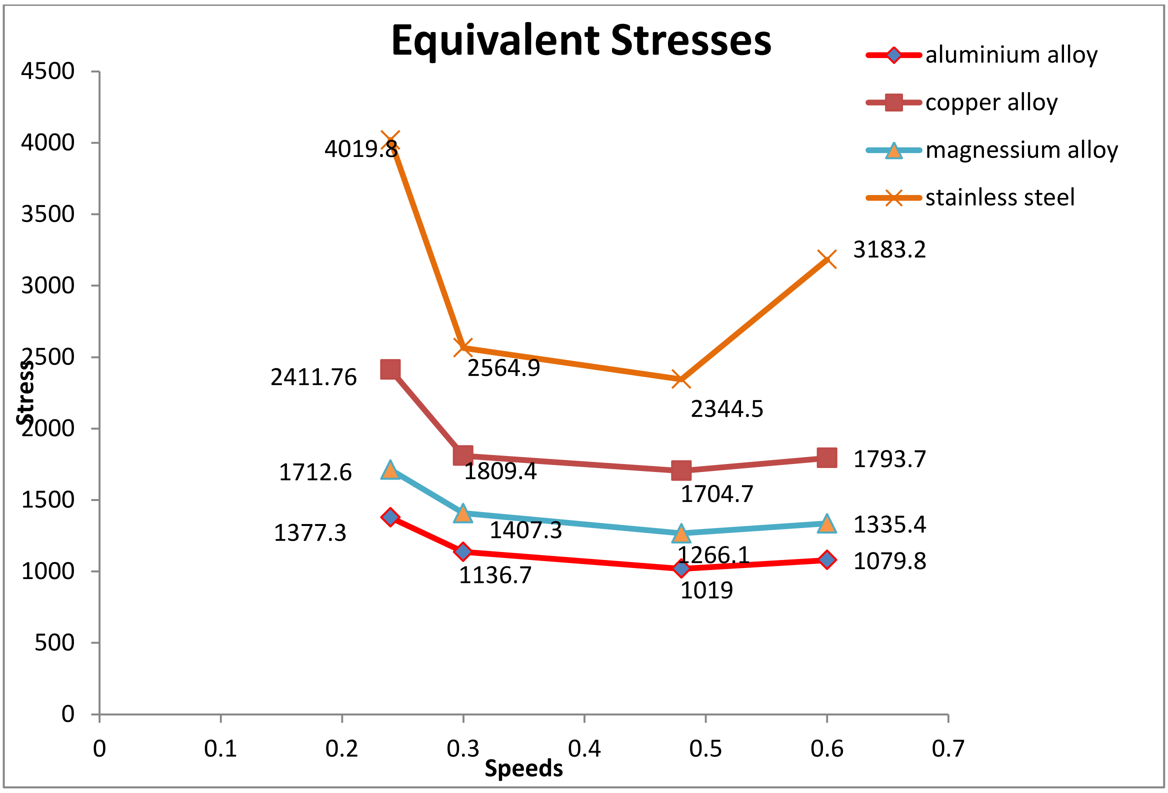


Fig 4.50 Equivalent Stresses

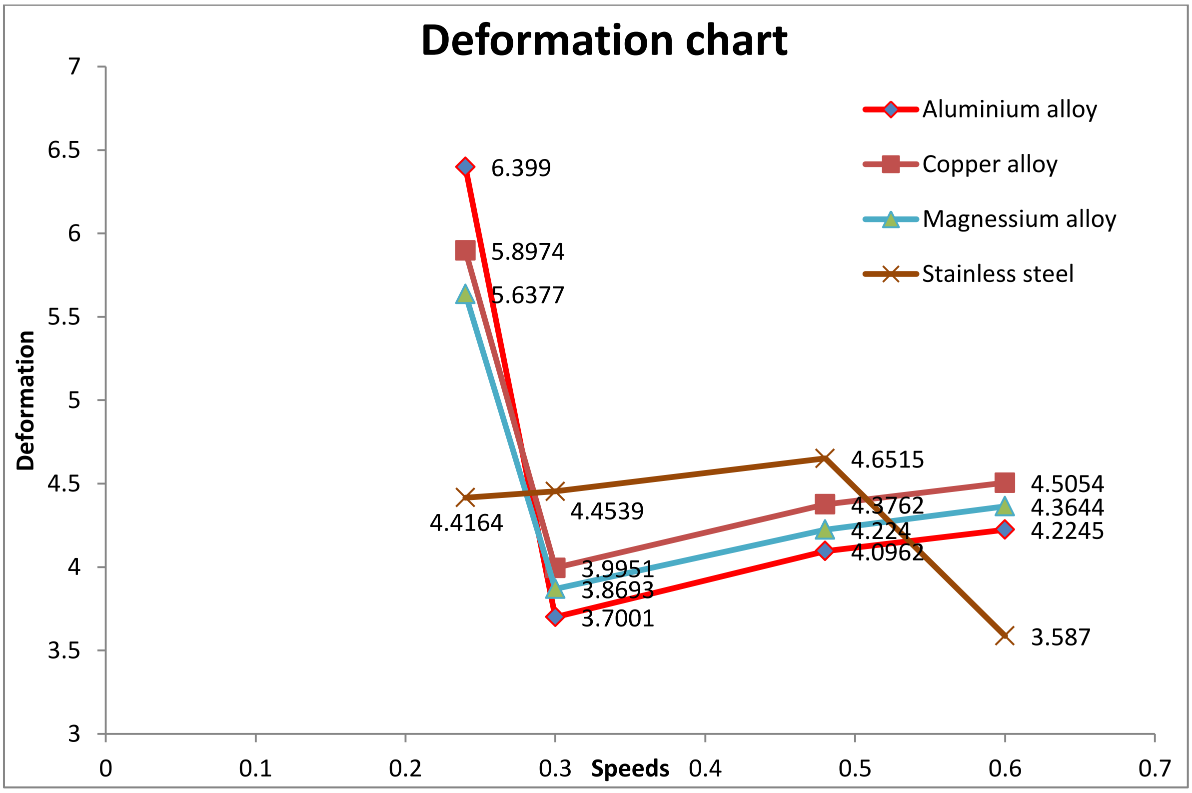


Fig 4.51 Directional Deformation

CHAPTER V
CONCLUSIONS

The Experimental analysis was conducted on four different materials of billet by fixing the material of roller. We have considered the Aluminium alloy, copper alloy, magnesium alloy and stainless steel as the materials for billet and D2 die steel as the material for the rollers. The analysis is carried out for four different speeds of rollers. The work conducted so far gives the following results

A. **Contact stresses**:-
   1. Maximum contact stresses was observed at 0.4 rad/s for stainless steel and minimum value was observed for aluminium alloy. Similar trend was observed for 0.3 rad/s 0.48 rad/s and 0.6 rad/s.
   2. Higher contact stresses was observed at lower roller speeds of 0.24 rad/s and minimum contact stresses was observed at 0.3 rad/s.

B. **Equivalent stresses:-**
   1. Maximum equivalent stress was observed for stainless steel at roller speed of 0.24 rad/s and minimum equivalent stress was observed for aluminium alloy at roller speed of 0.48 rad/s.
   2. Equivalent stress decreases with increase in roller speed from 0.24 rad/s to 0.48 rad/s.

C. **Directional deformation:-**
   1. Maximum directional deformation was observed for aluminium alloy at roller speed of 0.24 rad/s and the minimum directional deformation was observed for stainless steel at a roller speed of 0.6 rad/s.
   2. Directional deformation decreases with increase in roller velocity.

D. The optimal contact stress of 814.2 Mpa is obtained for aluminium alloy at roller speed of 0.3 rad/s.

E. The optimal equivalent stress of 1019 Mpa is obtained for aluminium alloy at roller speed of 0.48 rad/s.

F. The optimal directional deformation of 3.587 mm was observed for stainless steel at roller speed of 0.6 rad/s.

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