STRESS ANALYSIS OF BEVEL GEARS USED IN AUTOMOBILE DIFFERENTIAL

A project report submitted in partial fulfillment of the requirements for the Award of the Degree of

BACHELOR OF ENGINEERING
IN
MECHANICAL ENGINEERING

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Contents

ABSTRACT

Gears are an integral and necessary component in our day to day lives. They are present in the satellites we communicate with, automobiles and bicycles we travel with. Bevel gears are widely used because of their suitability towards transferring power between nonparallel shafts at almost any angle or speed. Gears are generally subjected to loads due to these loads, tooth bending stress and contact stress will be developed on the gear tooth. Much research on the action of the gear has confirmed that contact stresses also influence the formation of pits on the surface of the tooth. An analysis has been carried out for the four different types of materials used to make the bevel gear. The failure of gears due to contact stress is high compared to bending stress. Stress analysis has been a key area of research to minimize failure of the gear and optimize the design.

The Contact stress and bending stress in mating gears is the key parameter in gear design. Finite element analysis of a straight bevel gear tooth was carried out to evaluate the bending stresses. The stresses obtained by theoretical calculations at the root of the tooth are compared with the analytical results obtained using ANSYS software. Modeling was done by using Solid Works software. Bending stresses and contact stresses induced in bevel gears were determined by taking specifications of an **automobile differential**. A software program was developed using PHP web programming language to calculate the bending and contact stresses for four different materials at five different pitch angles. Numbers of iterations are carried out using the software to obtain the desired factor of safety. The analysis results obtained in ANSYS and theoretical results are good in agreement also the variation of factor of safety, bending stresses, contact stresses, with five pitch angles and for four different materials are plotted.

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Figure 1.1 Spur gears

Figure 1.2 Helical Gears

1.2.1.2 Helical Gears

In helical gear teeth are part of helix instead of straight across the gear parallel to the axis. The mating gears will have same helix angle but in opposite direction for proper mating. As the gear rotates, the contact shifts along the line of contact across the teeth.

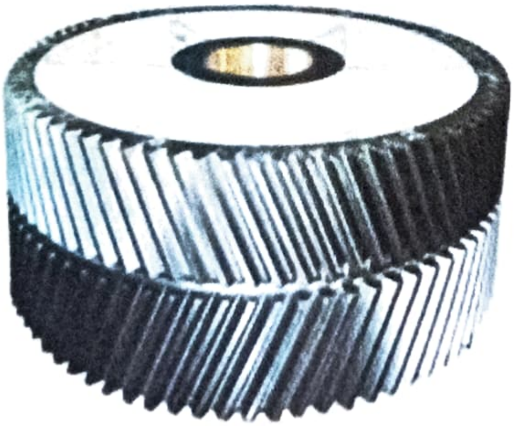


Figure 1.3 Herringbone Gears

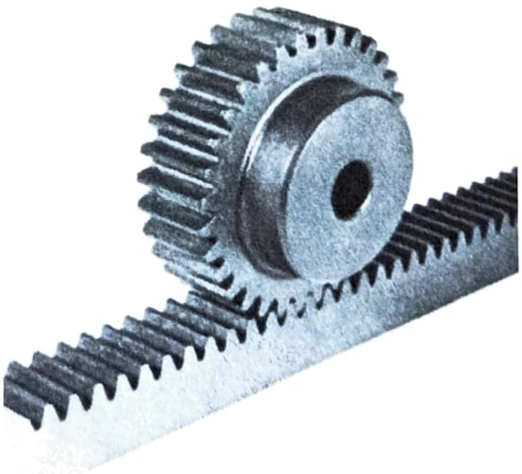


Figure 1.4 Rack and Pinion

1.2.1.3 Herringbone Gears

Herringbone gears are also known as **Double Helical Gears**. Herringbone gears are made of two helical gears with opposite helix angles, which can be up to 45 degrees.

1.2.1.4 *Rack and Pinion*

In these gears the spur rack can be considered to be spur gear of infinite pitch radius with its axis of rotation placed at infinity parallel to that of pinion. The pinion rotates while the rack translates.

1.2.2 Gears for intersecting shafts

The motion between two intersecting shafts is equivalent to the rolling of two cones. The gears used for intersecting shafts are called bevel gears. Gears under this category are following:

1.2.2.1 *Straight Bevel Gears*

Straight bevel gears are provided with straight teeth, radial to the point of intersection of the shaft axes and vary in cross section through the length inside generator of the cone. Straight Bevel Gears can be seen as modified version of straight spur gears in which teeth are made in conical direction instead of parallel to axis.

Figure 1.5 Straight Bevel Gears

Figure 1.6 Spiral Bevel Gears

1.2.2.2 *Spiral Bevel Gears*

Bevel gears are made with their teeth are inclined at an angle to face of the bevel. Spiral gears are also known as helical bevels.

1.2.3 Gears for Skew Shafts

The following gears are used to join two non-parallel and non-intersecting shafts.

1.2.3.1 Hypoid Gears

The Hypoid Gears are made of the frusta of hyperboloids of revolution. Two matching hypoid gears are made by revolving the same line of contact, these gears are not interchangeable.

1.2.3.2 Worm Gears

The Worm Gears are used to connect skewed shafts, but not necessarily at right angles. Teeth on worm gear are cut continuously like the threads on a screw. The gear meshing with the worm gear is known as worm wheel and combination is known as worm and worm wheel.

Figure 1.7 Hypoid Gears

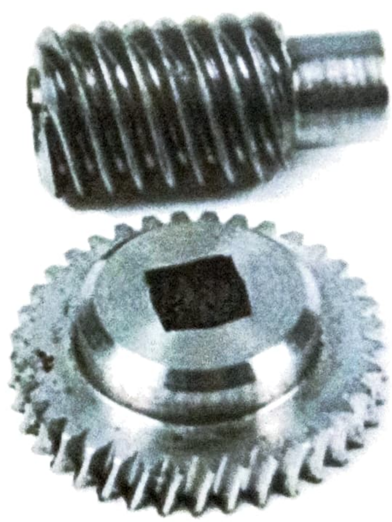


Figure 1.8 Worm Gears

1.3 Basic Gear Terminology

The following are the important dimensions and geometries concerned with toothed gear

1.3.1 Pitch Circle

Pitch circle is the apparent circle that two gears can be taken like smooth cylinders rolling without friction.

1.3.1.1 Addendum Circle

Addendum circle is the outer most profile circle of a gear. Addendum is the radial distance between the pitch circle and the addendum circle.

1.3.1.2 Dedendum Circle

Dedendum circle is the inner most profile circle. Dedendum is the radial distance between the pitch circle and the dedendum circle.

1.3.1.3 Clearance

Clearance is the radial distance from top of the tooth to the bottom of the tooth space in the mating gear.

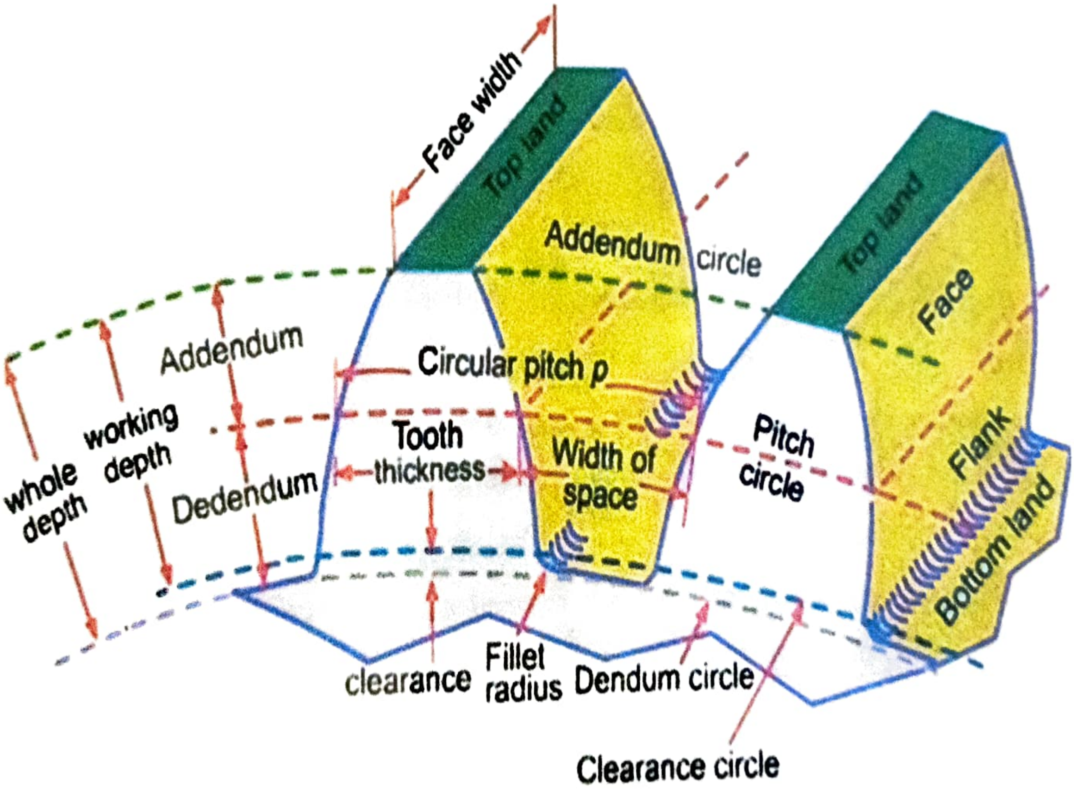


Figure 1.9 Basic Gear Terminology

1.3.1.4 Backlash

It is the difference between the tooth space and the tooth thickness, as measured on the pitch circle.

1.3.1.5 Full Depth

Full depth is sum of the addendum and the dedendum.

1.3.1.6 *Face Width*

Face width is length of tooth parallel to axes.

1.3.1.7 *Diametrical Pitch*

It is the ratio of number of teeth to the pitch circle diameter in millimetres. It denoted by p_d.

1.3.1.8 *Module*

It is the ratio of the pitch circle diameter in millimetres to the number of teeth. It is usually denoted by m.

$m = d/Z$

Where d= pitch circle diameter

Z= Number of teeth

1.3.1.9 *Circular Pitch*

It is the distance measured on the circumference of the pitch circle from a point of one tooth to the corresponding point on the next tooth. It is usually denoted by p_c.

1.3.1.10 *Gear Ratio*

Gear ratio is numbers of teeth of larger gear to smaller gear.

1.3.1.11 *Pressure Line*

Pressure line is the common normal at the point of contact of mating gears along which the driving tooth exerts force on the driven tooth.

1.3.1.12 *Pressure Angle*

Pressure angle is the angle between the common normal drawn at point of contact and common tangent of pitch circles at pitch point. It is also called angle of obliquity. High pressure angle requires wider base and stronger teeth.

1.3.1.13 *Pitch Angle*

It is the angle made by the pitch line with the axis of the shaft. It is denoted by θ_P.

1.4 Law of Gearing

Law of gearing states that common normal to the tooth profile at the point of contact should always pass through a fixed point called pitch point in order to obtain a constant velocity ratio

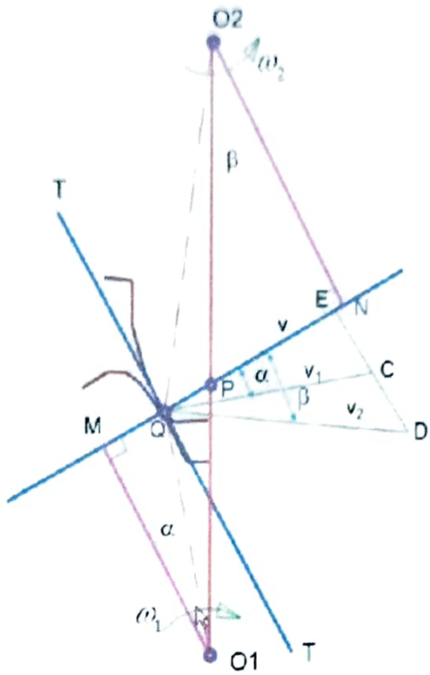


Figure 1.10 Law of Gearing

Where gear wheel-1 is considered point Q moves in the direction of QC. Velocity along QC is V_1. Where gear wheel-2 is considered point Q moves in the direction of QD. Velocity along QD is V_2. As the teeth are to remain in contact, then the components of these velocities along the common normal MN must be equal.

1.4.1 Derivation of law of gearing

$$V = v_1 cos\alpha = v_2 cos\beta \dots \dots 1$$

$$V_1 = O_1 Q w_1 \dots \dots \dots \dots 2$$

$$V_2 = O_2 Q w_2 \dots \dots 3$$

Substituting 2 and 3 in 1 we get,

$$V = O_1 Q w_1 cos\alpha = O_2 Q w_2 cos\beta \dots \dots .4$$

$$cos\alpha = \frac{O_1 M}{O_1 Q} \dots \dots 5 \, ; cos\beta = \frac{O_2 N}{O_2 Q} \dots \dots \dots .6$$

Substituting 5 and 6 in 4 we get,

$$O_1Qw_1 \times \frac{O_1M}{O_1Q} = O_2Qw_2 \times \frac{O_2N}{O_2Q}$$

$$\frac{w_1}{w_2} = \frac{O_2N}{O_1M} \quad \dots\dots\dots 7$$

Consider similar triangles O_1MP and O_2NP as shown below.

$$\frac{O_2N}{O_1M} = \frac{d_2}{d_1} = \frac{Z_2}{Z_1} \quad \dots\dots\dots\dots 8$$

Substituting 8 in 7 we get,

$$\frac{w_1}{w_2} = \frac{Z_2}{Z_1}$$

Hence it is proved that velocity ratio is constant.

1.5 Beam Strength of Bevel Gears

The size of cross section of the tooth of a bevel gear varies along the face width. In order to determine the beam strength of the tooth of a bevel gear, it is considered to be equivalent to a formative spur gear in a plane perpendicular to the tooth element.

Consider an elemental section of the tooth at a distance x from the apex o and having a width dx. Applying the Lewis equation to a formative spur gear at a distance x from the apex,

$$\delta(S_b) = m_x \times b_x \times \sigma_b \times Y \quad \dots\dots\dots\dots\dots\text{(a)}$$

Where, $\delta(S_b)$ = Beam strength of the elemental section (N)

m_x = Module of the section

b_x = Face width of elemental section (mm)

Y = Lewis form factor based on virtual number of teeth

From the figure,

$$\frac{r_x}{R} = \frac{x}{A_o} \; or \; r_x = \frac{Rx}{A_o} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots (b)$$

The elemental section,

$$m_x = \frac{2r_x}{z} = \frac{2xR}{zA_o} \qquad \text{.....................(c)}$$

At the large end of the tooth,

$$m_x = \frac{2R}{z} \qquad \text{........................ (d)}$$

From (c) and (d),

$$m_x = m(\frac{x}{A_o}) \qquad \text{........................ (e)}$$

$$b_x = dx \qquad \text{.............................. (f)}$$

Substituting (e) and (f) in (a) we get

$$\delta(S_b) = m(\frac{x}{A_o}) \times dx \times \sigma_b \times Y \text{........ (g)}$$

Now we get,

$$M_t = m \times b \times \sigma_b \times Y \times R\left[1 - \frac{b}{A_o} + \frac{b^2}{3A_o{}^2}\right] \text{...... (h)}$$

Assuming beam strength (S_b) as the tangential force at the large end of tooth,

$$M_T = S_b \times R \text{.............. (i)}$$

From (h) and (i)

$$S_b = m \times b \times \sigma_b \times y\left[1 - \frac{b}{A_o} + \frac{b^2}{3A_{O^2}}\right]$$

The face width of the bevel gear is limited to one-third of the cone distance. Therefore, the last term in the bracket will never be more than (1/27).

Neglecting the last term,

$$S_b = m \times b \times \sigma_b \times y\left[1 - \frac{b}{A_o}\right]$$

Where,

(S_b) = Beam strength of the tooth (N)

m = Module at the large end of the tooth (mm)

b = Face width (mm)

Y = Lewis form factor based on virtual number of teeth

A_o = Cone distance (mm)

$\left[1 - \frac{b}{A_o}\right]$ = is called bevel factor.

But we have,

$$Z_p' = \frac{Z_p}{COS\gamma}$$

And

$$Z_g' = \frac{Z_g}{COS\gamma} = \frac{Z_g}{COS(90-\gamma)} = \frac{Z_g}{SIN\gamma}$$

Substituting above equations in (e)

$$Q = \frac{2Z_g}{Z_g + Z_p tan\gamma}$$

The material constant K is the same as for the spur gears and is given by

$$K = \frac{\sigma_c^2 \times sin\alpha \times cos\alpha \left[\frac{1}{E_p} + \frac{1}{E_g}\right]}{1.4}$$

When the pinion as well as gear is made of steel and pressure is 20 degree the value of K is given by

$$K = 0.16\left(\frac{BHN}{100}\right)^2$$

The wear strength indicates the maximum value of the tangential force at the large end of the tooth that the tooth can transmit without pitting failure. It should be more than the effective force between the meshing teeth.

CHAPTER 2

LITERATURE SURVEY

2 LITERATURE REVIEW

2.1 Bending Stresses of Bevel Gears

Ratnadeepnish M.Jadeja et al [1] Here in this paper after doing the analytical calculation and analysis in ANSYS of straight teeth bevel gear, spiral bevel gear and zerol bevel gear, one conclude that the features of zerol bevel gear are good for the power transmission at higher speed and higher load. The zerol bevel gear has higher strength to resist the stress. Because of the curvature shape of the teeth load distribution is in two directional and continuously distribute the load in two directions, while in straight bevel gear load is applied in line form and at same time in full teeth. They have meshed the part by taking tetrahedron element and element size is 1mm and faces are 0.5mm for those areas where the stress concentration is high. Two of the surfaces are fixed in the reference of the gear teeth where the load is applied. Here load is applied in the form of pressure. The amount of tangential load is applied on the some specific area of the gear teeth by the pinion. That area is defining as the contact region of the gear teeth and the pinion teeth.

This paper can recommend the zerol bevel gear for transmission of power at 90° instead the spiral bevel gear and straight teeth bevel gear because of the following reason:

- Easy to manufacture compare to straight teeth bevel gear and spiral bevel gear
- Have a high strength to resist the stress.
- Work without any noise at high speed because of its curvature surface pitting effect reduces.

2.2 Bending Strength of Bevel Gear by FEM

Abhijeet v. patil et al [2] prepared solid modeling in CATIA and meshing is done. Analysis is done by using ANSYS workbench 12.1.In this project they have taken static structural material and given design inputs such as power 2.2kw, Number of teeth of pinion 20, Pitch diameter of pinion 60mm, Module 03mm and pressure angle 20deg.They calculated theoretical and got the bending strength value and the analytical solutions are compared to validate the model used for the finite element analysis.

The finite element analysis results are pretty much close to the analytically evaluated results. The mean tooth root bending stress, evaluated by selecting the nodes at the root of the contact teeth, has the value of 37,016 MPa, which corresponds to the 17% difference with the analytical result.

We see a great similarity between the numerical and the analytical results. From the results evaluated, it can be said that the FEA Analysis is validated. The difference in between is caused by many factors. The accuracy of the FEA results may be increased by using more mesh elements, which encapsulate contact regions more densely. Also a smaller tolerance for the solution of the stiffness matrix can be imposed.

2.5 Design of Contact Stress Analysis of Straight Bevel Gears

F. K. Choyetal et al [5], provided a comparison and benchmarking of experimental results obtained from a damaged gear transmission system with those generated from numerical model. conclusions for this study as follows: 1. A study of the dynamic changes in a gear transmission system due to (a) no gear tooth damage, (b) single gear tooth damage,(c) two consecutive gear teeth damage, and (d) three consecutive gear teeth damage is successfully conducted. 2. The vibration signature analysis using a joint time-frequency procedure, the Wigner-Ville distribution (WVD), seems to be quite effective in identifying single and multiple teeth damage in a gear transmission.

2.6 Structural and Model Analysis of a Composite Material

B. Venkatesh et al [6], obtained Von-Misses stress by theoretical and ANSYS software for Aluminum alloy, values obtained from ANSYS are less than that of the theoretical calculations. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions, which are safe and less than the other materials like steel. Aluminum alloy reduces the weight up to 5567% compared to the other materials. Aluminum is having unique property (i.e. corrosive resistance), good surface finishing, hence it permits excellent silent operation. Weight reduction is a very important criterion, in order to minimize the unbalanced forces setup in the marine gear system, there by improves the system performance. By the above exhaustive literature review, we can say that the gear needs to be redesigned providing energy saving by weight reduction, providing internal damping, reducing Lubrication requirement without increasing cost. Such a scope is provided by application of composite material providing solution to other existing problems in current gears available. Therefore this work is concerned with t he replacement of existing metallic gear with composite material gear in order to make it lighter and increasing the efficiency of mechanical machines with the aid of computer aided engineering.

2.7 Design of Acoustical Optimized Bevel Gears Using Manufacturing Simulation

Christian brecher et al [7] The comparison of the measured and the simulated TE showed that the FE-based tooth contact analysis ZaKo3D is capable of giving a good agreement between simulations and testing. The requirement is that the scatter of the topography is known and, if necessary, considered in the simulation. The comparison of the simulation with the averaged topography and the simulation with the consideration of all teeth showed difference of more than 50 %. Additionally, the results lead to the concept that by applying a targeted topography scatter, it is possible to reduce the TE respectively the excitation level.

Therefore, the method is applied for an exemplary gear set. Two variants are investigated; a ground target topography is calculated and as well a variant with a scatter in the topography deviations. The topography scatter is derived from a possible lapping process, but can be also applied on purpose in the grinding process. By applying the micro geometry scatter from tooth to tooth, the results of the TE calculation show that the amplitudes of the tooth mesh frequencies decrease. In parallel, the amplitudes of the frequencies in between the tooth mesh frequencies are rising. The TE of the ground reference shows a tonal distribution.

2.8 Static & Dynamic Analysis of Spur Gear using Different Materials

M. Keerthi et al [8] investigated to reduce the stress distribution, deformation and weight of spur gear by using composite materials in the application of gear box. The designed composite spur gear is compared with the existing gear materials, such as structural steel, gray cast iron and aluminum alloy. The tool which is used to analyze the different spur gear materials is ANSYS. In this, the analysis of torque loading and stress induced are to be performed for the materials chosen. The final outputs of these analyses for all the materials are to be compared. From this comparison, the stress induced, deformation and weight for composite spur gear materials are to be less than that of the general spur gear materials.

It was concluded that the stress values are calculated for composite materials is approximately same as compared to the structural steel, gray cast iron and aluminum alloy. So from these analysis results, we conclude that, the stress induced, deformation and weight of the composite spur gear is almost same as compared to the structural steel spur gear, gray cast iron spur gear and aluminum alloy spur gear. So, Composite materials are capable of using in automobile vehicle gear boxes instead of existing cast steel gears with better results. The natural frequency of Structural Steel Spur Gear varies from 2019.7 Hz to 6399.7 Hz. For Gray Cast Iron Spur Gear the natural frequency varies from 1575.2 Hz to 4990.8 Hz, whereas for Aluminum Alloy Spur Gear the natural frequency varies from 2003.8 Hz to 6353.2 Hz. The design is safe since the frequencies obtained exceeded the natural frequency of the spur gear (41.66 Hz).

2.9 Design and Analysis of Crown Pinion of A Differential Gear Box For Reduced Number of Teeth To Improve Torque Transmitted

Matthew D Brown et al [9] This paper gives a detailed approach to spiral bevel gear design and analysis. Key design parameters are investigated in accord with industry standards and recommended practices for use in a medium class helicopter. A final gear design is proposed and analyzed to show that proper margins of safety have been included in the design. Upon completion of the design phase of the gear, analysis was conducted to ensure appropriate margins of safety had been implemented into the design. Calculated values of Hertz stress and bending stress are less than the allowable stresses as per AGMA standards. As a result, the stresses produced in the gear teeth were acceptable, mitigating the risk of failure to the designed gear teeth.

2.10 Tooth Contact Analysis and Manufacture on Multitasking Machine of Large-Sized Straight Bevel Gears with Equi-Depth Teeth

Kazumasa Kawasaki et al [10] Large-sized straight bevel gears are widely used in the plant of large-sized power generation when the gears have large size. The tooth contact analysis of large-sized straight bevel gears with equi-depth teeth was achieved and these gears were manufactured on a multitasking machine. For this study, the mathematical model of straight bevel gears by complementary crown gears considering manufacture on multitasking machine was proposed, and tooth contact pattern as well as transmission errors of these straight bevel gears with modified tooth surfaces were analyzed in order to clarify the meshing and contact of these gears. Next, the numerical coordinates on the tooth surfaces of the bevel gears were calculated and the tooth profiles were modeled using a 3DCAD system. Five-axis control machines were utilized. The gear work was machined by swarf cutting using a coated carbide end mill. After rough cutting, the gear-work was heat-treated and it was finished based on a CAM process through the calculated numerical coordinates. The pinion was also machined similarly. The real tooth surfaces were measured using a coordinate measuring machine and the tooth flank form errors were detected using the measured coordinates. As a result, the obtained tooth flank form errors were small. In addition, the tooth contact pattern of the manufactured large-sized straight bevel gears was compared with those of tooth contact analysis. As a result, there was good agreement.

2.11 Scope of Work from Literature Survey

A comprehensive examination of existing literature revealed some of the gaps in works reported on stress analysis of bevel gears. The observed gaps lead to the formulation of the present problem which is summarized below. The work done particularly in the area of Stress Analysis of bevel gears had been published only in a limited scope. The works reported in this field had made use of different materials and studied the influence of effect of pitch angle on bending and contact stresses and factor of safety.

From the above literature, it is understood that various researchers considered various parameters to find the effect on bending and contact stresses with change in

CHAPTER 3

THEORETICAL CALCULATIONS

- Ultimate Compressive Strength = 820MPa
- Yield Tensile Strength = 276 MPa
- Bulk modulus = 83.3 GPa

3.3.2 Chromium Nickel Steel Alloy

- Density = 7800 kg/m3
- Young modulus = 200 GPa
- Poisson's ratio = 0.28
- Ultimate Tensile Strength = 680MPa
- Yield Tensile Strength = 280 MPa
- Bulk modulus = 69.6 GPa

3.3.3 Structural steel

- Density = 7850 kg/m3
- Young modulus = 200 GPa
- Poisson's ratio = 0.3
- Ultimate Tensile Strength = 460 MPa
- Yield Tensile Strength = 250 MPa
- Bulk modulus = 166 GPa

3.3.4 Cast Iron

- Density = 7300 kg/m3
- Young modulus = 190 GPa
- Poisson's ratio = 0.27
- Ultimate Tensile Strength = 4000MPa
- Yield Tensile Strength = 280 MPa
- Bulk modulus = 69.6 GPa

3.4 Sample Calculations Were Done For Material Phosphor Bronge102 by Taking The Specifications

- Density (ρ) =$8.85 g/cm^3$
- Young's modulus (E)=121Gpa

CONDITION: If V>20 Then $C_v = \frac{5.6}{5.6+\sqrt{v}}$

$$C_v = 0.53$$

$$P_{eff} = \frac{C_s}{C_v} \times P_t$$

$$P_t = \frac{1.5}{0.53} \times 2002.368$$

$$P_{eff} = 5601.23$$

Beam Strength (S_b) $= M \times b \times \sigma_b \times \pi \times Y \left[1 - \frac{b}{A_O}\right]$

$$P_{eff} = m \times b \times \sigma_b \times \pi \times Y \left[1 - \frac{b}{A_o}\right]$$

$$Y = 0.154 - \frac{0.912}{z'}$$

$$Z' = \frac{Z}{cos\theta}$$

$$Z' = 18.6$$

$$y = 0.1049$$

$$A_O = \sqrt{(\frac{D_p}{2})^2 + (\frac{D_g}{2})^2}$$

$$A_O = 106.3mm$$

By substituting all the values in the above equation we get $\sigma_{b_w} = 64.30N/mm^2$

Ultimate tensile stress (S_{ut}) = 650N/mm^2

Permissible Bending Stress = 40% of S_{ut}

Factor of safety (FOS) = $\frac{\sigma_{bu}}{\sigma_{bw}} = \frac{141.67}{64.30}$

Factor of safety = 2.2

Wear Strength (S_W) $= \frac{0.75 \times b \times Q \times D_p \times K}{COS\theta}$

$$Q = \frac{Z \times Z_g}{Z_g \times Z_p \times tan\theta_p}$$

$$Q = 1.1328$$

$$S_w = 0.75 \times 50 \times 1.1328 \times 140 \times \sigma_c{}^2 \times sin\alpha \times cos\alpha \left[\frac{1}{E_p} + \frac{1}{E_g}\right]$$

$$S_w = 0.01820\sigma_c{}^2$$

$$P_t = 0.01820\sigma_c^2$$

$$\sigma_c^2 = \frac{2002.368}{0.0182}$$

$$\sigma_c = 11.13N/mm^2$$

The remaining calculations for different materials are done by using graphical user interface (GUI) developed by using PHP Hypertext pre processor.

A graphical user interface (GUI) is developed to do the number of iterations in the preliminary stage of Design of Bevel Gears.

3.6 Introduction to PHP: Hypertext Preprocessor

PHP started out as a small open source project that evolved as more and more people found out how useful it was. Rasmus Lerdorf unleashed the first version of PHP in 1994.

- PHP is a recursive acronym for "PHP: Hypertext Preprocessor".
- PHP is a server side scripting language that is embedded in HTML. It is used to manage dynamic content, databases, session tracking, even build entire e-commerce sites.
- It is integrated with a number of popular databases, including MySQL, Postgre SQL, Oracle, Sybase, Informix, and Microsoft SQL Server.
- PHP is pleasingly zippy in its execution, especially when compiled as an Apache module on the UNIX side. The MySQL server, once started, executes even very complex queries with huge result sets in record-setting time.
- PHP supports a large number of major protocols such as POP3, IMAP, and LDAP. PHP4 added support for Java and distributed object architectures (COM and CORBA), making n-tier development a possibility for the first time.
- PHP Syntax is same as C-language.

3.7 Common Uses Of PHP

- PHP performs system functions, i.e. from files on a system it can create, open, read, write, and close them.
- PHP can handle forms, i.e. gather data from files, save data to a file, through email you can send data, return data to the user.

- You add, delete, modify elements within your database through PHP
- Access cookies variables and set cookies
- Using PHP, you can restrict users to access some pages of your website

3.8 Characteristics Of PHP

Five important characteristics make PHP's practical nature possible –

- Simplicity
- Efficiency
- Security
- Flexibility

3.9 GUI Developed Using PHP Hypertext Preprocessor

Select File > New Project (Ctrl-Shift-N on Windows and Linux, ⌘-Shift-N on Mac OS). Create a new PHP project named "wish list". When you create a PHP project, it contains the index fileindex.php by default. For information on creating and configuring a PHP project, see Setting up a PHP Project.

3.10 Interface

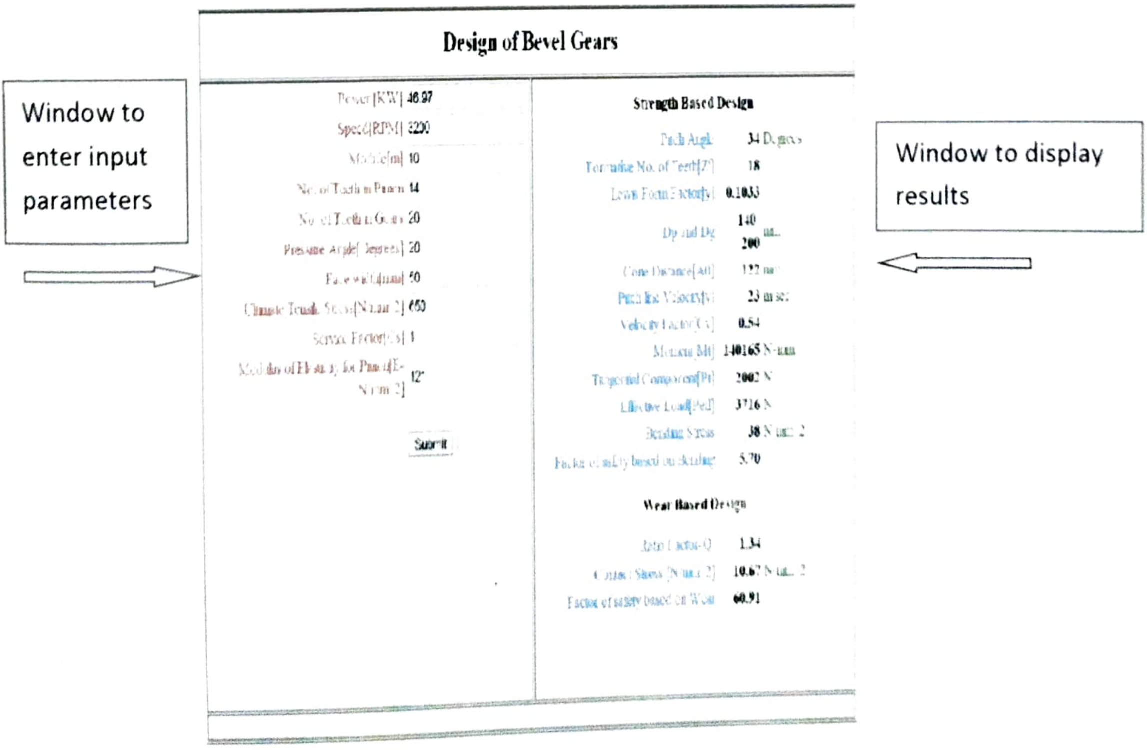


Figure 3.1 Developed Interface

3.11 Theoretical results obtained through PHP program.

3.11.1 Bending stress at pitch angle 20^0 for four materials.

Figure 3.2 Bending stress for PB102

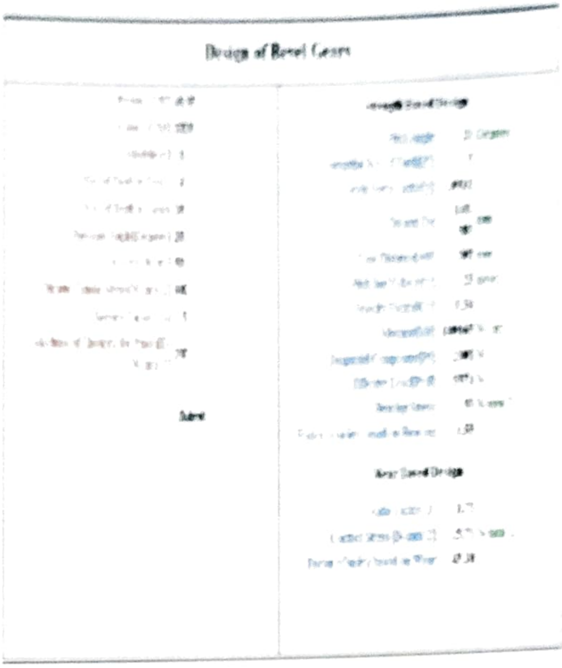


Figure 3.3 Bending stress for Cr-Ni STEEL

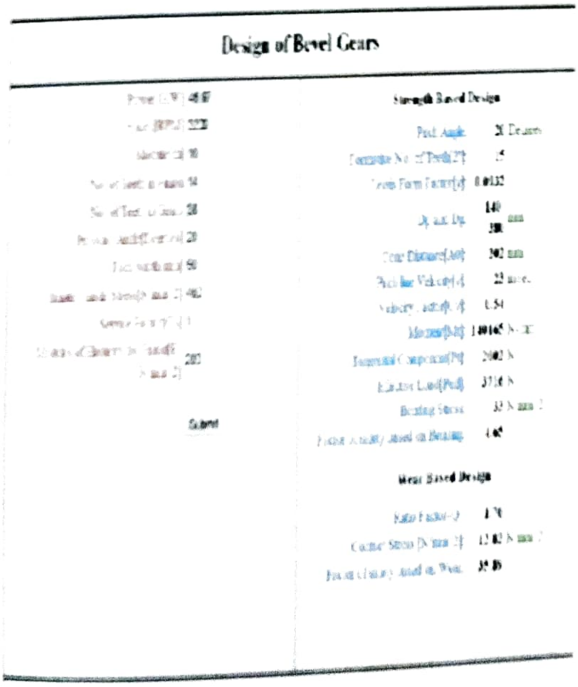


Figure 3.4 Bending stress for Structural Steel

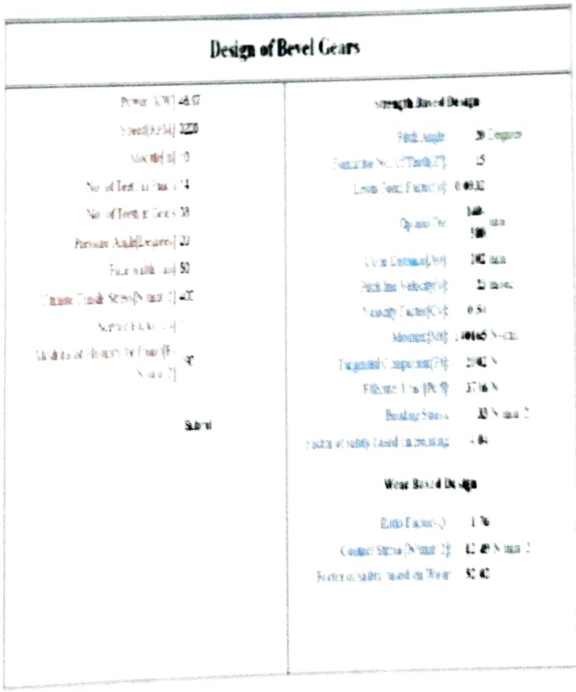


Figure 3.5 Bending stress for Cast Iron

3.11.2 Bending stress at pitch angle 25^0 for four materials.

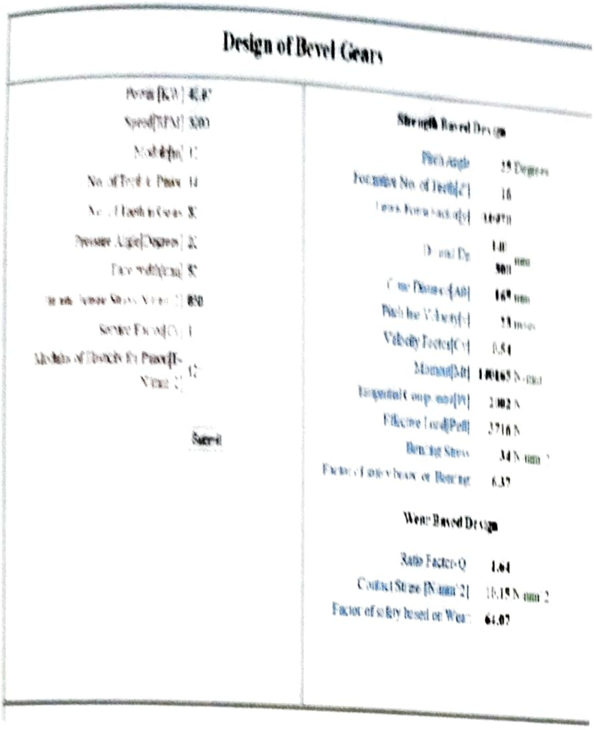


Figure 3.6 Bending stress for PB102

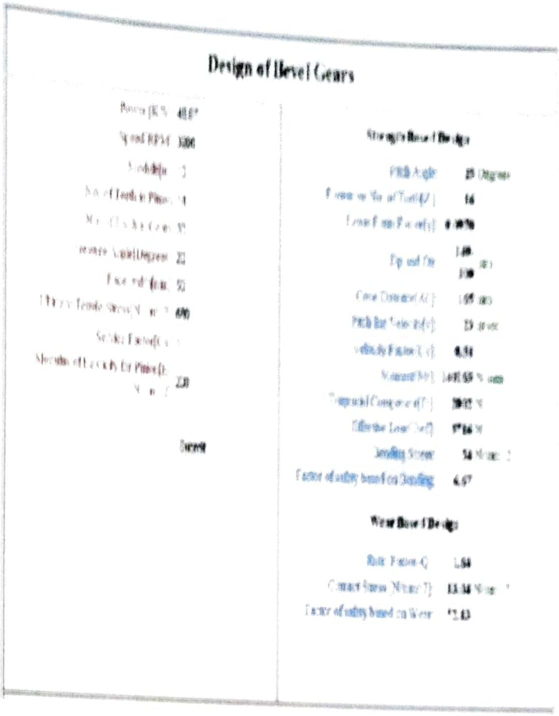


Figure 3.7 Bending stress for Cr-Ni Steel

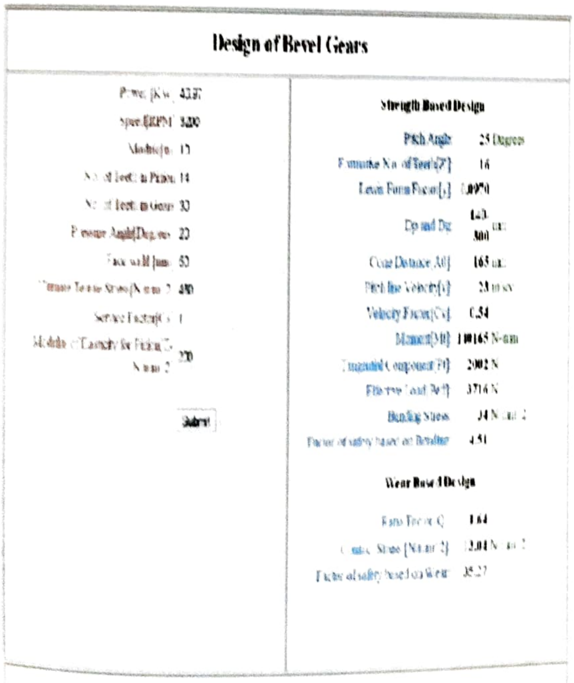


Figure 3.8 Bending stress for Structural Steel

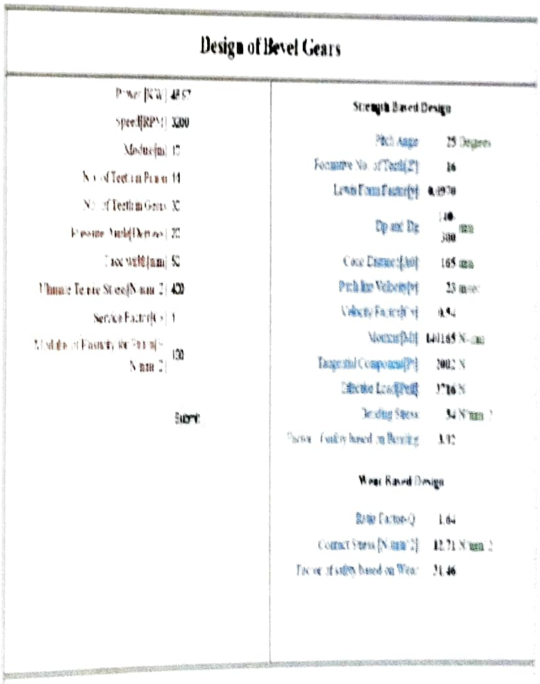


Figure 3.9 Bending stress for Cast Iron

3.11.3 Bending stress at pitch angle 30° for four materials.

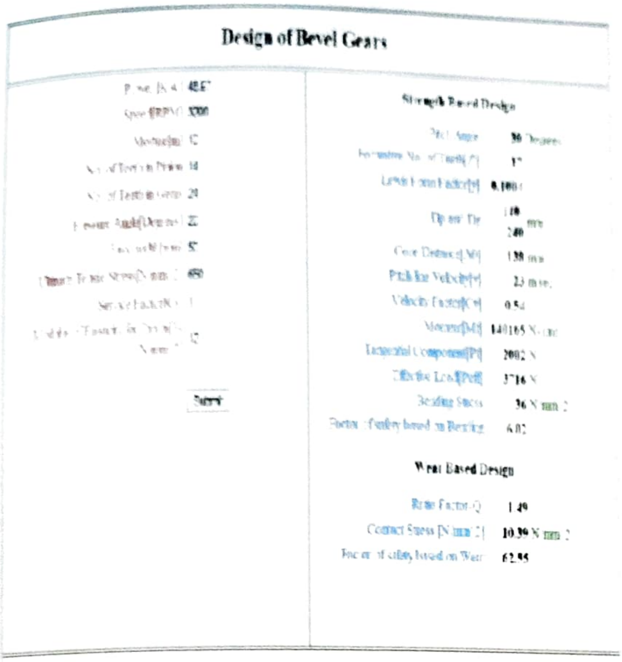


Figure 3.10 Bending stress for PB102

Figure 3.11 Bending stress for Cr-Ni Steel

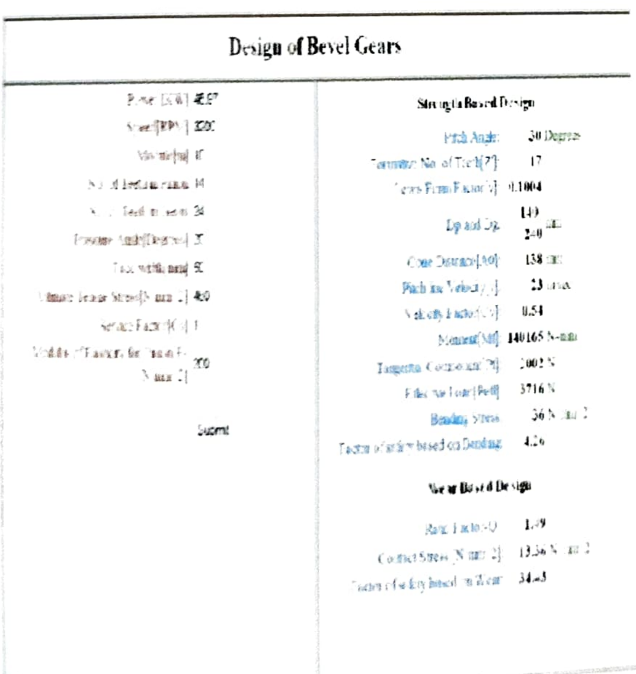


Figure 3.12 Bending Stress for Structural Steel

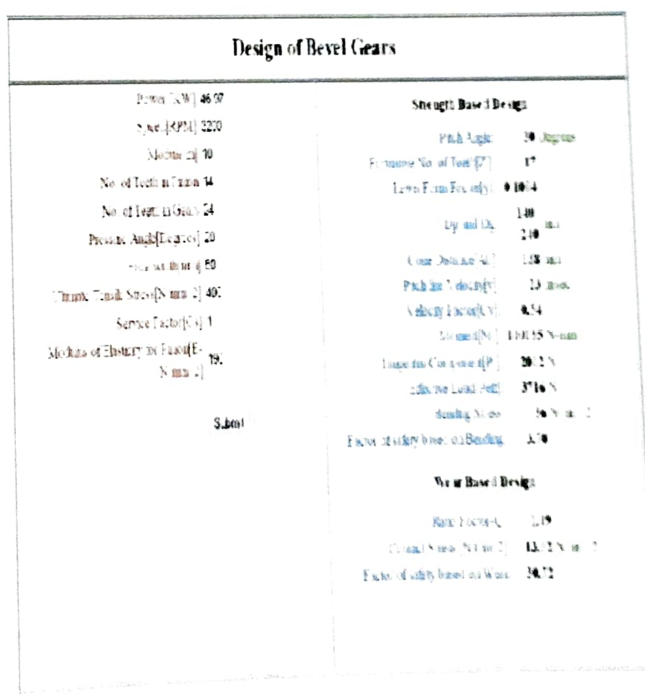


Figure 3.13 Bending stress for Cast Iron

3.11.4 Bending stress at pitch angle 35° for four materials.

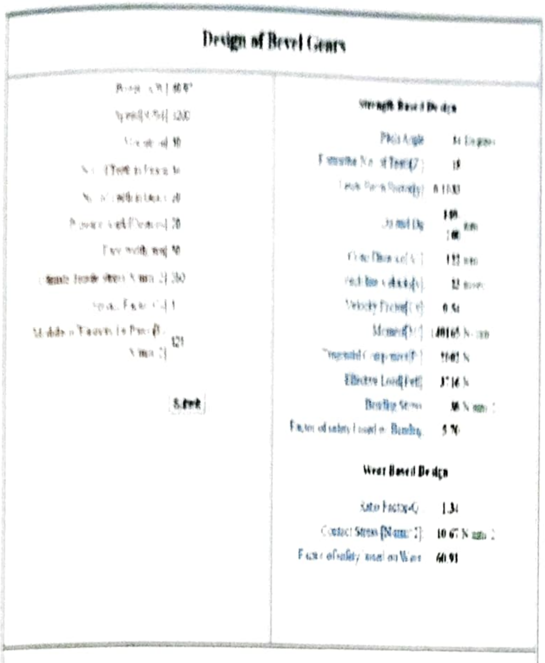


Figure 3.14 Bending stress for PB102

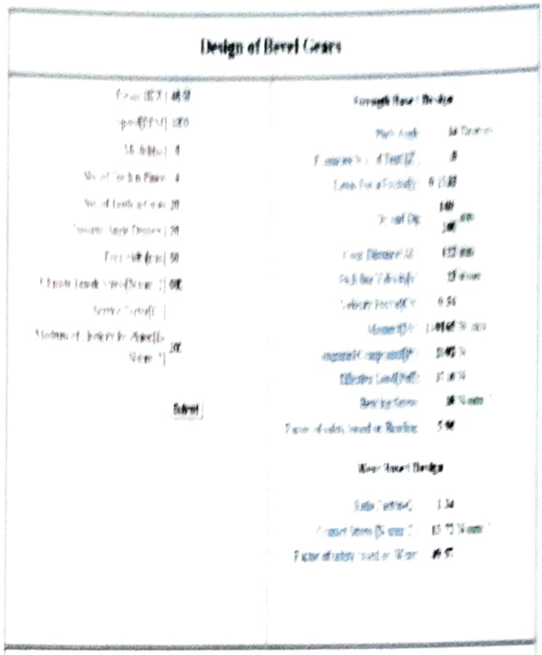


Figure 3.15 Bending stress for Cr-Ni Steel

Figure 3.16 Bending stress for Structural Steel

Figure 3.17 Bending stress for Cast Iron

3.11.5 Bending stress at pitch angle 40° for four materials.

Figure 3.18 Bending stress for PB102

Figure 3.19 Bending stress for Cr-Ni Steel

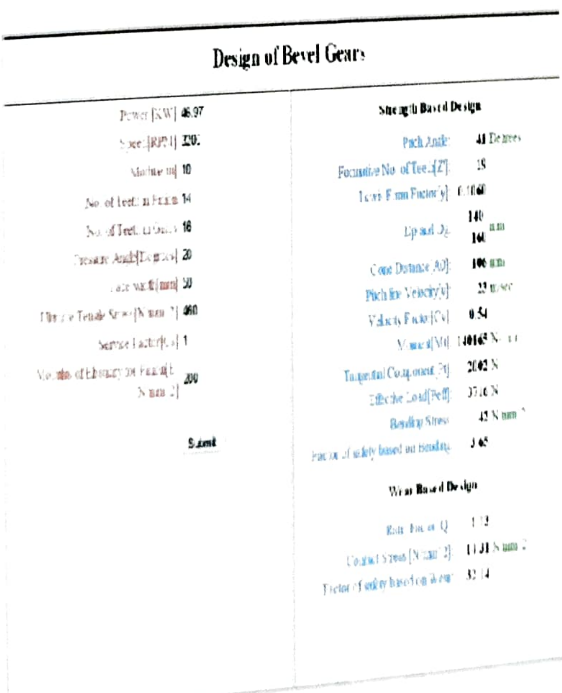


Figure 3.20 Bending Stress for Structural Steel

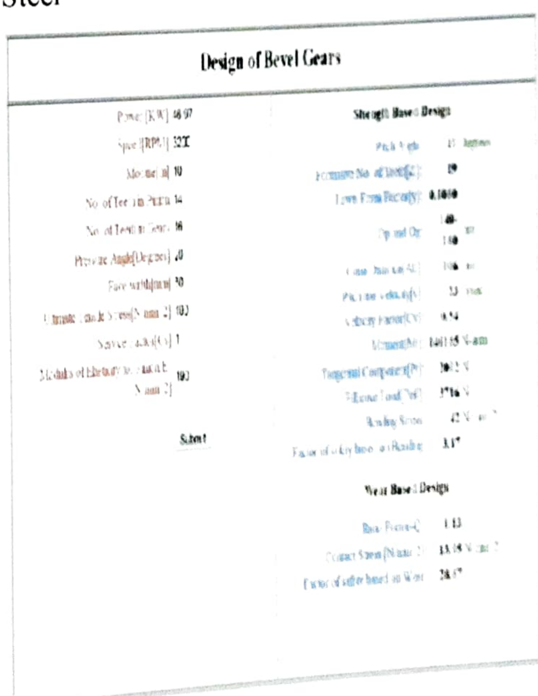


Figure 3.21 Bending stress for Cast Iron

CHAPTER 4

SOLID WORKS INTRODUCTION

4 SOLIDWORKS INTRODUCTION

4.1 Introduction

Solid Works is design automation software. In Solid Works, you sketch ideas and experiment with different designs to create 3D models. Solid Works is used by students, designers, engineers, and other professionals to produce simple and complex parts, assemblies, and drawings.

Solid Works works the way engineers design and think and that is why it has become successful so quickly. Engineers and drafters say that it is easy to learn and gives them a model that they have complete confidence in manufacturing and know that it will work, just by using the tools provided with this one piece of software. Solid works is powerful. The figure 6.1 shows the solid works interface.

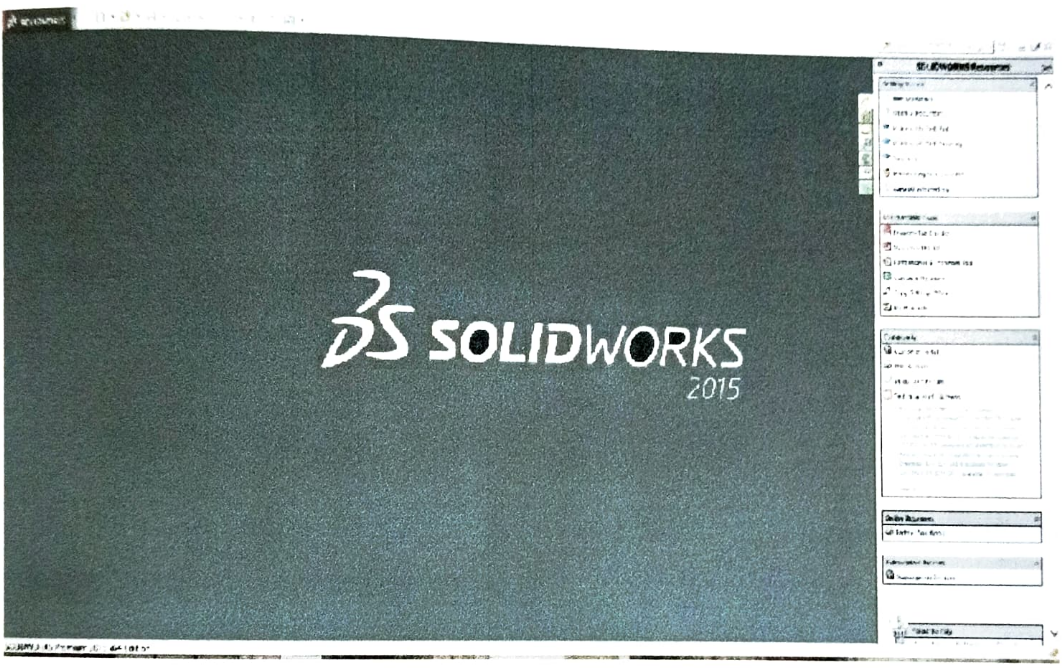


Figure 4.1 Solid works interface

- To start our projects select the sheet of paper shown. Notice there is another sheet of paper on the right side panel and you can use that one as well.
- Select PART from the dialog box shown and SELECT OK. We are going to make our FIRST part or drawing in Solid works. Basically solid works model is made up of PART, ASSEMBLY, DRAWING.
- Next, we are asked for a PLANE to begin our sketch. According to our drawing requirement, select the plane (as shown in the figure 6.2) in which the

part must be drawn. It should highlight and use your left mouse button to select it.

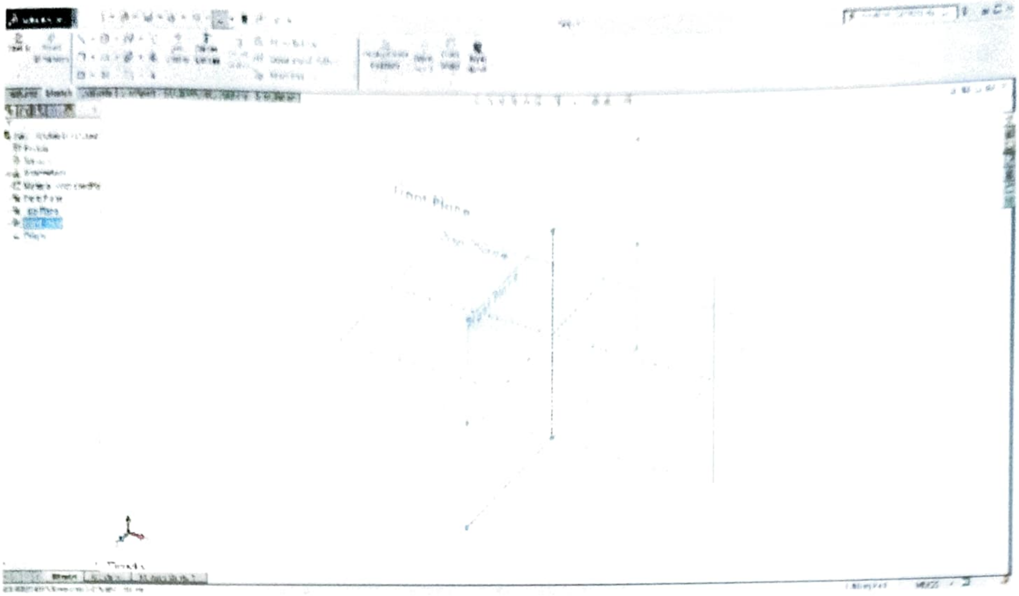


Figure 4.2 plane selection

- Construct the drawing of required part and by giving the dimensions by smart dimensioning.
- After constructing all the parts of the component, assemble the parts to obtain the component. Further obtain the drawing of the component.

4.1.1 Intended Audience

This document is for new Solid Works users. In this document, you are introduced to concepts and design processes in a high-level approach.

Solid Works Help contains a comprehensive set of tutorials that provide step-by-step instruction on many of the features of Solid Works.

4.2 Terminology

These terms appear throughout the Solid Works software and documentation as shown in the figure 6.3.

- **Origin:** Appears as two blue arrows and represents the (0, 0, 0) coordinate of the model. When a sketch is active, a sketch origin appears in red and represents the (0, 0, 0) coordinate of the sketch. You can add dimensions and relations to a model origin, but not to a sketch origin.

- **Plane:** Flat construction geometry. You can use planes for adding a 2D sketch, section view of a model, or a neutral plane in a draft feature, for example.

- **Axis:** Straight line used to create model geometry, features, or patterns. You can create an axis in different ways, including intersecting two planes. The Solid Works application

- **Face:** Boundaries that help define the shape of a model or a surface. A face is a Selectable area (planar or non-planar) of a model or surface. For example, a rectangular solid has six faces.

- **Edge:** Location where two or more faces intersect and are joined together. You can select edges for sketching and dimensioning, for example.

- **Vertex:** Point at which two or more lines or edges intersect. You can select vertices sketching and dimensioning, for example.

Table 4.1 Data used for preparing the Gear in Solidworks

Parameter	**Bevel gear**	
	Pinion	Gear
No. of teeth	14	16
Normal module	10	10
Pressure angle (deg)	20	20
Mounting distance	100	100
Nominal shaft diameter(mm)	90	90
Face Width (mm)	50	50
Hub diameter	50	50
Torque (N-m)	182.5	
Power (K-w)	46.97	46.97
Speed (rpm)	3200	
Contact force (N)	140165	

4.3 Solid Modeling of Bevel Gear

During the gear design, the main parameters that would describe the designed gear such as module, pressure angle, and number of teeth could be used as the parameters to define the gear. Relation is used to express dependencies among the dimension needed for defining the basic parameters on which the model is depends. The gears with different geometric properties can be modeled from the existing model by just varying the few parameters on which it depends. In this work, module, pressure angle, numbers of teeth, mounting distance, and the face width of both the gears are taken as input parameters. I used these parameters, in combination with its features to generate the geometry of the Bevel gear and all essential information to create the model. By using the relational equation, the accurate three dimensional Bevel gear models are developed. The assembly of gear is done by consider the left and right Bevel gear. Then the file is saved as IGES format. The proportions of gear obtained from theoretical analysis have been used for preparing geometric model of gear.

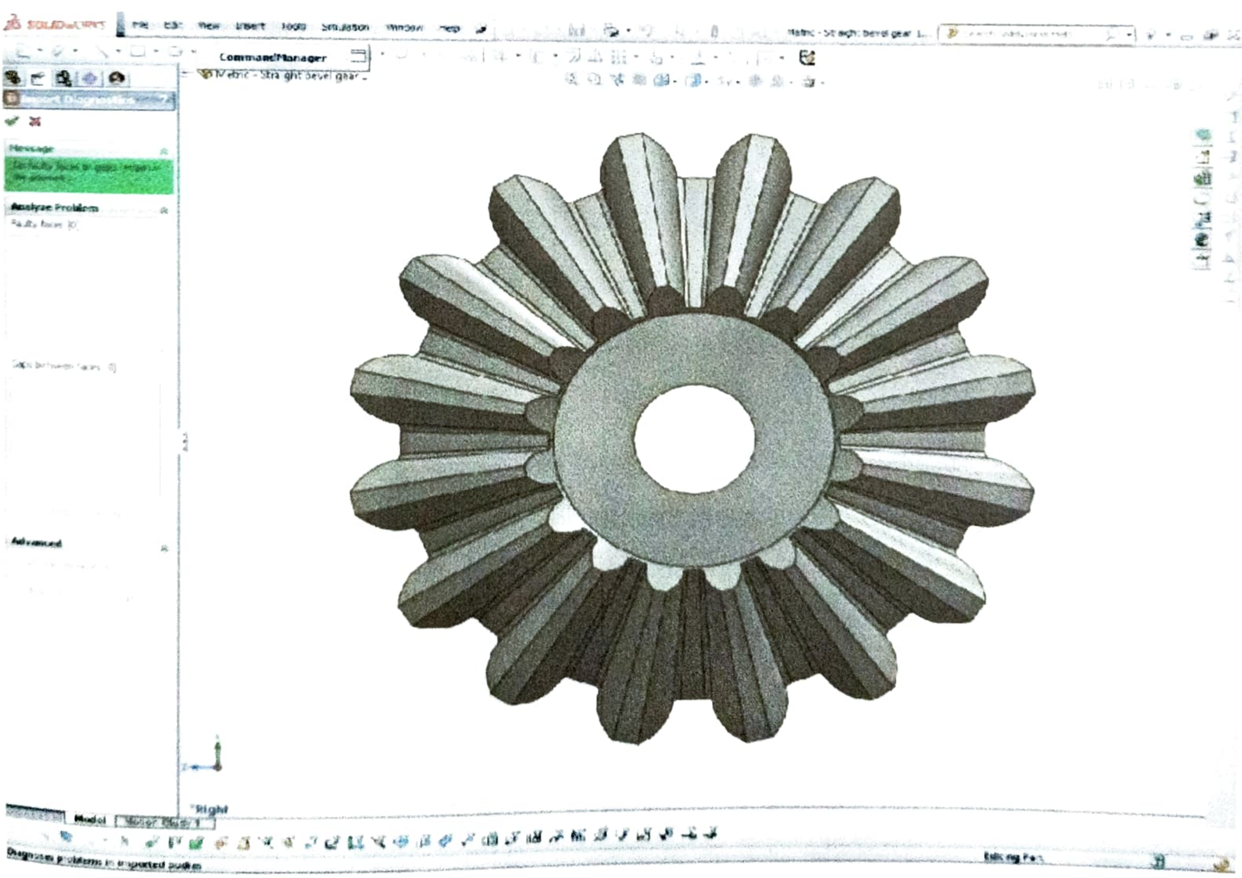


Figure 4.3 Bevel Gear Model prepared in Solidworks software

4.4 Assembly of Bevel Gear

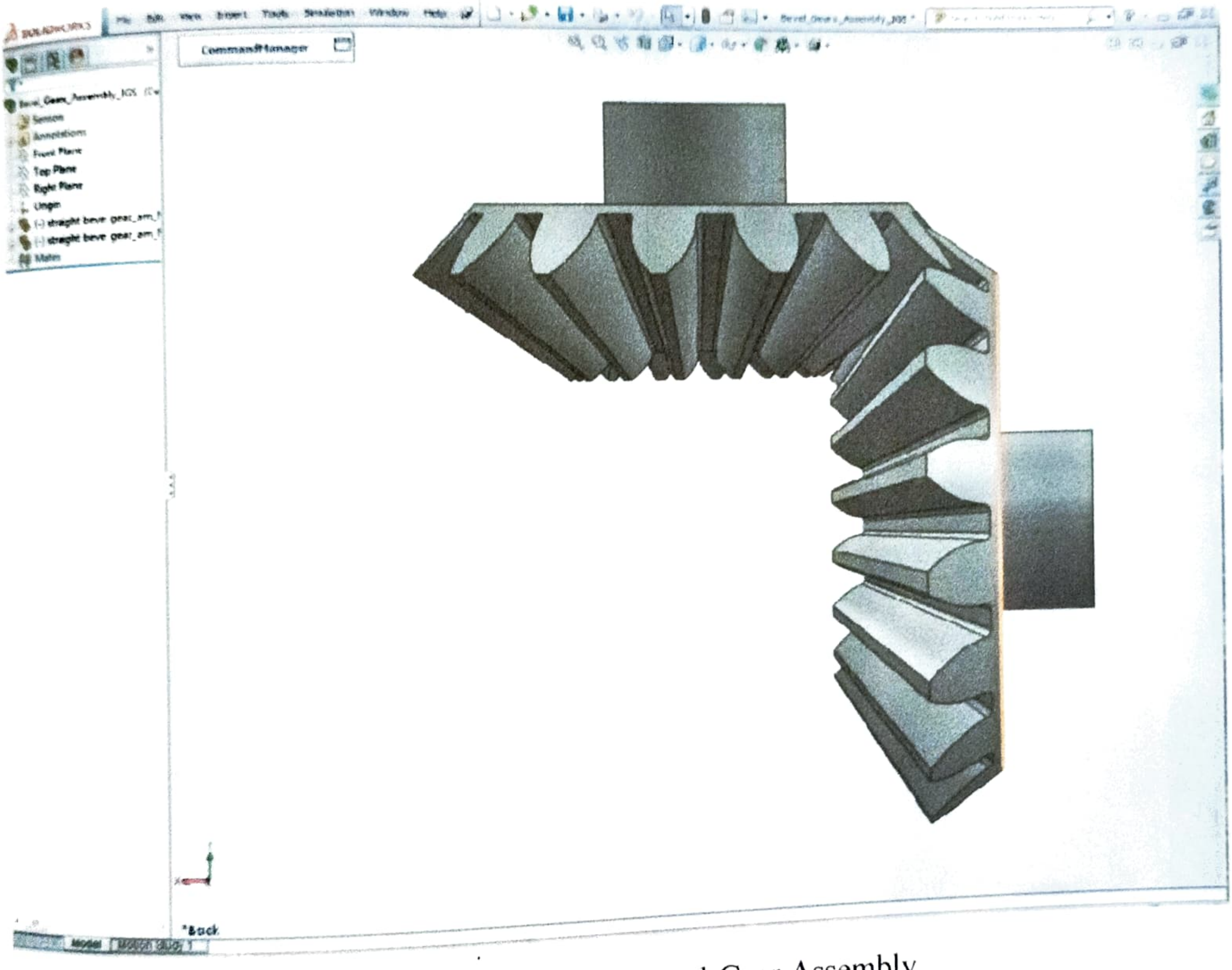


Figure 4.4 Bevel Gear Assembly

1. Import the two gears such that their axis is at an angle of 90^0 using perpendicular mate.
2. Align the two gears according to their center distance using distance mate.
3. Align the teeth properly using coincident mate.

CHAPTER 5

INTRODUCTION TO ANSYS SOFTWARE

5 INTRODUCTION TO ANSYS SOFTWARE

5.1 Introduction

Welcome to the world of Computer Aided Engineering (CAE) with ANSYS Workbench. If you are a new user, you will be joining hands with thousands of users of this Finite Element Analysis software package. If you are familiar with the previous releases of this software, you will be able to upgrade your designing skills with tremendous improvement in this latest release.

In the Graphical User Interface (GUI) of ANSYS Workbench, the user can generate 3-dimensional (3D) and FEA models, perform analysis, and generate results of analysis. You can perform a variety of tasks ranging from Design Assessment to Finite Element Analysis to complete Product Optimization Analysis by using ANSYS Workbench. ANSYS Workbench, developed by ANSYS Inc., USA, is a Computer Aided Finite Element ANSYS also enables you to combine the stand-alone analysis system into a project and to manage the project workflow.

The following is the list of analyses that can be performed by using ANSYS Workbench:

1. Design Assessment
2. Electric
3. Explicit Dynamics
4. Fluid Flow (CFX)
5. Fluid Flow (FLUENT)
6. Harmonic Response
7. I.C. Engine
8. Linear Buckling
9. Magneto static
10. Modal
11. Random Vibration
12. Response Spectrum
13. Rigid Dynamics
14. Static Structural
15. Steady-State Thermal
16. Thermal-Electric
17. Transient Structural
18. Transient Thermal.

5.2 Starting ANSYS Workbench 15.0

To start ANSYS Workbench 15.0, choose Start > Programs/All Programs > ANSYS 15.0 > Workbench 15.0 from the Taskbar, refer to Figure 5.1. Alternatively, you can start ANSYS Workbench by double-clicking on the Workbench shortcut icon displayed on the desktop of your computer. After the necessary files are loaded and licenses are verified, the Workbench window along with the Getting Started window will be displayed on the screen, as shown in Figure 5.1

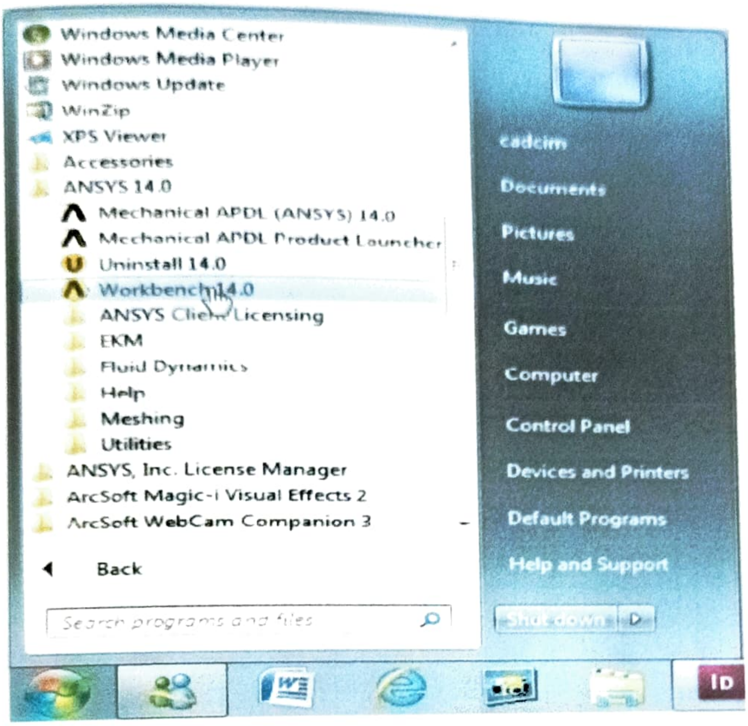


Figure 5.1 ANSYS work bench Icon in Windows OS

The Getting Started window guides you to use the interface of ANSYS Workbench effectively. To close this window, choose the OK button.

The Workbench window helps streamline an entire project to be carried out in ANSYS Workbench 14.0. In this window, one can create, manage, and view the workflow of the entire project created by using standard analysis systems. The Workbench window mainly consists of Menu bar, Standard toolbar, the Toolbox window, Project Schematic window, and the Status bar, refer to Figure 37. Various components of the Workbench window are discussed next.

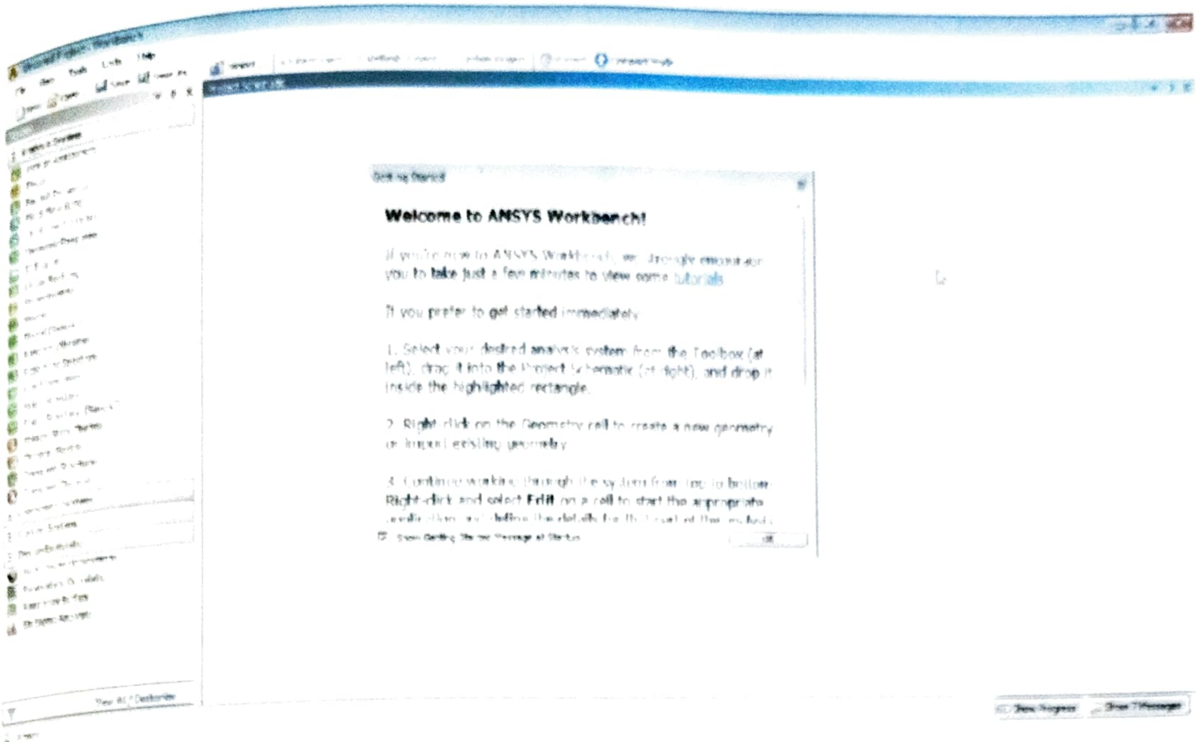


Figure 5.2 Interface of work bench

5.3 Project Schematic Window

The Project Schematic window helps manage an entire project. It displays the workflow of entire analysis project. To add an analysis system to the Project Schematic window, drag the analysis system from the Toolbox window and drop it into the green-colored box displayed in the Project Schematic window, as shown in Figure Alternatively, double-click on an analysis system in the Toolbox window to include it in the Project Schematic window. You can also add an analysis system to the Project Schematic window by using the shortcut menu displayed on right-clicking in the Project Schematic window. The procedure of adding an analysis system by using the shortcut menu is discussed later in this chapter.

In the Project Schematic window, when you click on the down arrow available at the top right corner, a fly out is displayed with various options to close, float, restore, minimize, and maximize the Project Schematic window, refer to Figure 5.3

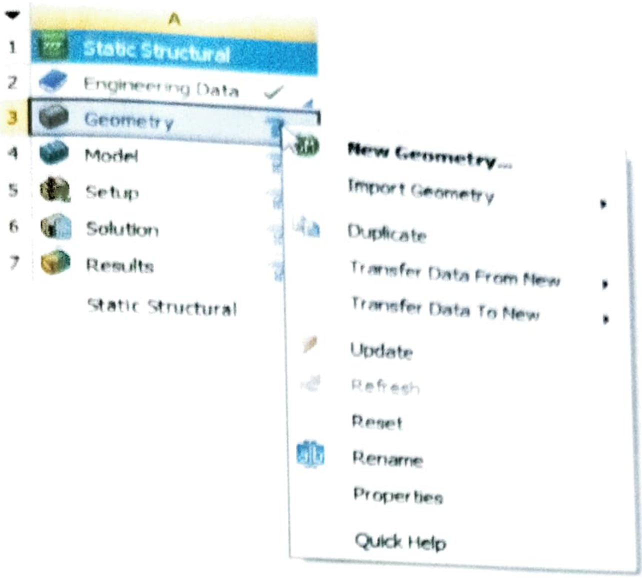


Figure 5.4 Static Structural Module

- Engineering data such as young's modulus, density, poisons ratio is given t the material

Properties of Outline Row 3: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	7850	kg m^-3		
3	⊞ Isotropic Secant Coefficient of Thermal Expansion				
6	⊟ Isotropic Elasticity				
7	Derive from	Young's Mo...			
8	Young's Modulus	2E+11	Pa		
9	Poisson's Ratio	0.3			
10	Bulk Modulus	1.6667E+11	Pa		
11	Shear Modulus	7.6923E+10	Pa		
12	⊞ Alternating Stress Mean Stress	Tabular			
16	⊞ Strain-Life Parameters				

Figure 5.5 Selection of material

After importing the geometry the environment of contact and bending will be seen like this.

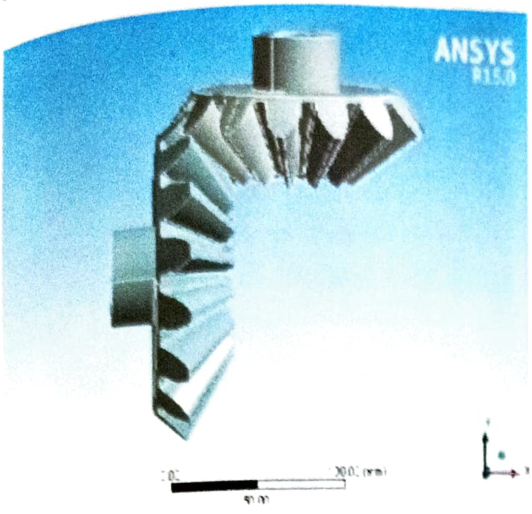


Figure 5.6 Assembly for Contact Stress Analysis

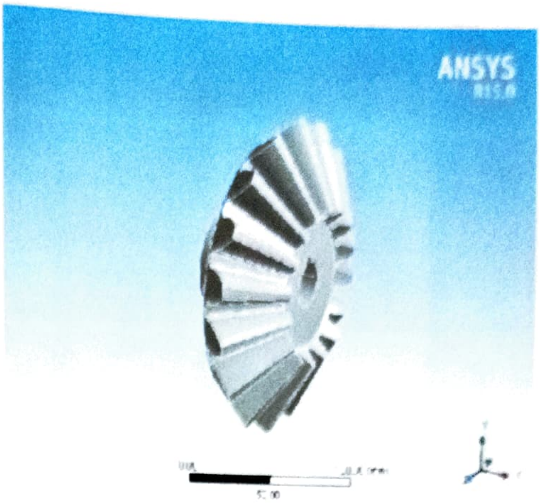


Figure 5.7 Bevel Gear for Bending Stress Analysis

Meshing is done by taking sizing and in sizing coarse medium mesh is given as shown in fig5.8

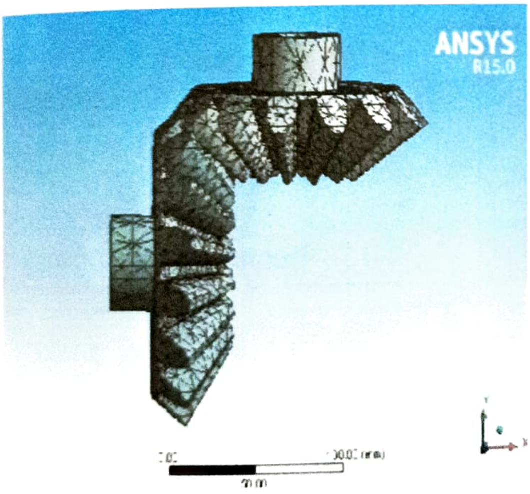


Figure 5.8 Assembly after Meshing

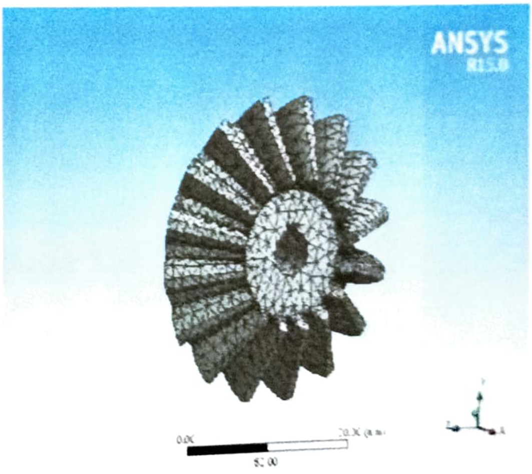


Figure 5.9 Bevel Gear after Meshing

Moment for the pinion and frictionless support for the gear is given for contact model as shown in fig.45 and 46. Fixed support is given to the hub of the gear and tangential force of 2002.01N is given to one of the tooth of the gear as shown in fig.47 and 48.

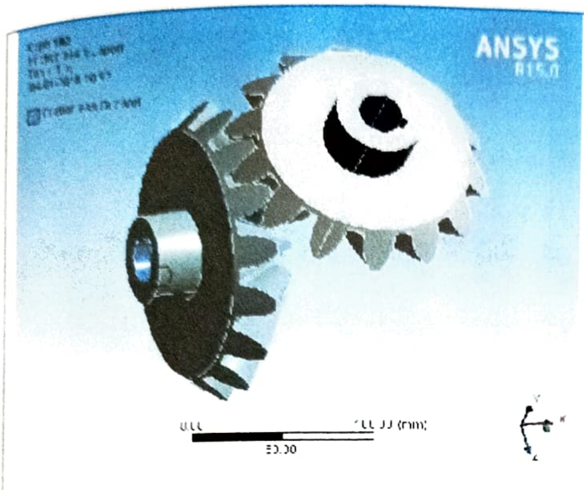


Figure 5.10 Friction less support

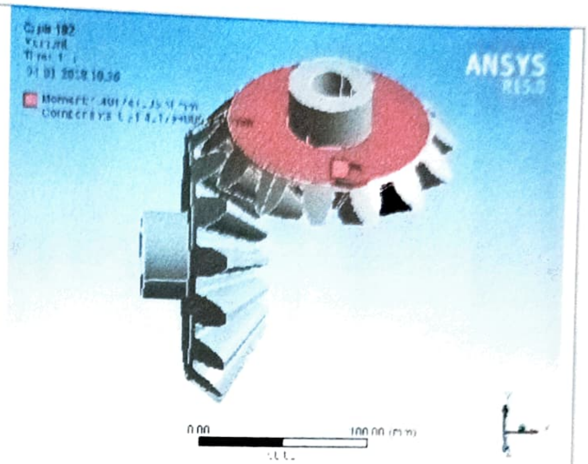


Figure 5.11 Moment

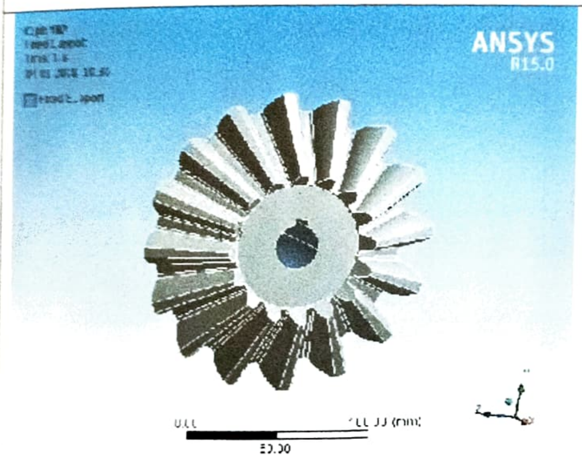


Figure 5.12 Fixed support

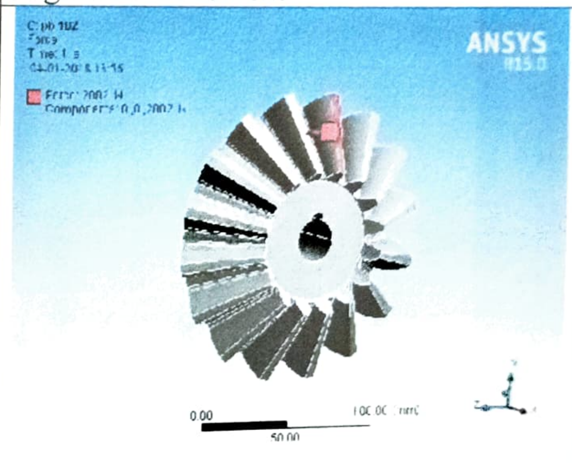


Figure 5.13 Tangential Force

CHAPTER 6

ANSYS RESULTS

6 ANSYS RESULTS

6.1 Induced Stresses

Bending Stresses and Contact stresses had been obtained using ANSYS software.

6.1.1 Bending and Contact Stresses induced in Bevel Gear for Cast Iron

6.1.1.1 Bending Stresses at pitch angle 20^0

Bending Stresses obtained at 20^0 pitch angle are listed in the Table 6.1

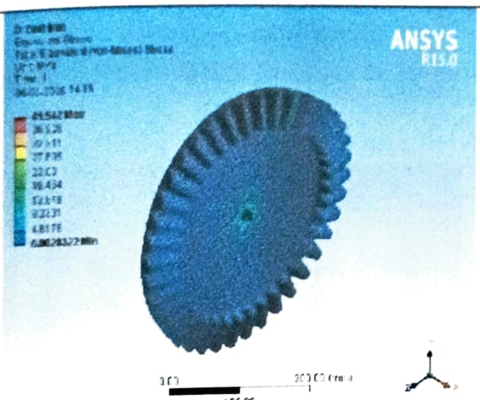


Figure 6.1 von-Mises Stresses at 20^0 pitch angle

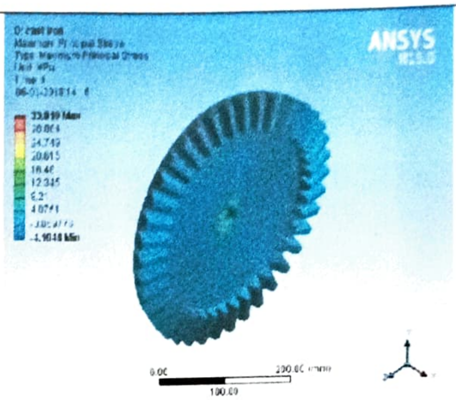


Figure 6.2 Max principal stress at 20^0 pitch angle

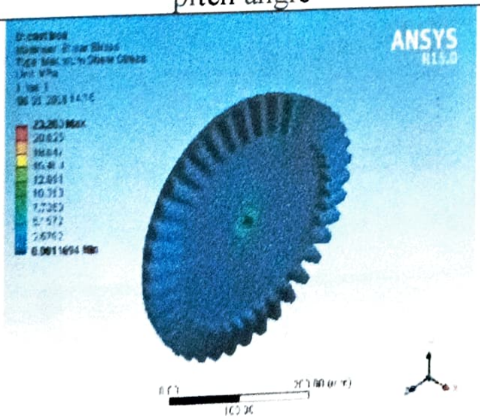


Figure 6.3 Max shear stress at 20^0 pitch angle

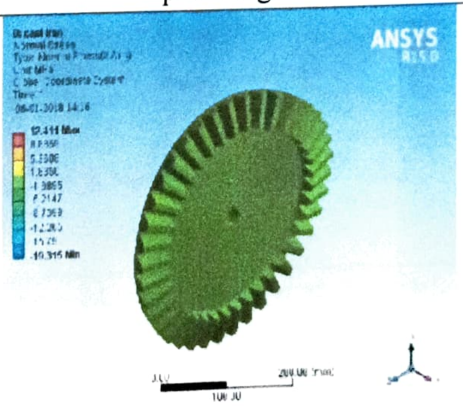


Figure 6.4 Normal stress at 20^0 pitch angle

Table 6.1 Induced Stresses at 20^0 Pitch angle

Stresses	**ANSYS Result in N/mm^2**
Von mises stress	41.54
Max principal stress	33.61
Max shear stress	23.2
Normal stress	12.41

6.1.1.2 Contact Stress at pitch angle 20⁰

Contact Stresses at 20^0 pitch angle is listed in Table 6.2

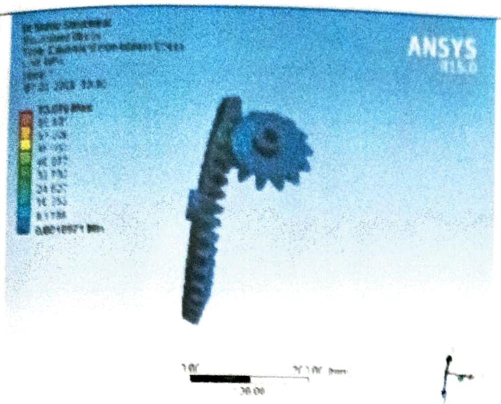


Figure 6.5 von-Mises Stresses at 20^0 pitch angle

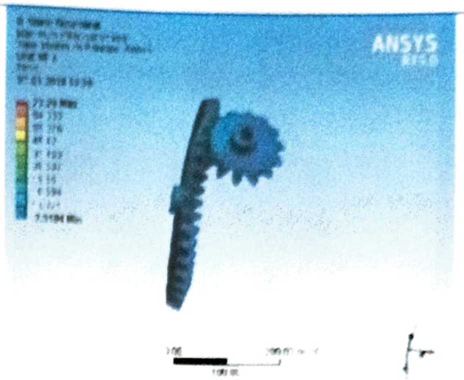


Figure 6.6 Max principal stress at 20^0 pitch angle

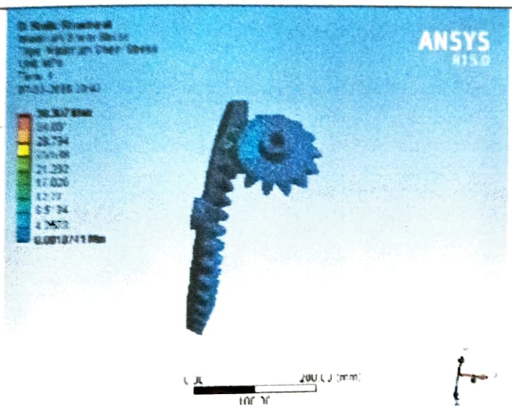


Figure 6.7 Max shear stress at 20^0 pitch angle

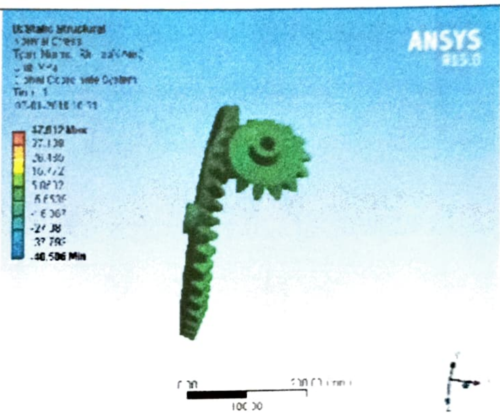


Figure 6.8 Normal stress at 20^0 pitch angle

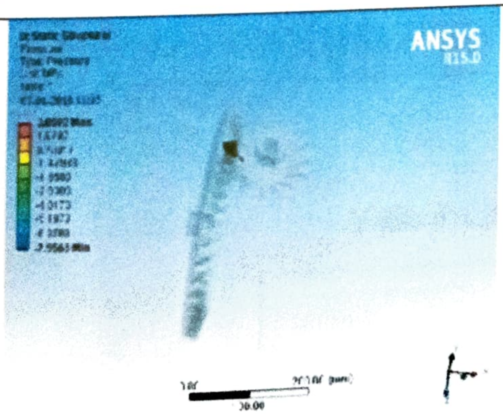


Figure 6.9 Contact Pressure at 20^0

Table 6.2 Contact Stresses at 200 Pitch angle

Stesssese	**Value in N/mm^2**
von-Mises	73.57
Maximum Principal Stress	73.29
Maximum Shear Stress	38.30
Normal Stress	47.91

6.1.1.3 Bending Stress at Pitch Angle 25⁰

Bending Stresses obtained at 25^0 pitch angle are listed in the Table 6.3

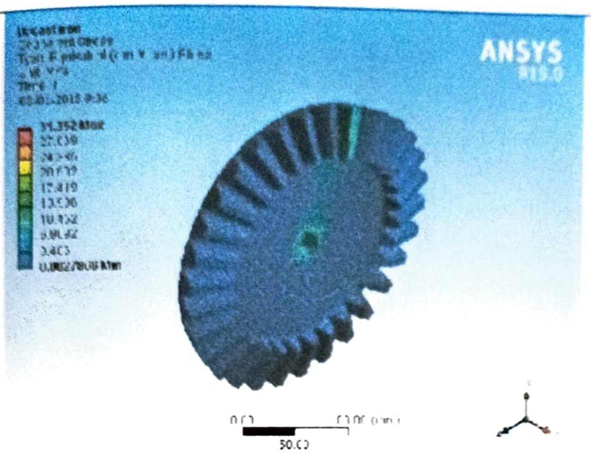


Figure 6.10 Von –Mises stress at 25^0

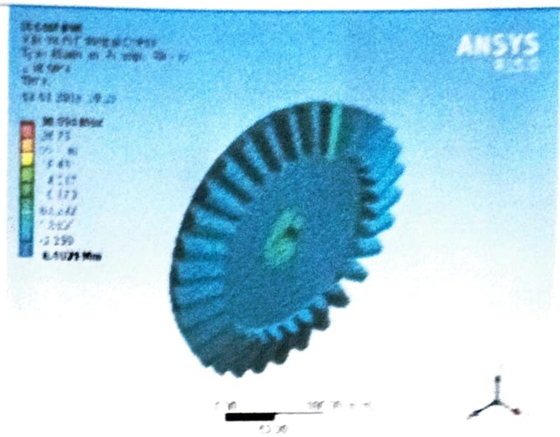


Figure 6.11 Max principal stress at 25^0

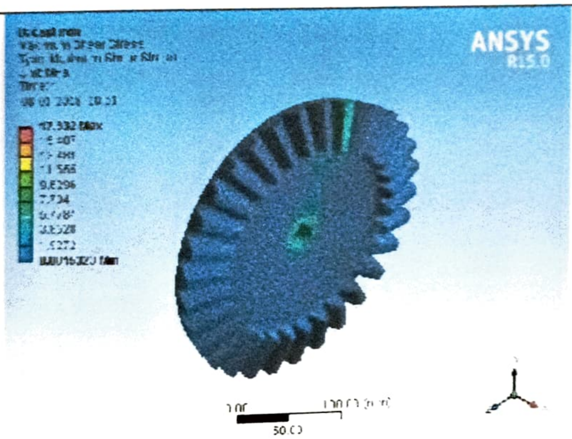


Figure 6.12 Max shear stress at 25^0

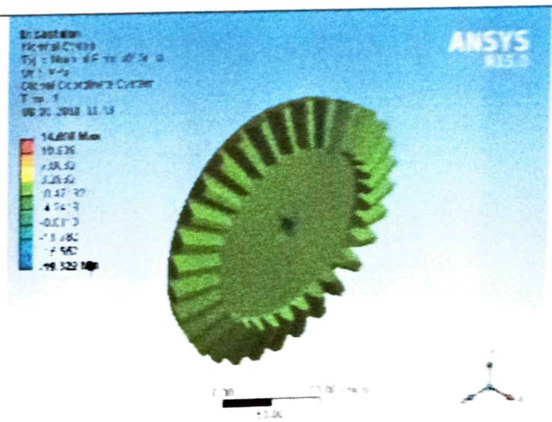


Figure 6.13 Normal stress at 25^0

Table 6.3 Bending Stresses at 25^0

Stresses	**Value in N/mm²**
Von mises stress	31.35
Max principal stress	30.59
Max shear stress	17.33
Normal stress	14.60

6.1.1.4 *Contact stress at pitch angle 25^0.*

Contact Stresses obtained at **25^0** pitch angle are listed in the Table 6.4

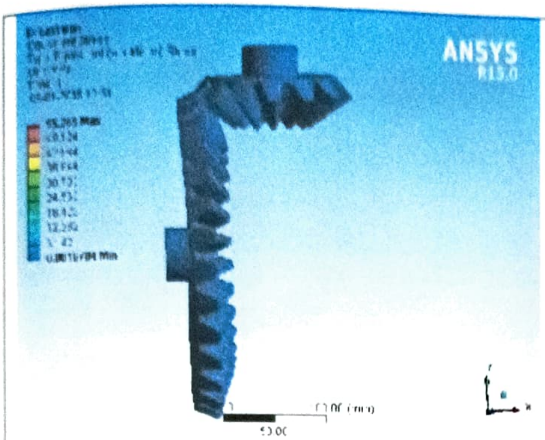


Figure 6.14 von –Mises stress at 25^0

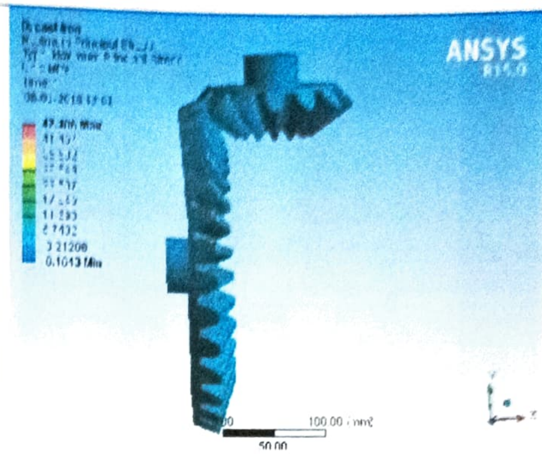


Figure 6.15Max principal stress at 25^0

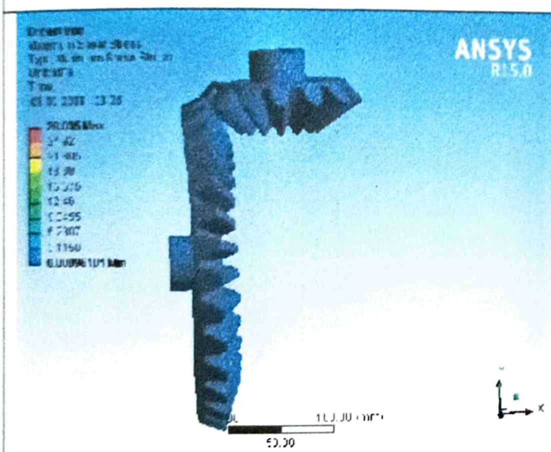


Figure 6.16 Max shear stress at 25^0

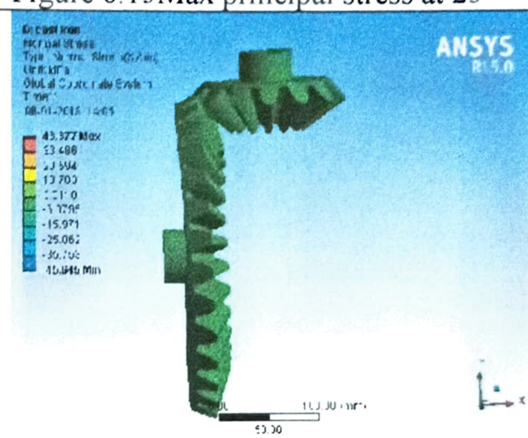


Figure 6.17 Normal stress at 25^0

Table 6.4 Contact Stresses at 25^0

Stresses	**Value in N/mm^2**
Von mises stress	55.26
Max principal stress	47.40
Max shear stress	28.03
Normal stress	43.37
Contact Pressure	20.07

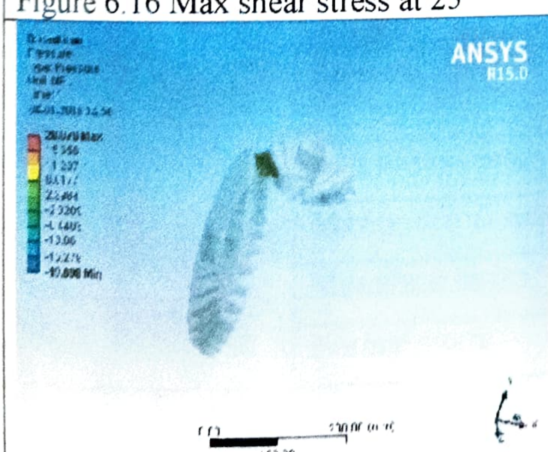


Figure 6.18 Contact Pressure at 25^0

6.1.1.5 Bending Stress at Pitch Angle 30⁰

Bending Stresses obtained at **30⁰** pitch angle are listed in the Table 6.5

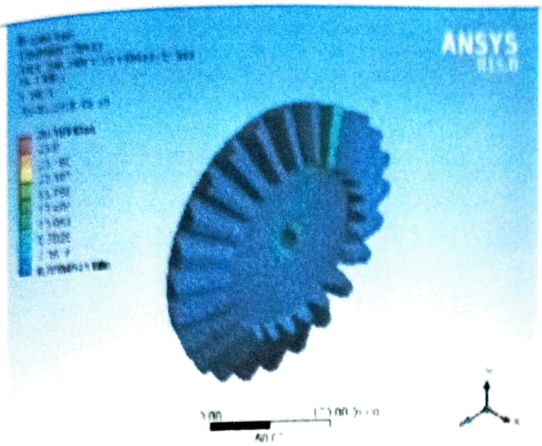


Figure 6.19 von Mises stress at 30⁰

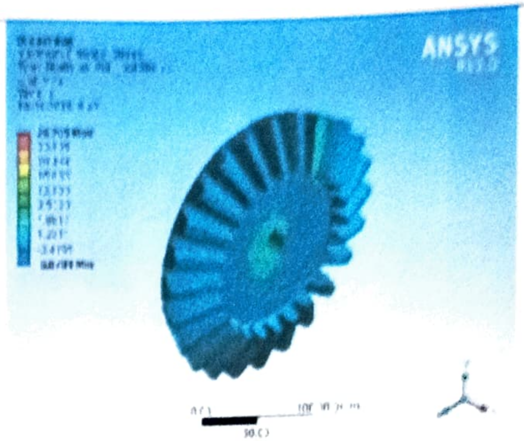


Figure 6.20 Max principal sress at 30⁰

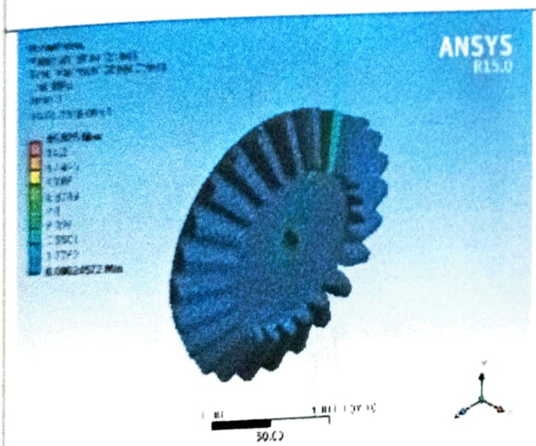


Figure 6.21 Maximum shear stress at 30⁰

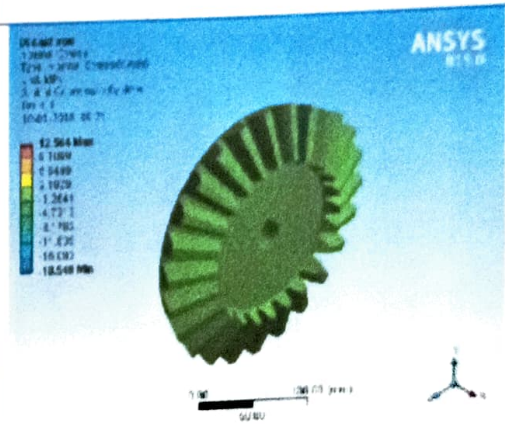


Figure 6.22 Normal stress at 30⁰

Table 6.5 Bending Stresses at 30⁰

Stresses	**Value in N/mm²**
Von mises stress	30.16
Max principal stress	26.78
Max shear stress	15.97
Normal stress	12.56

6.1.1.6 *Contact stress at pitch angle 30°*

Contact Stresses obtained at **30°** pitch angle are listed in the Table 6.6

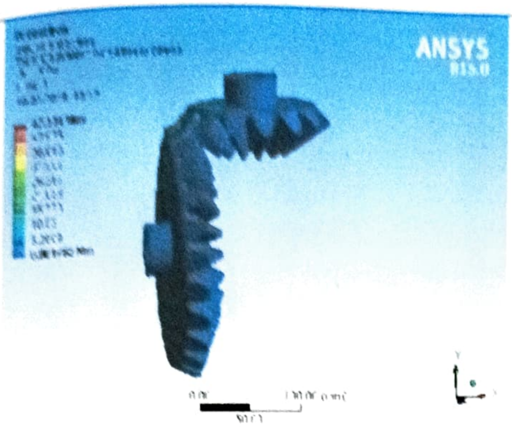


Figure 6.23 von Mises stress at 30°

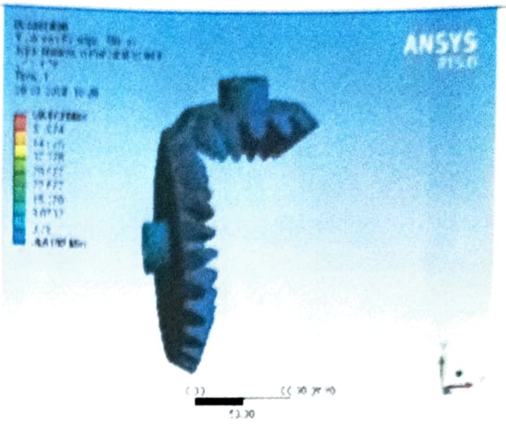


Figure 6.24 Max principal stress at 30°

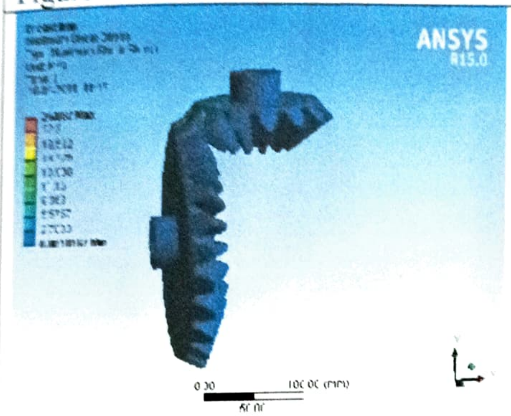


Figure 6.25 Maximum shear stress at 30°

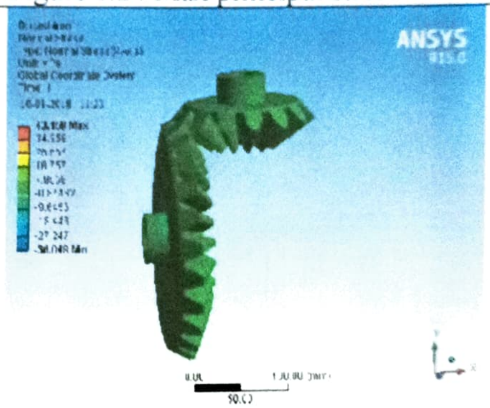


Figure 6.26 Normal stress at 30°

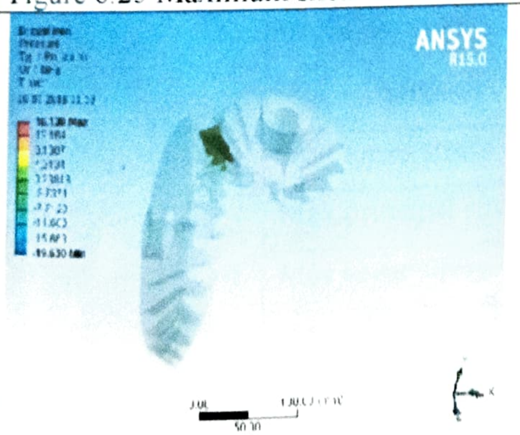


Figure 6.27 Contact force at 30°

Table 6.6 Contact Stresses at 30°

Stresses	**Value in N/mm²**
Von mises stress	47.33
Max principal stress	59.17
Max shear stress	25.28
Normal stress	43.15
Contact Pressure	16.13

6.1.1.7 Bending Stress at Pitch Angle 35^0.

Bending Stresses obtained at **35^0** pitch angle are listed in the Table 6.7

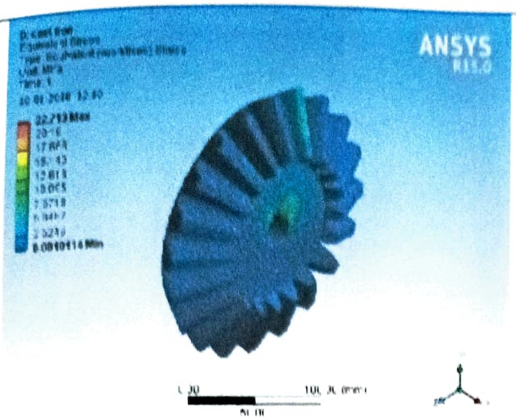


Figure 6.28 von –Mises stress at 35^0

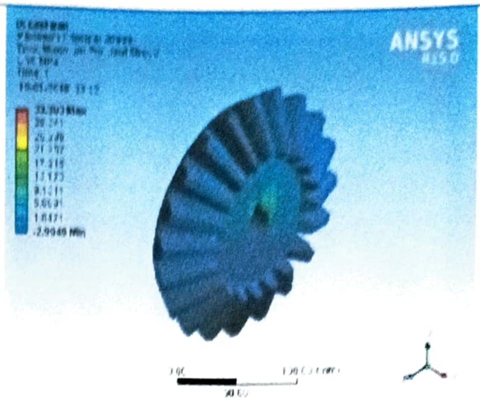


Figure 6.29 Max principal stress at 35^0

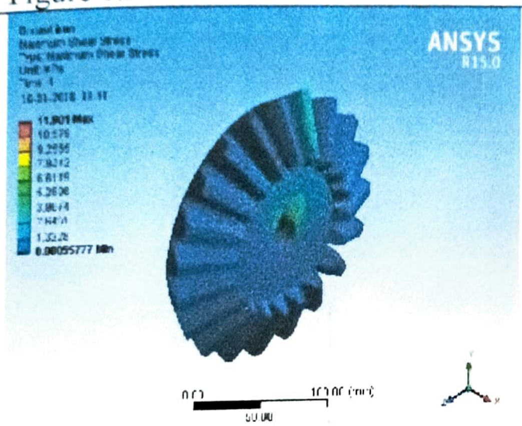


Figure 6.30 Max shear stress at 35^0

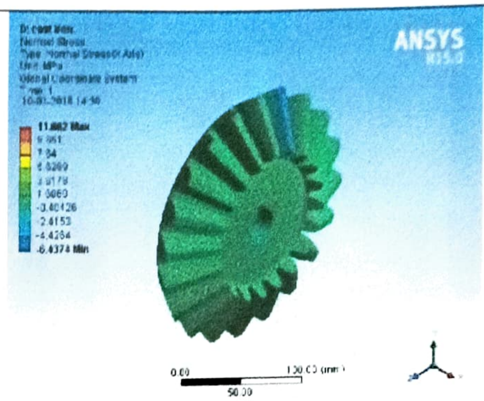


Figure 6.31 Normal stress at 35^0

Table 6.7 Bending Stresses at 35^0

Stresses	**obtained value in N/ mm^2**
Von mises stress	22.71
Max principal stress	33.38
Max shear stress	11.90
Normal stress	11.66

6.1.1.8 *Contact stress at pitch angle 35⁰.*

Contact Stresses obtained at **35⁰** pitch angle are listed in the Table 6.8.

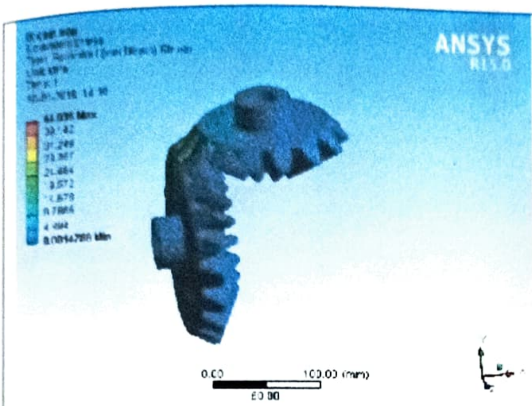


Figure 6.32 von –Mises stress at 35⁰

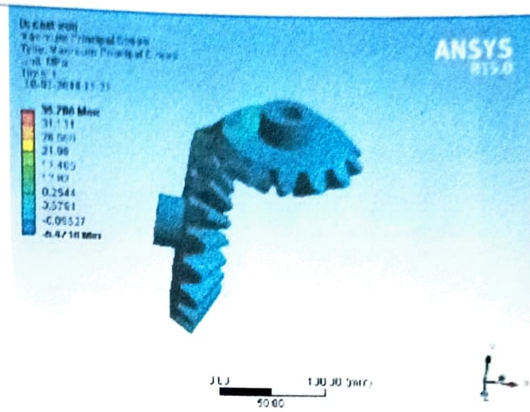


Figure 6.33 Max principal stress at 35⁰

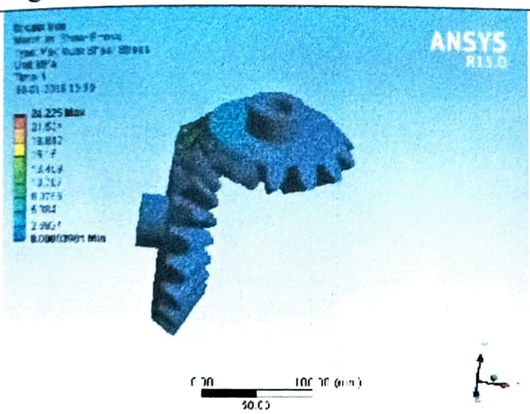


Figure 6.34 Max shear stress at 35⁰

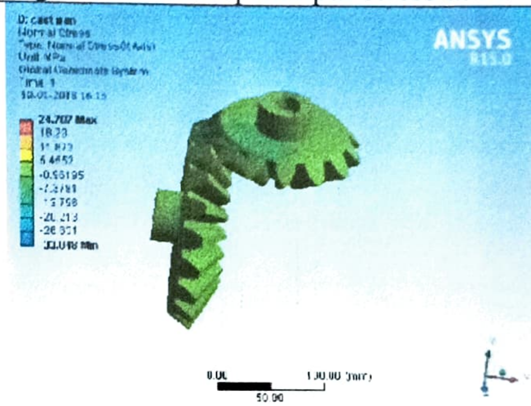


Figure 6.35 Normal stress at 35⁰

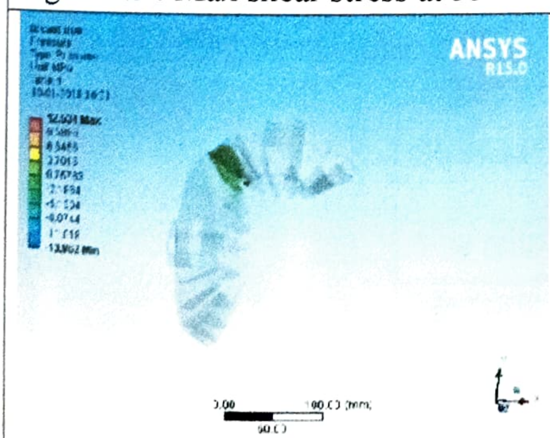


Figure 6.36 Contact Pressure at 35⁰

Table 6.8 Contact Stresses at 35⁰

Stresses	**Value in N/mm²**
Von mises stress	44.03
Max principal stress	35.70
Max shear stress	24.22
Normal stress	24.70
Contact Pressure	12.53

6.1.1.9 *Bending Stress at Pitch Angle 40°*

Bending Stresses obtained at **40°** pitch angle are listed in the Table 6.9

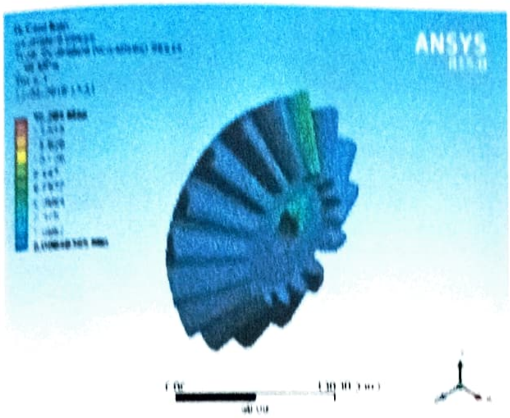


Figure 6.37 von Mises stress at 40°

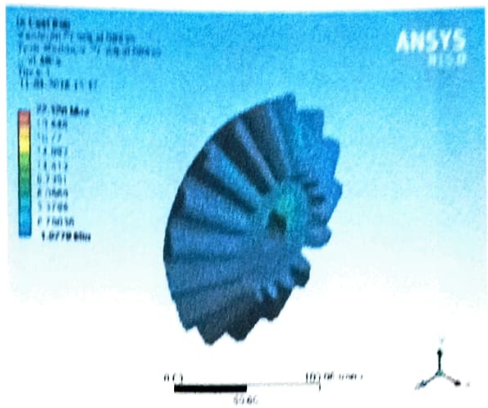


Figure 6.38 Max principal stress at 40°

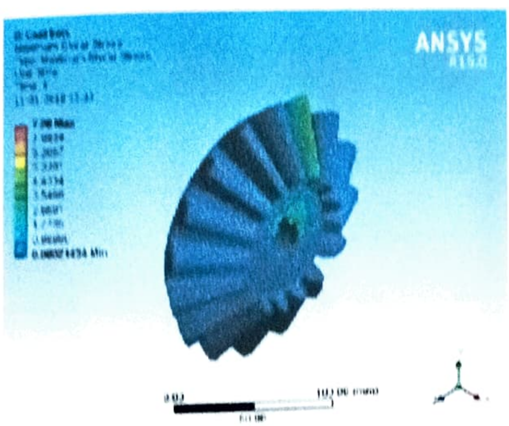


Figure 6.39 Max shear stress at 40°

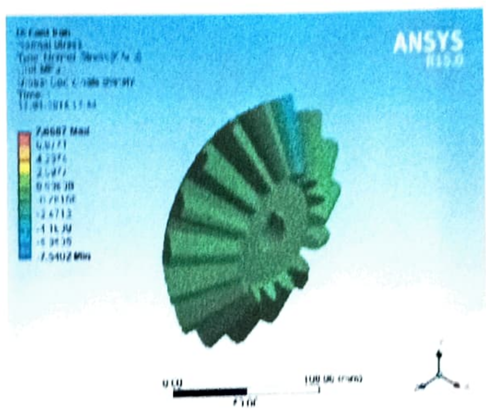


Figure 6.40 Normal stress at 40°

6.9 Bending Stresses at 40°

Stresses	**Value in N/mm²**
Von mises stress	15.20
Max principal stress	22.12
Max shear stress	7.98
Normal stress	7.66

6.1.1.10 Contact stresses at pitch angle 40⁰

Contact Stresses obtained at **40⁰** pitch angle are listed in the Table 6.10

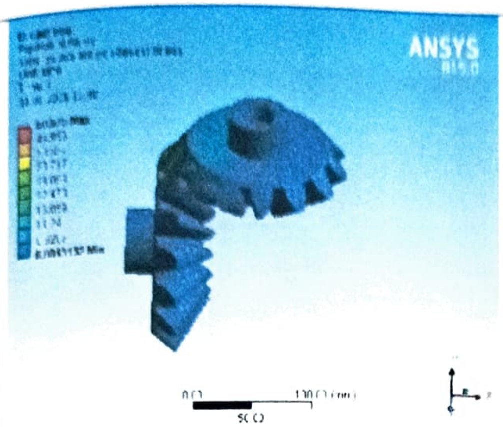


Figure 6.41 von Mises stress at 40^0

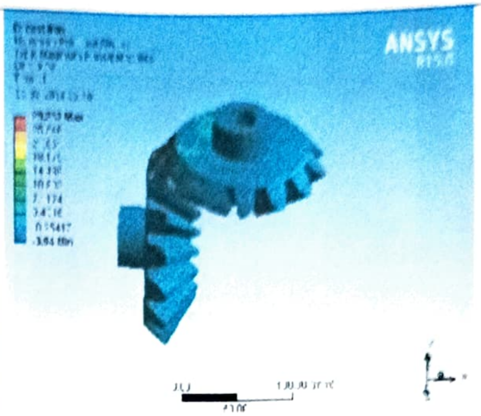


Figure 6.42 Max principal stress at 40^0

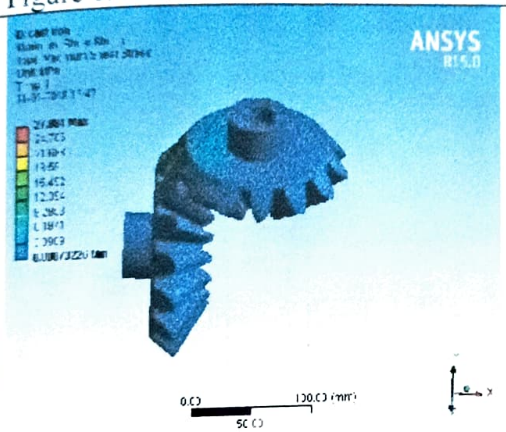


Figure 6.43 Max shear stress at 40^0

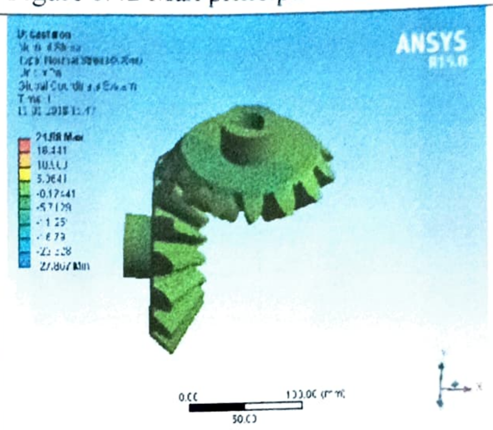


Figure 6.44 Normal stress at 40^0

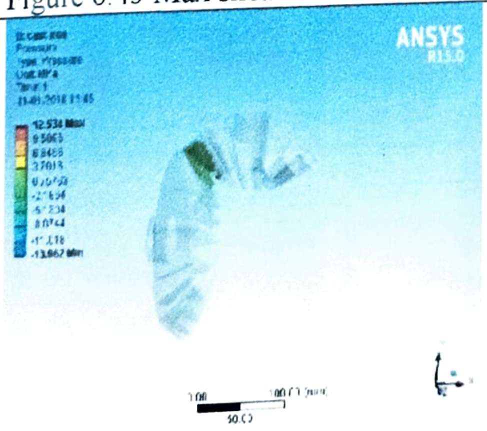


Figure 6.45 Contact Pressure at 40^0

Table 6.10 Contact Stresses at 40^0

Stressese	**Value in N/mm²**
Von mises stress	50.57
Max principal stress	29.23
Max shear stress	27.88
Normal stress	21.48
Contact Pressure	14.85

6.1.2 Bending And Contact Stresses Induced In Bevel Gear For Pb102

6.1.2.1 Bending Stress at pitch angle 20⁰

Bending Stresses obtained at **20⁰** pitch angle are listed in the Table 6.11.

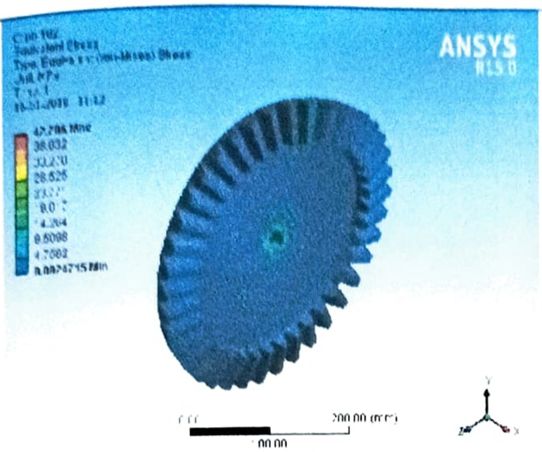


Figure 6.46 von - Mises stress at 20⁰

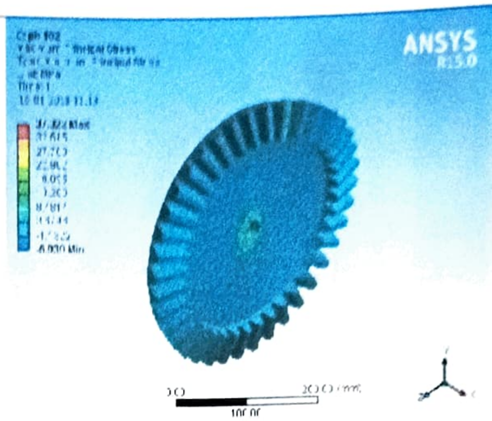


Figure 6.47 Max principal stress at 20⁰

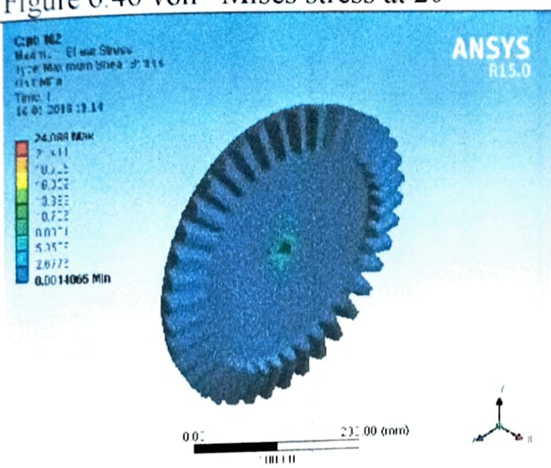


Figure 6.48 Max shear stress at 20⁰

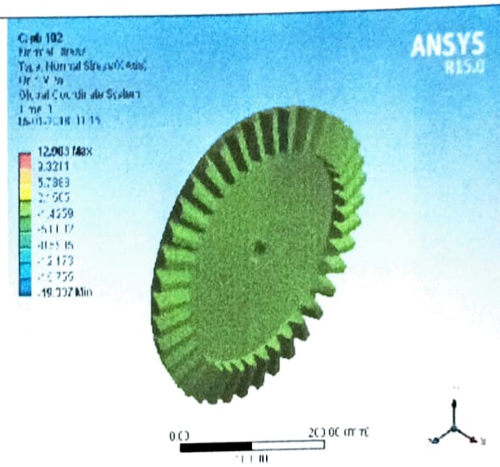


Figure 6.49 Normal stress at 20⁰

Table 6.11 Bending Stresses at 20⁰

Stresses	**Obtained value in N/ mm^2**
Von mises stress	39.70
Max principal stress	45.76
Max shear stress	21.27
Normal stress	19.24

6.1.2.2 Contact stress at pitch angle 20^0

Contact Stresses obtained at 20^0 pitch angle are listed in the Table 6.12

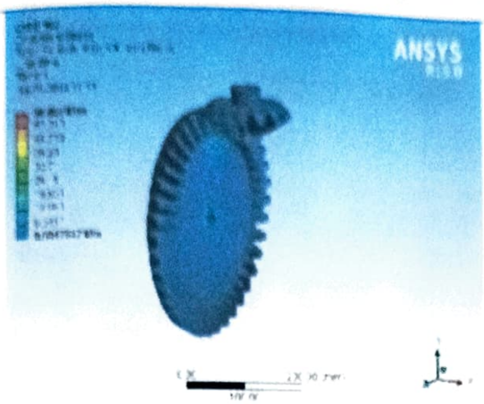


Figure 6.50 von –Mises stress at 20^0

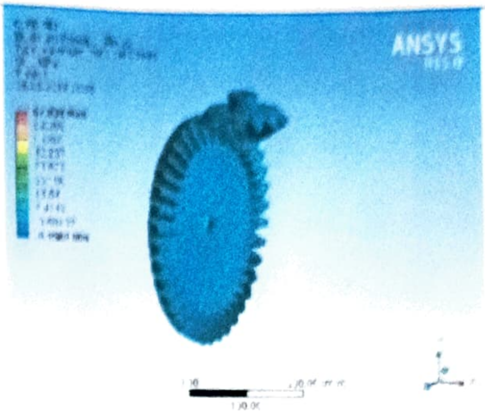


Figure 6.51 Max principal stress at 20^0

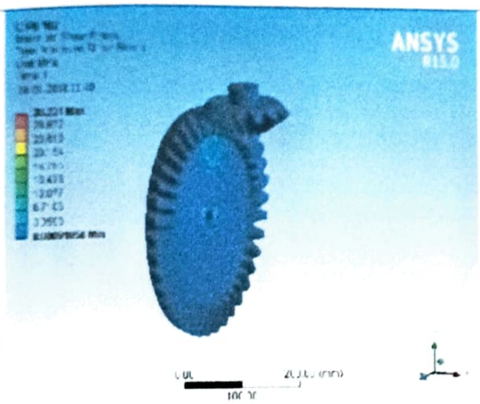


Figure 6.52 Max shear stress at 20^0

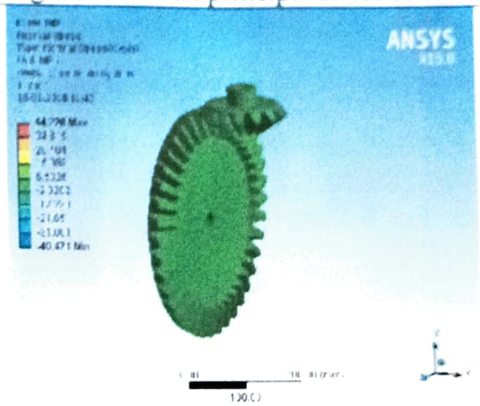


Figure 6.53 Normal stress at 20^0

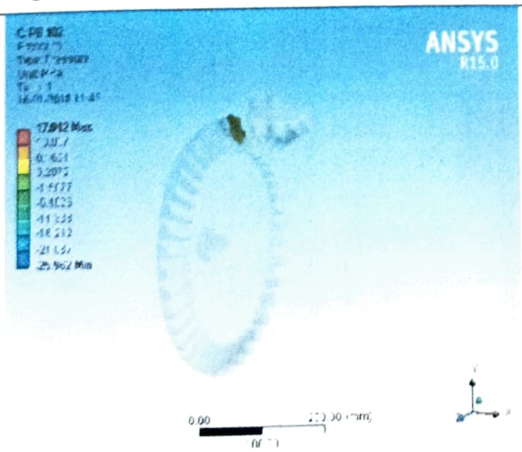


Figure 6.54 Contact force at 20^0

Table 6.12 Contact Stresses at 20^0

Stresses	**Obtained value in N/ mm^2**
von mises stress	58.85
Max principal stress	67.93
Max shear stress	30.23
Normal stress	44.22
Contact Pressure	17.91

6.1.2.3 *Bending Stress at pitch angle 25⁰*

Bending Stresses obtained at **25⁰** pitch angle are listed in the Table 6.13

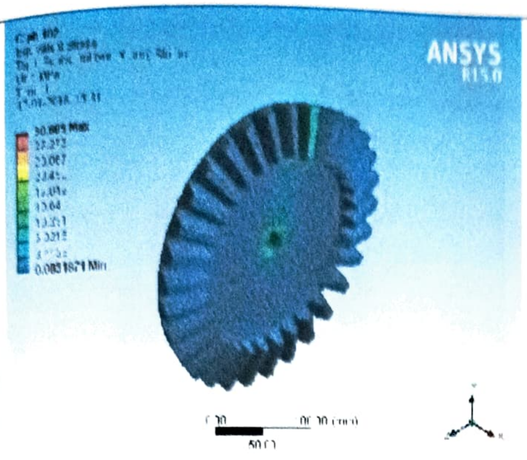


Figure 6.55 von –Mises stress at 25⁰

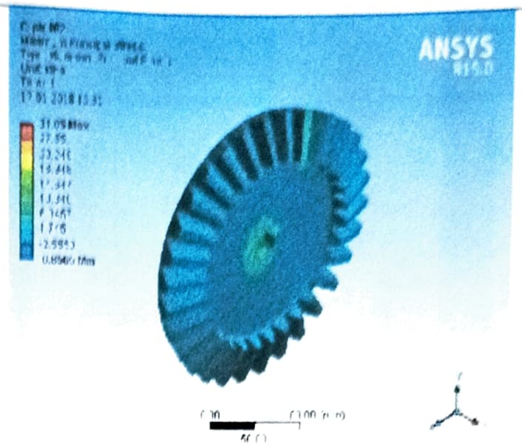


Figure 6.56 Max principal stress at 25⁰

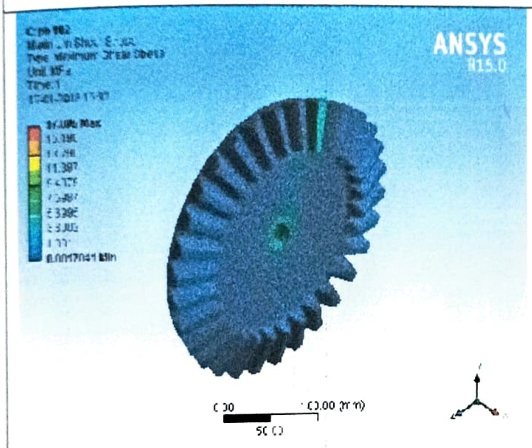


Figure 6.57 Max shear stress at 25⁰

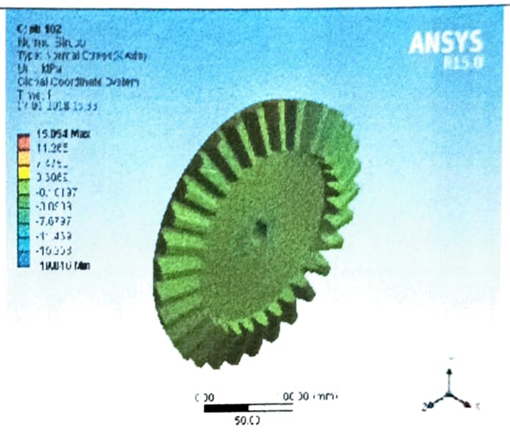


Figure 6.58 Normal stress at 25⁰

Table 6.13 Bending Stresses at 25⁰

Stresses	**Obtained value in N/ mm^2**
von mises stress	32.86
Max principal stress	31.84
Max shear stress	17.76
Normal stress	15.54

6.1.2.4 Contact stress at pitch angle 25⁰

Contact Stresses obtained at 25⁰ pitch angle are listed in the Table 6.14

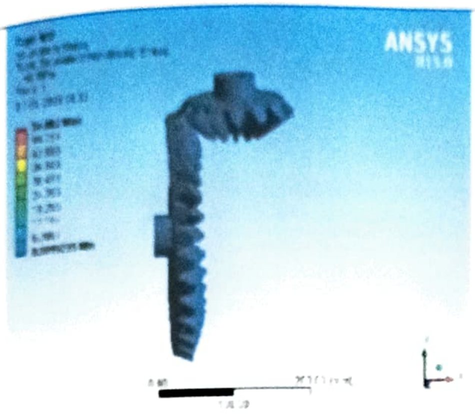


Figure 6.59 von –Mises stress at 25⁰

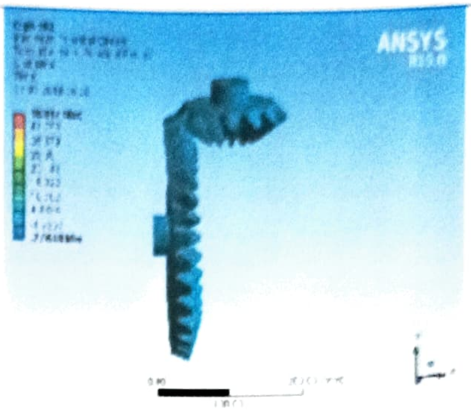


Figure 6.60 Max principal stress at 25⁰

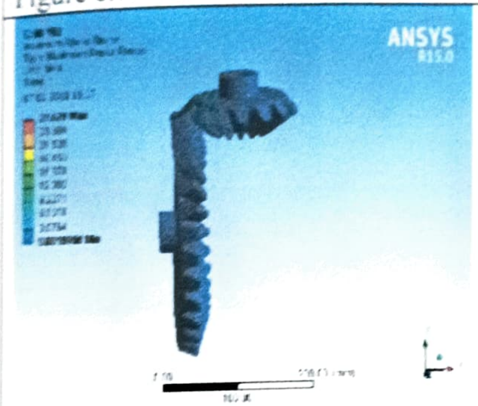


Figure 6.61 Max shear stress at 25⁰

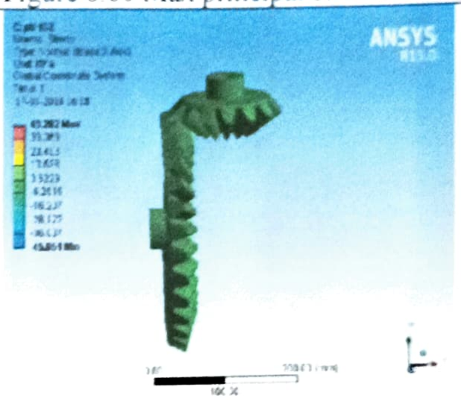


Figure 6.62 Normal stress at 25⁰

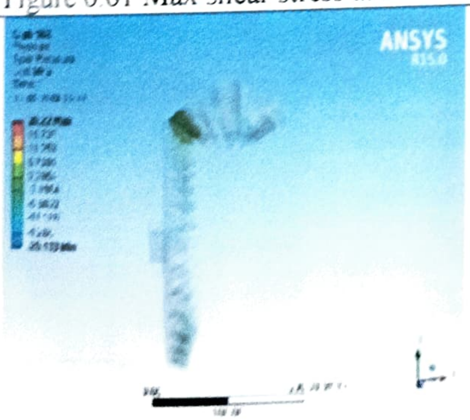


Figure 6.63 Contact force at 25⁰

Table 6.14 Contact Stresses at 25⁰

Stresses	**Value in N/mm^2**
von mises stress	54.88
Max principal stress	48.61
Max shear stress	27.67
Normal stress	43.28
Contact Pressure	20.22

6.1.2.5 Bending Stress at pitch angle 30°

Bending Stresses obtained at 30° pitch angle are listed in the Table 6.15

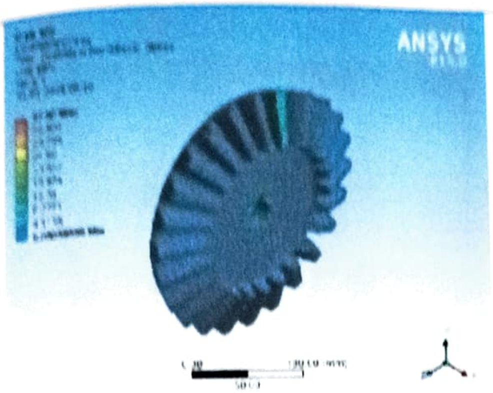


Figure 6.64 von –Mises stress at 30°

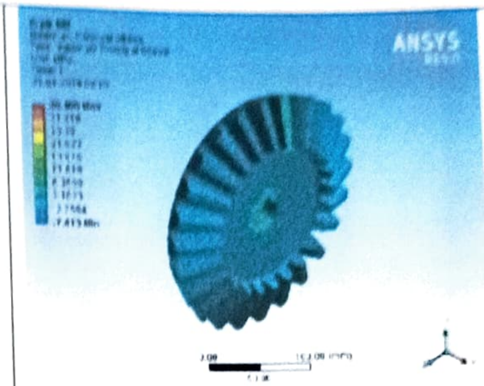


Figure 6.65 Max principal stress at 30°

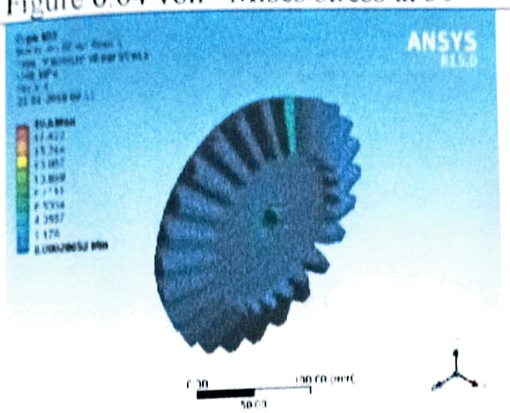


Figure 6.66 Max shear stress at 30°

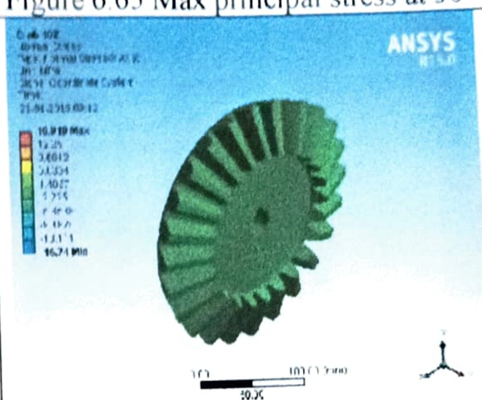


Figure 6.67 : Normal stress at 30°

Table 6.15 Bending Stresses at 30°

Stresses	obtained value in N/ mm^2
von mises stress	37.02
Max principal stress	36.10
Max shear stress	19.6
Normal stress	15.19

6.1.2.6 *Contact stress at pitch angle 30⁰*

Contact Stresses obtained at **30⁰** pitch angle are listed in the Table 6.16

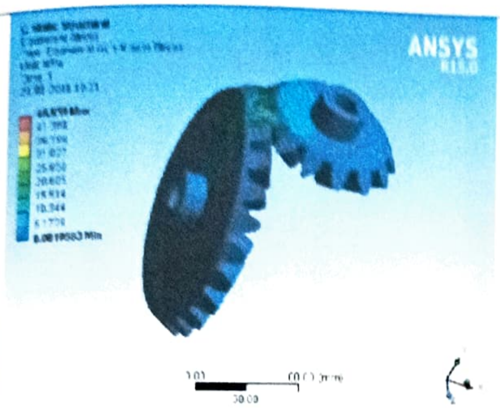


Figure 6.68 von –Mises stress at 30^0

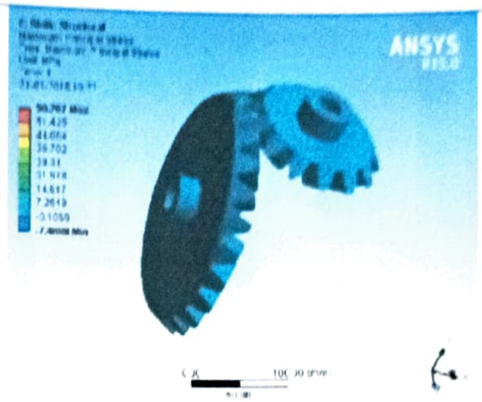


Figure 6.69 Max principal stress at 30^0

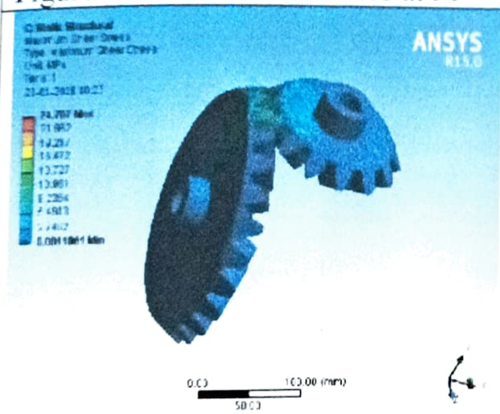


Figure 6.70 Max shear stress at 30^0

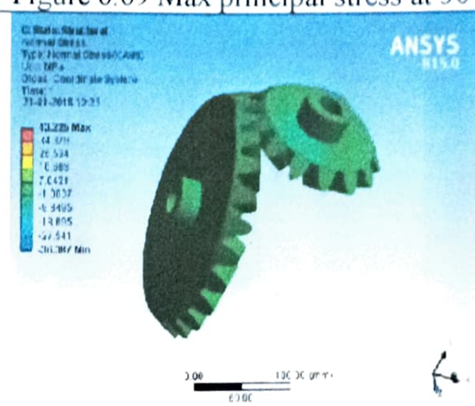


Figure 6.71 Normal stress at 30^0

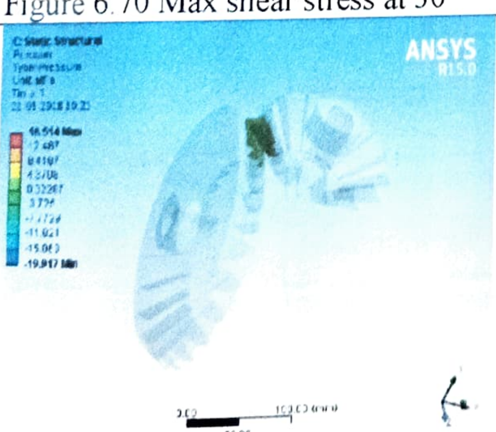


Figure 6.72 : Contact force at 30^0

Table 6.16 contact stress at pitch angle 30^0

Stresses	**obtained value in N/ mm²**
von mises stress	46.53
Max principal stress	58.78
Max shear stress	24.70
Normal stress	43.22
Contact Pressure	16.51

6.1.2.7 Bending Stress at pitch angle 35⁰

Bending Stresses obtained at **35⁰** pitch angle are listed in the Table 6.17.

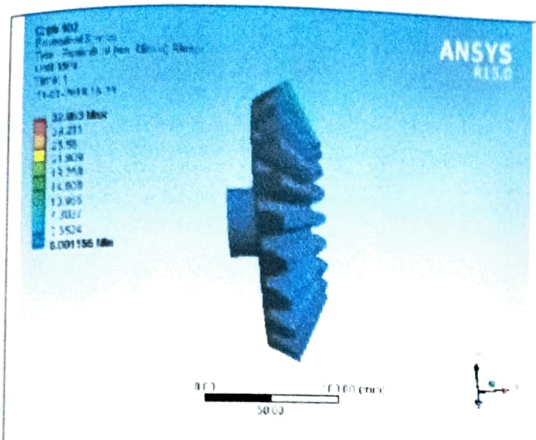


Figure 6.73: von –Mises stress at 35^0

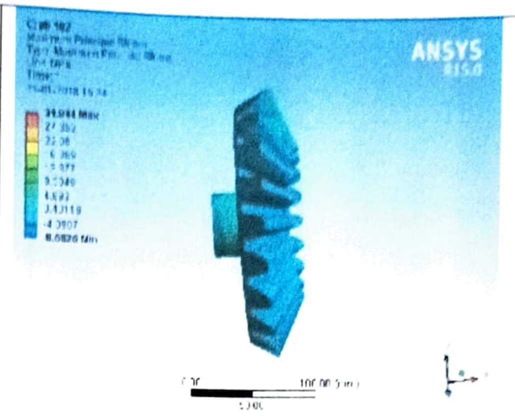


Figure 6.74 Max principal stress at 35^0

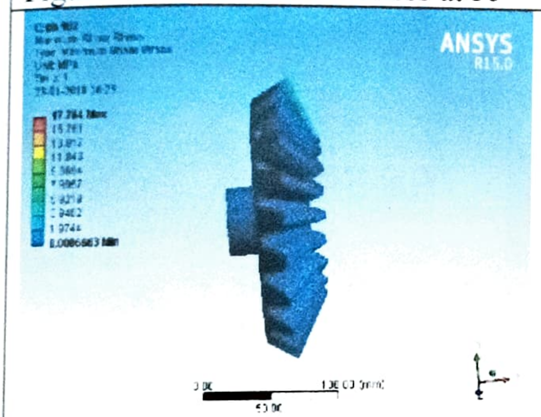


Figure 6.75 Max shear stress at 35^0

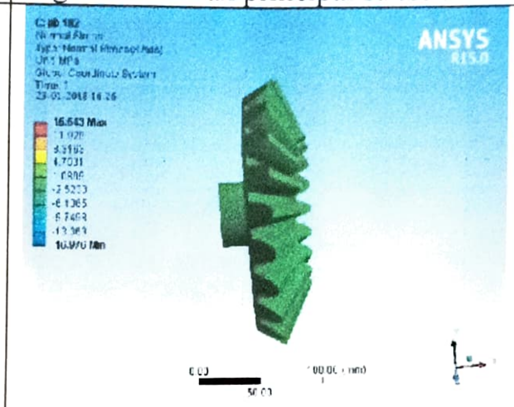


Figure 6.76 Normal stress at 35^0

Table 6.17 Bending Stress at pitch angle 35^0

Stressese	**Value in N/mm^2**
von mises stress	32.86
Max principal stress	31.84
Max shear stress	17.76
Normal stress	15.54

6.1.2.8 *Contact stress at pitch angle 35⁰*

Contact Stresses obtained at **35⁰** pitch angle are listed in the Table 6.18

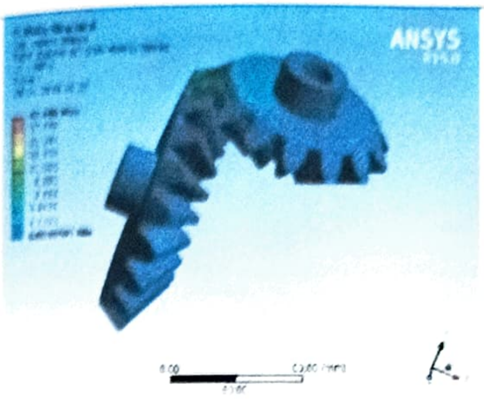


Figure 6.77 von –Mises stress at 35⁰

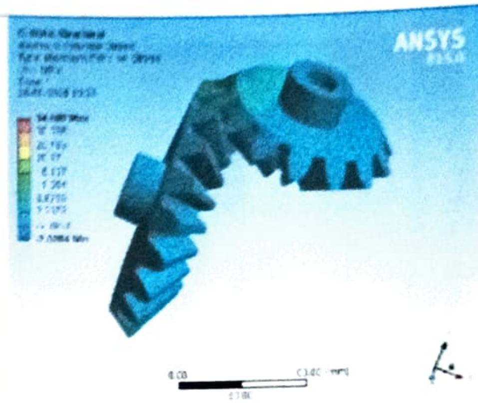


Figure 6.78 Max principal stress at 35⁰

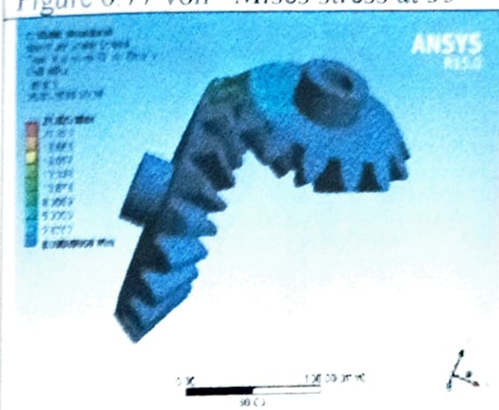


Figure 6.79 Max shear stress at 35⁰

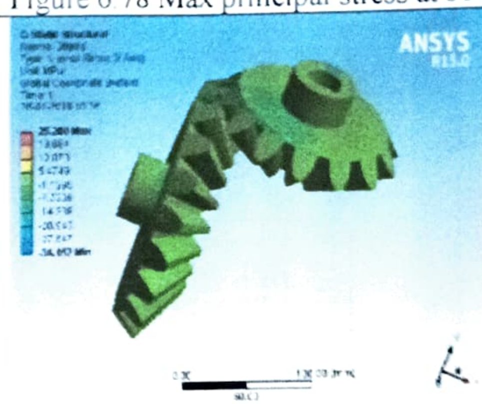


Figure 6.80 Normal stress at 35⁰

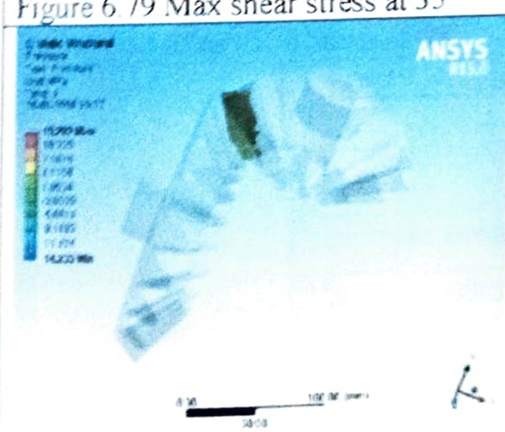


Figure 6.81 Contact Pressure at 35⁰

Table 6.18 Contact stress at pitch angle 35⁰

Stresses	**Value in N/mm²**
von mises stress	46.53
Max principal stress	58.78
Max shear stress	24.70
Normal stress	43.22
Contact Pressure	16.51

6.1.2.9 *Bending Stress at pitch angle 40⁰*

Bending Stresses obtained at **40^0** pitch angle are listed in the Table 6.19.

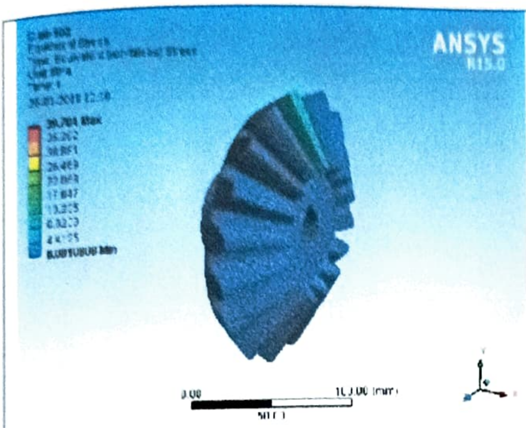


Figure 6.82 von –Mises stress at 40^0

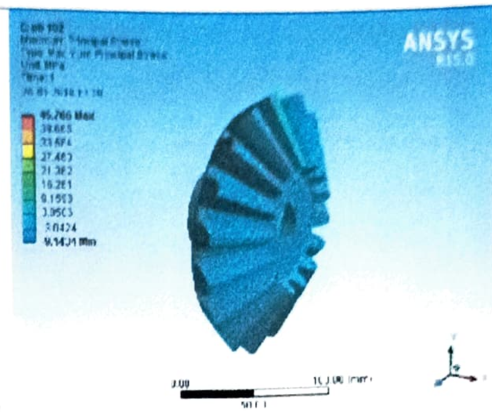


Figure 6.83 Max principal stress at 40^0

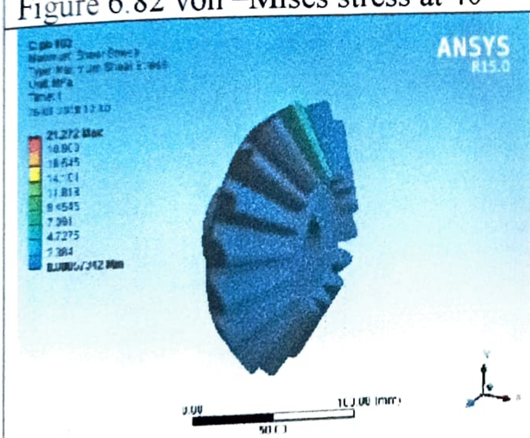


Figure 6.84 Max shear stress at 40^0

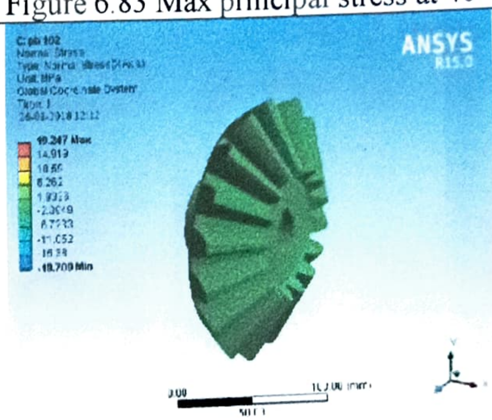


Figure 6.85 Normal stress at 40^0

Table 6.19 Bending Stress at pitch angle 40^0

Stresses	**Value in N/mm^2**
von mises stress	39.70
Max principal stress	45.76
Max shear stress	21.27
Normal stress	19.24

6.1.2.10 Contact stress at pitch angle 40⁰

Contact Stresses obtained at **40⁰** pitch angle are listed in the Table 6.20

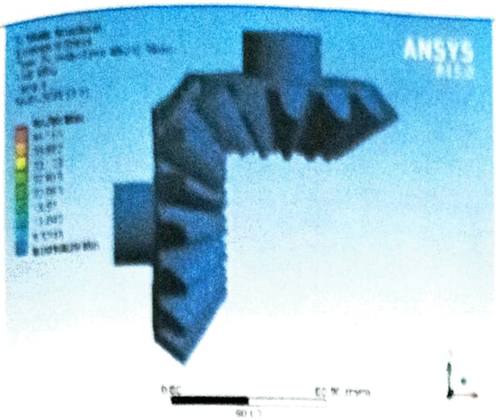


Figure 6.86 von Mises stress at 40⁰

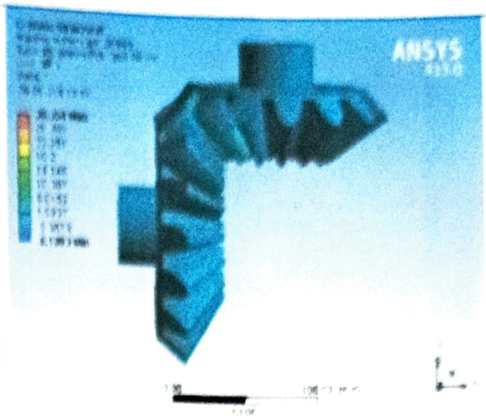


Figure 6.87 Max principal stress at 40⁰

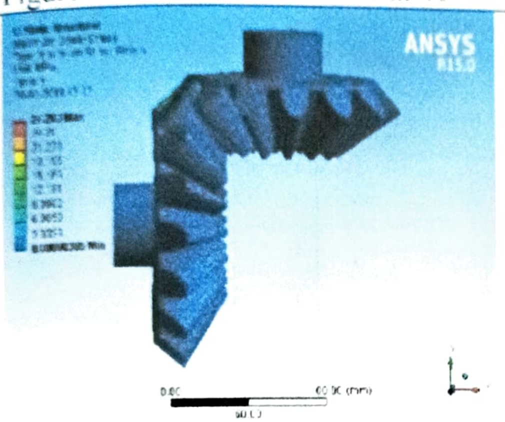


Figure 6.88 Max shear stress at 40⁰

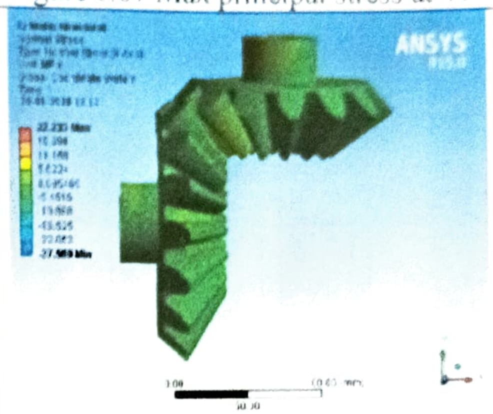


Figure 6.89 Normal stress at 40⁰

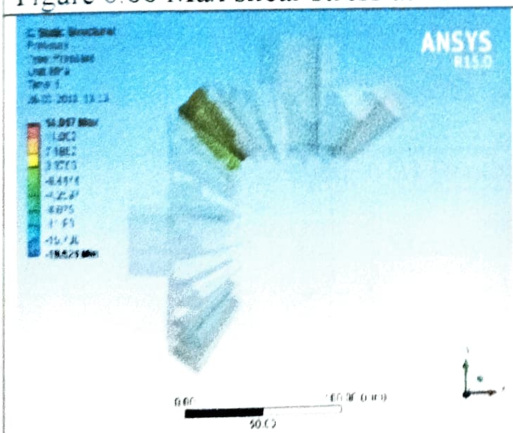


Figure 6.90 Contact Pressure at 40⁰

Table 6.20 Contact stress at pitch angle 40⁰

Stresses	**Value in N/mm²**
von mises stress	49.70
Max principal stress	30.35
Max shear stress	27.29
Normal stress	22.23
Contact Pressure	14.81

6.1.3 Bending and Contact Stresses Induced In Bevel Gear By Taking Cr-Ni Steel As Material

6.1.3.1 *Bending Stress at pitch angle 20°*

Bending Stresses obtained at **20°** pitch angle are listed in the Table 6.21

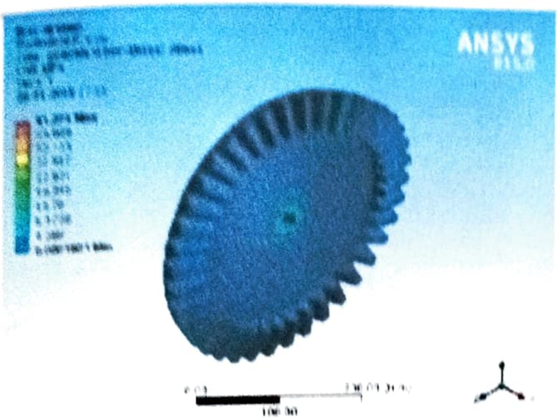


Figure 6.91 von –Mises stress at pitch angle 20°

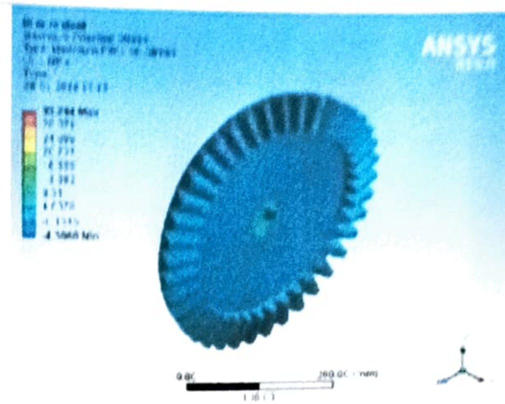


Figure 6.92 Max principal stress at pitch angle 20°

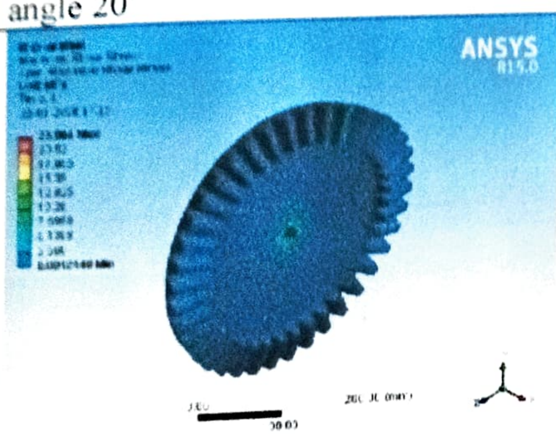


Figure 6.93 Max shear stress at pitch angle 20°

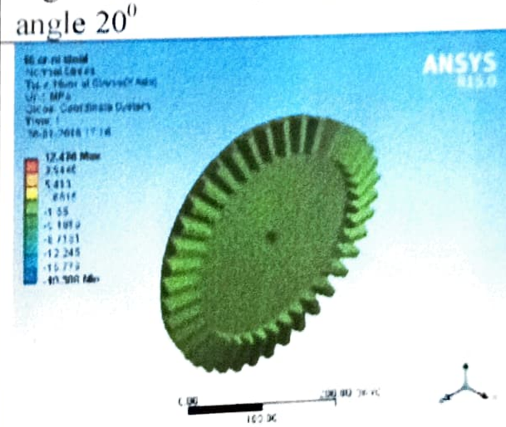


Figure 6.94 Normal stress at pitch angle 20°

Table 6.21 Bending Stress at pitch angle 20°

Stresses	**Value in N/mm²**
von mises stress	41.27
Max principal stress	33.24
Max shear stress	23.08
Normal stress	12.47

6.1.3.2 Contact stress at pitch angle 20⁰

Contact Stresses obtained at **20⁰** pitch angle are listed in the Table 6.22

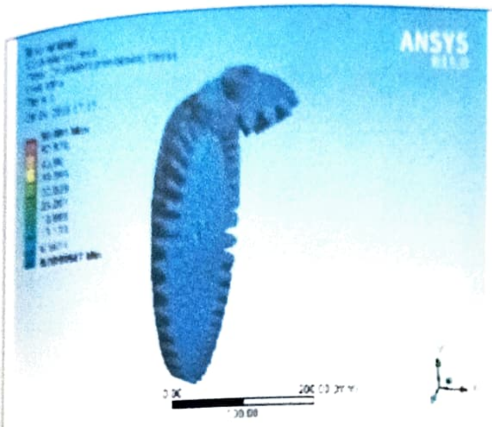


Figure 6.95 von Mises stress at pitch angle 20^0

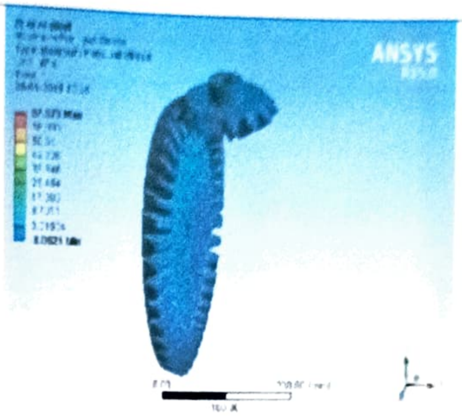


Figure 6.96 Max principal stress at pitch angle 20^0

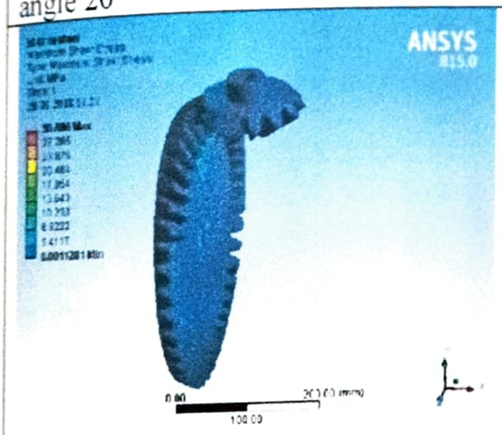


Figure 6.97 Max shear stress at pitch angle 20^0

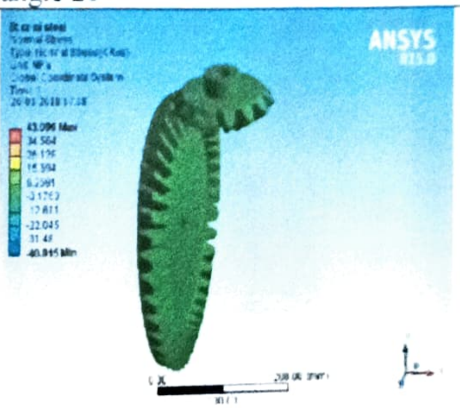


Figure 6.98 Normal stress at pitch angle 20^0

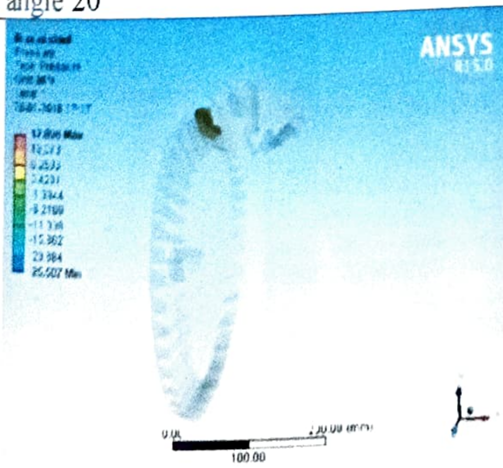


Figure 6.99 Contact Pressure at pitch angle 20^0

Table 6.22 Contact stress at pitch angle 20^0

Stresses	**Value in N/mm^2**
von mises stress	59.09
Max principal stress	67.37
Max shear stress	30.69
Normal stress	43.49
Contact Pressure	17.89

6.1.3.3 *Bending Stress at pitch angle 25⁰*

Bending Stresses obtained at **25^0** pitch angle are listed in the Table 6.23

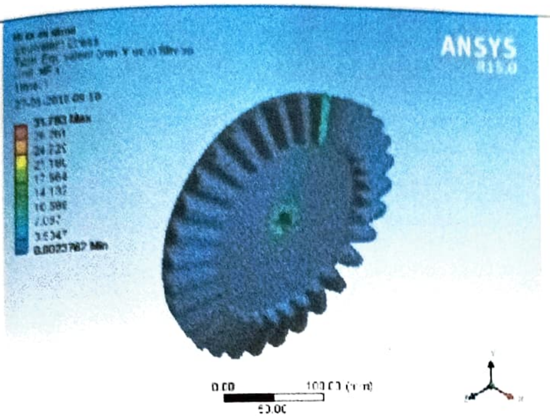


Figure 6.100 von –Mises stress at pitch angle 25^0

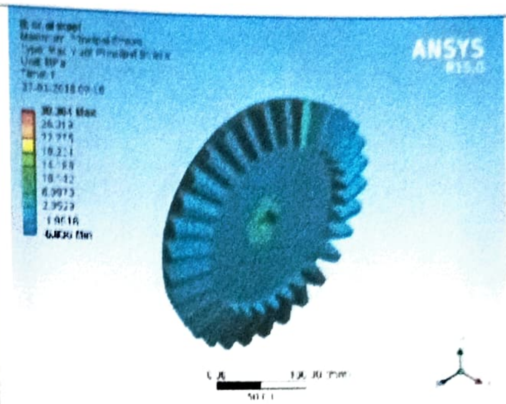


Figure 6.101 Max principal stress at pitch angle 25^0

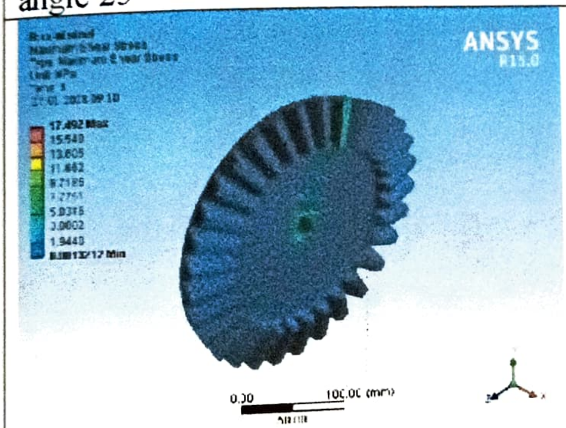


Figure 6.102 Max shear stress at pitch angle 25^0

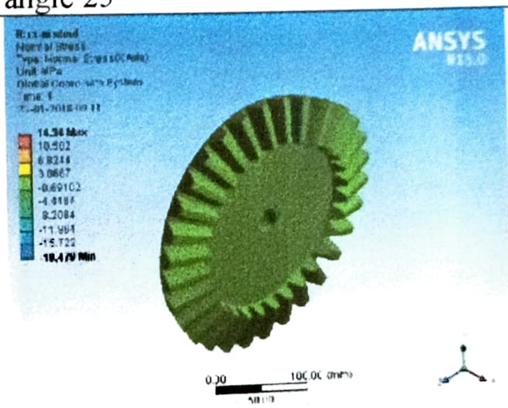


Figure 6.103 Normal stress at pitch angle 25^0

Table 6.23 Bending Stress at pitch angle 25^0

Stresses	**Value in N/mm^2**
von mises stress	31.79
Max principal stress	30.36
Max shear stress	17.49
Normal stress	14.34

6.1.3.4 *Contact stress at pitch angle 25⁰*

Contact Stresses obtained at **25^0** pitch angle are listed in the Table 6.24

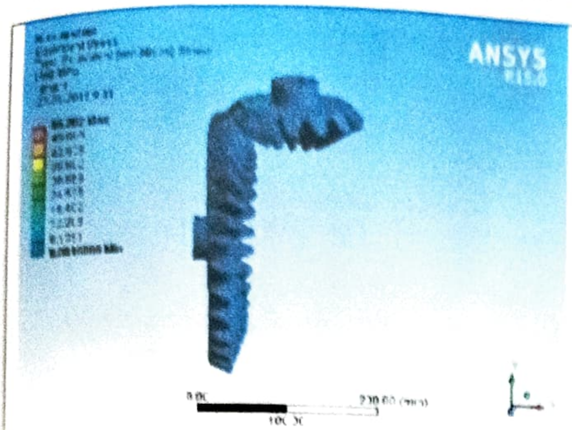


Figure 6.104 von –Mises stress at pitch angle 25^0

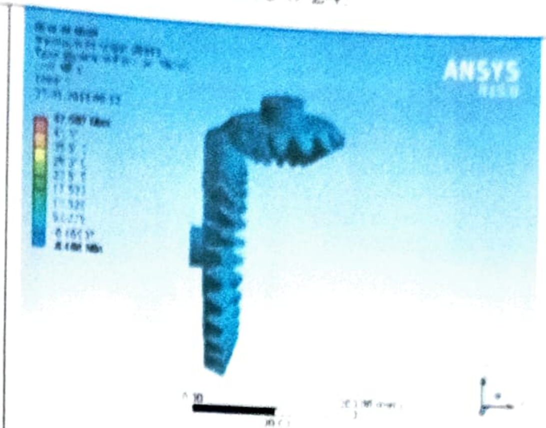


Figure 6.105 Max principal stress at pitch angle 25^0

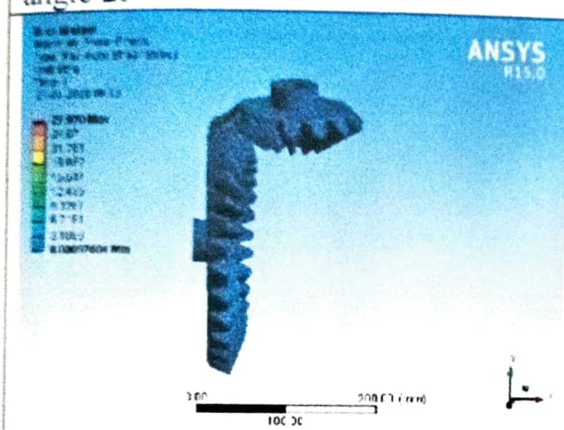


Figure 6.106 Max shear stress at pitch angle 25^0

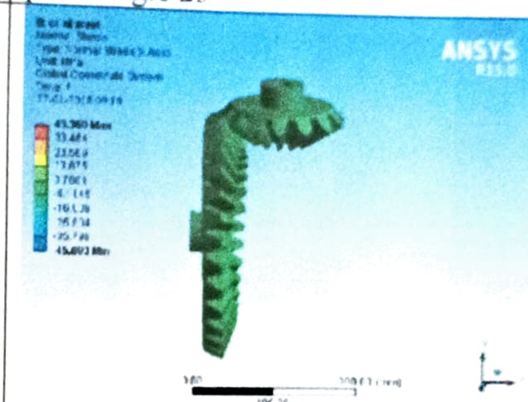


Figure 6.107 Normal stress at pitch angle 25^0

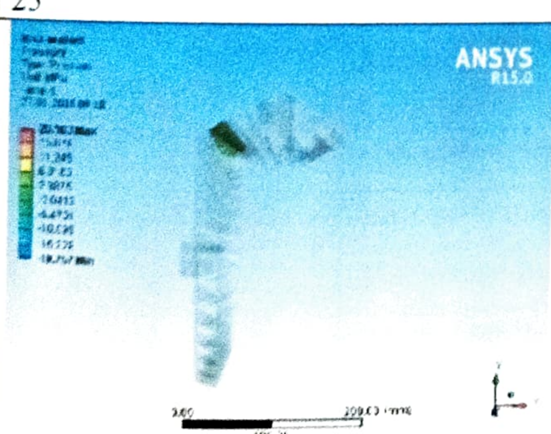


Figure 6.108 Contact Pressure at pitch angle 25^0

Table 6.24 Contact stress at pitch angle 25^0

Stresses	**Value in N/mm²**
von mises stress	55.20
Max principal stress	47.50
Max shear stress	27.97
Normal stress	43.35
Contact Pressure	20.10

6.1.3.5 Bending Stress at pitch angle 30°

Bending Stresses obtained at **30°** pitch angle are listed in the Table 6.25

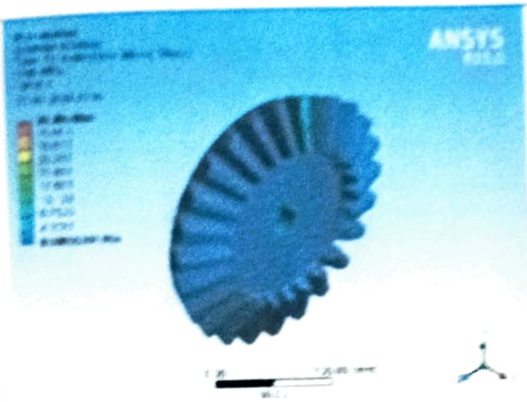


Figure 6.109 von –Mises stress at 30°

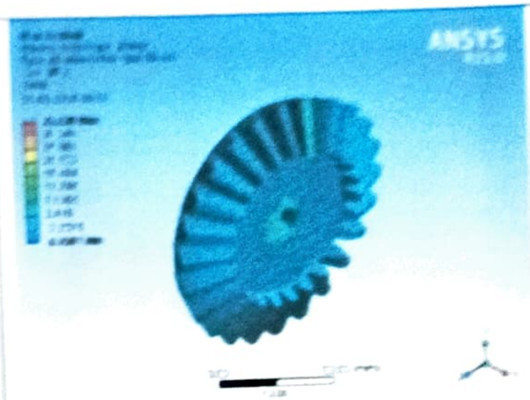
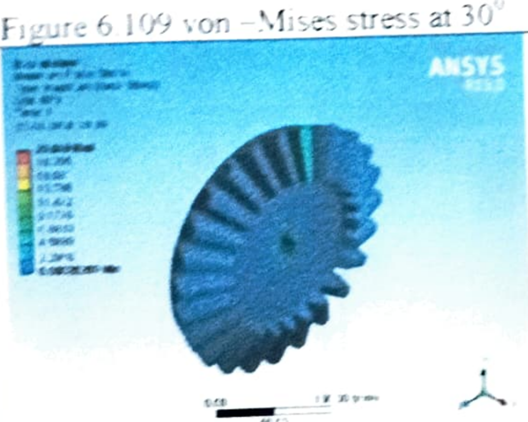


Figure 6.110 Max principal stress at 30°



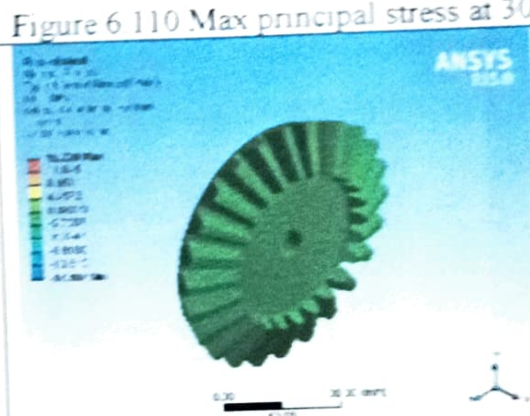


Table 6.25 Bending Stress at pitch angle 30°

Stresses	**Value in N/mm^2**
von mises stress	39.38
Max principal stress	35.23
Max shear stress	20.64
Normal stress	15.23

6.1.3.6 Contact stress at pitch angle 30⁰

Contact Stresses obtained at **30^0** pitch angle are listed in the Table 6.26

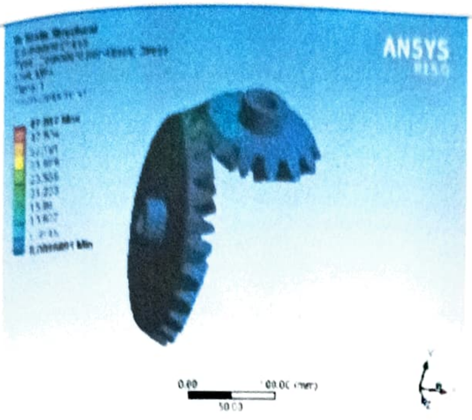


Figure 6.111 von –Mises stress at pitch angle 30^0

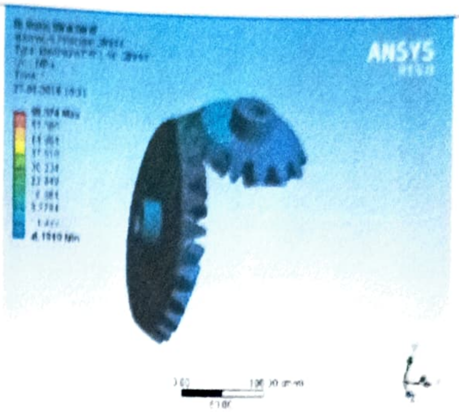


Figure 6.112 Max principal stress at pitch angle 30^0

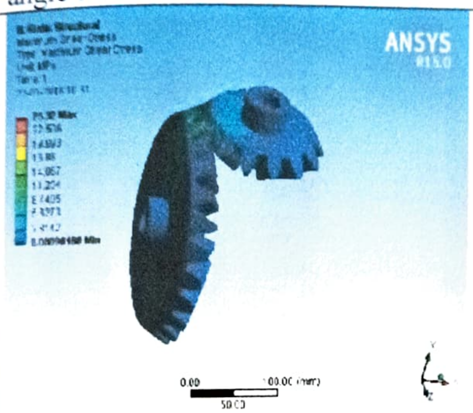


Figure 6.113 Max shear stress at pitch angle 30^0

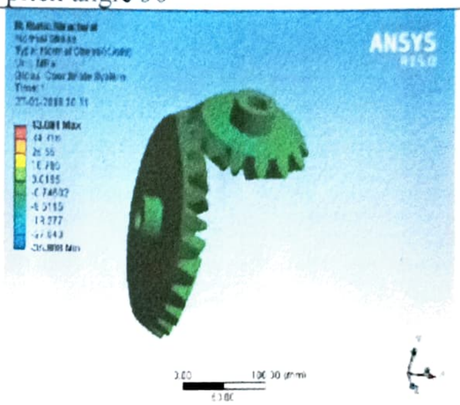


Figure 6.114 Normal stress at pitch angle 30^0

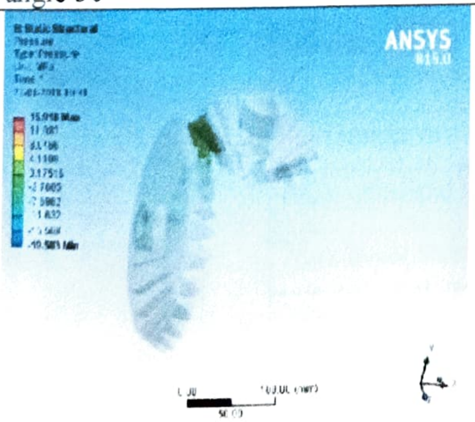


Figure 6.115 Contact Pressure at pitch angle 30^0

Table 6.26 Contact stress at pitch angle 30^0

Stresses	**Value in N/mm^2**
von mises stress	47.81
Max principal stress	59.37
Max shear stress	25.32
Normal stress	43.08
Contact Pressure	15.91

6.1.3.7 *Bending Stress at pitch angle 35⁰*

Bending Stresses obtained at **35⁰** pitch angle are listed in the Table 6.27

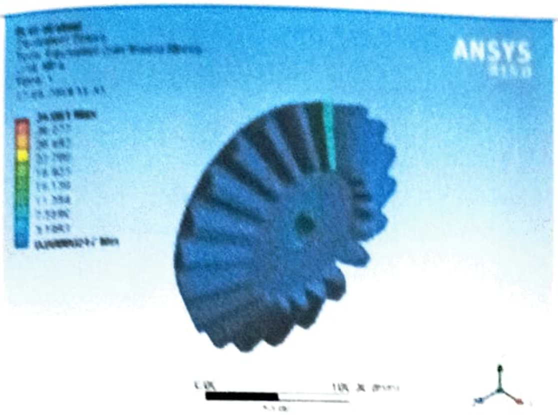


Figure 6.116 von –Mises stress at 35⁰

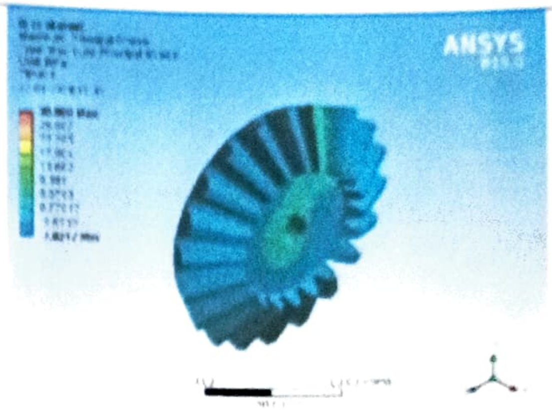


Figure 6.117 Max principal stress at 35⁰

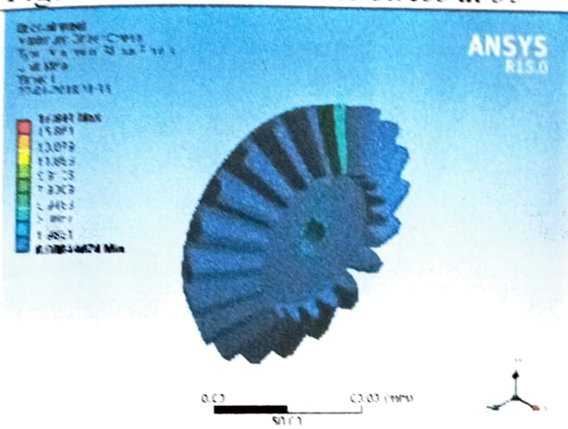


Figure 6.118 Max shear stress at 35⁰

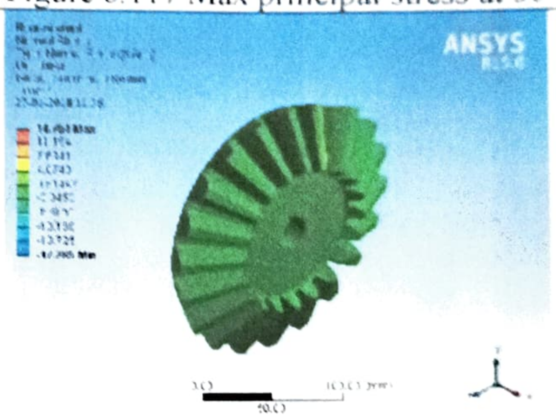


Figure 6.119 Normal stress at 35⁰

Table 6.27 Bending Stress at pitch angle 35⁰

Stresses	**Value in N/mm²**
von mises stress	34.06
Max principal stress	30.88
Max shear stress	17.84
Normal stress	14.75

6.1.3.8 *Contact stress at pitch angle 35⁰*

Contact Stresses obtained at **35⁰** pitch angle are listed in the Table 6.28

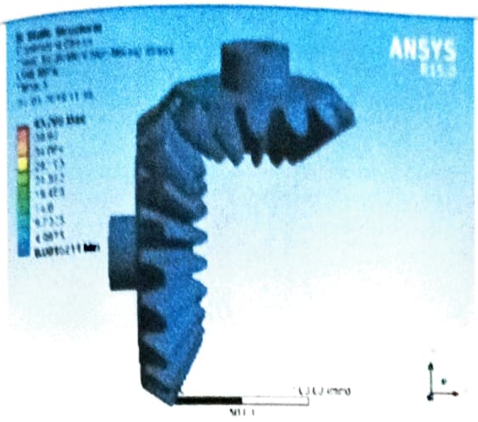


Figure 6.120 von –Mises stress at 35⁰

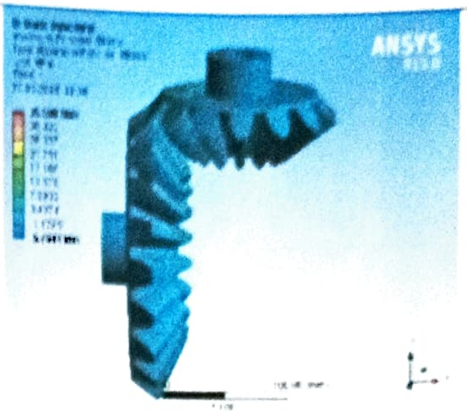


Figure 6.121 Max principal stress at 35⁰

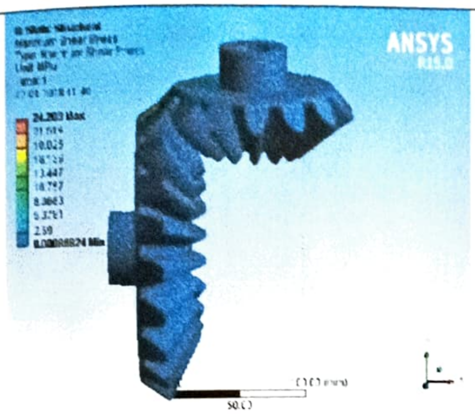


Figure 6.122 Max shear stress at 35⁰

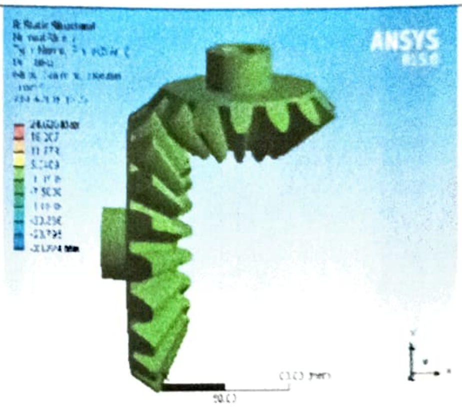


Figure 6.123 Normal stress at 35⁰

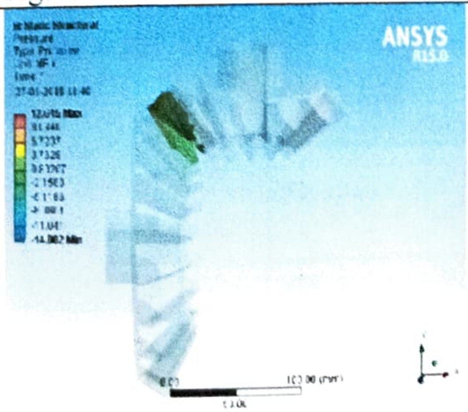


Figure 6.124 Contact Pressure at 35⁰

Table 6.28 Contact stress at pitch angle 35⁰

Stresses	**Value in N/mm²**
von mises stress	43.79
Max principal stress	35.50
Max shear stress	24.20
Normal stress	24.63
Contact Pressure	12.64

6.1.3.9 *Bending Stress at pitch angle 40^0*

Bending Stresses obtained at **40^0** pitch angle are listed in the Table 6.29

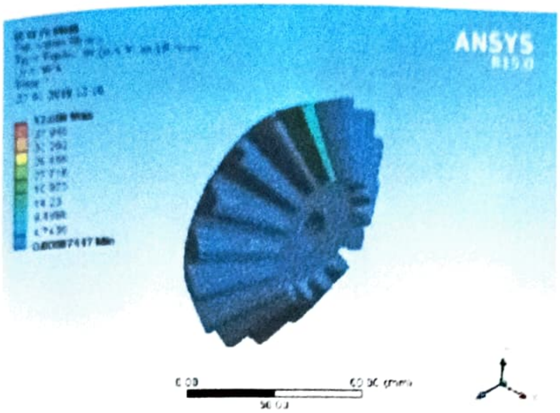


Figure 6.125 von –Mises stress at pitch angle 40^0

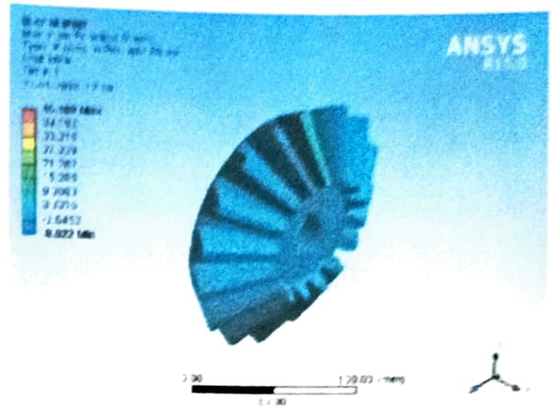


Figure 6.126 Max principal stress at pitch angle 40^0

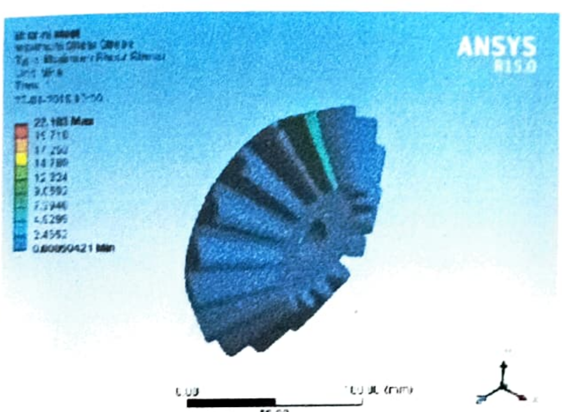


Figure 6.127 Max shear stress at pitch angle 40^0

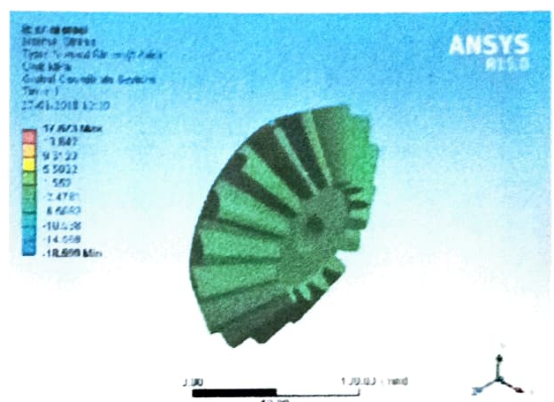


Figure 6.128 Normal stress at pitch angle 40^0

Table 6.29 Bending Stress at pitch angle 40^0

Stresses	**Value in N/mm^2**
von mises stress	42.68
Max principal stress	45.16
Max shear stress	22.18
Normal stress	17.67

6.1.3.10 Contact stress at pitch angle 40⁰

Contact Stresses obtained at **40⁰** pitch angle are listed in the Table 6.30.

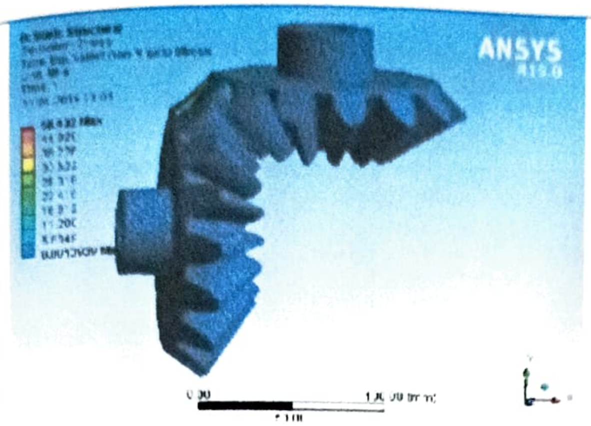


Figure 6.129 von –Mises stress at pitch angle 40^0

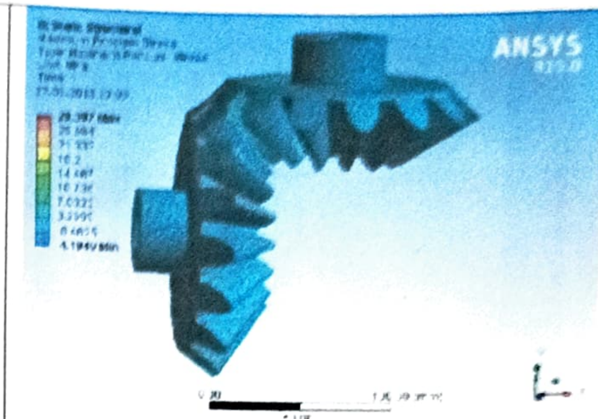


Figure 6.130 Max principal stress at pitch angle 40^0

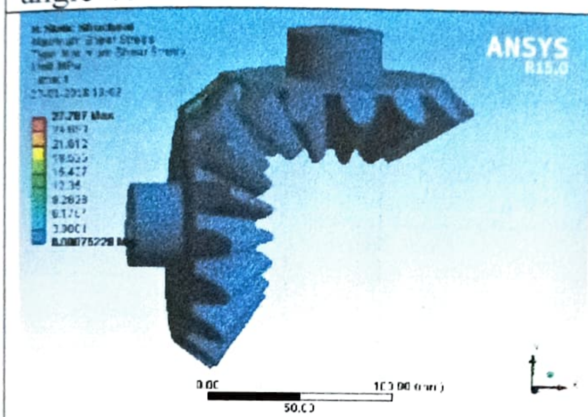


Figure 6.131 Max shear stress at pitch angle 40^0

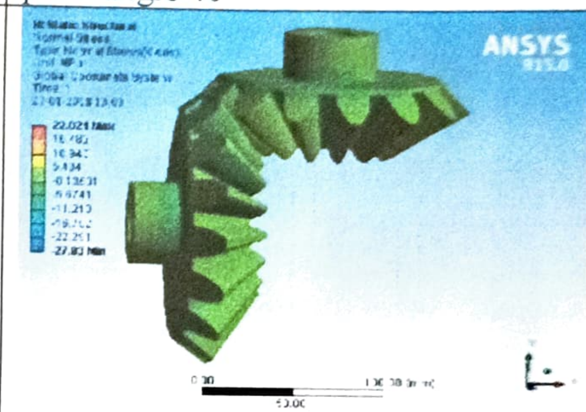


Figure 6.132 Normal stress at pitch angle 40^0

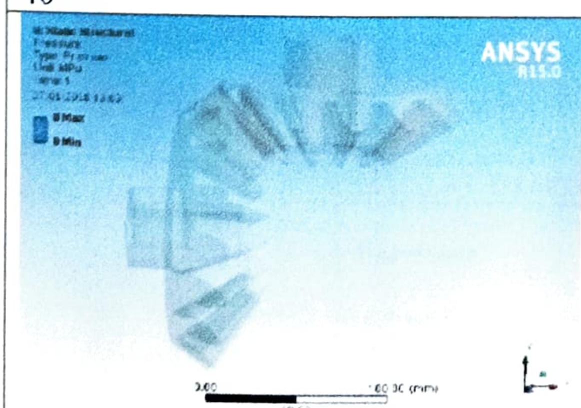


Figure 6.133 Contact Pressure at pitch angle 40^0

Table 6.30 Contact stress at pitch angle 40^0

Stresses	**Value in N/mm^2**
von mises stress	50.43
Max principal stress	29.39
Max shear stress	27.78
Normal stress	22.02
Contact Pressure	14.81

6.1.4 Bending and Contact Stresses Induced In Bevel Gear By Taking Structural Steel As Material

6.1.4.1 *Bending Stress at pitch angle 20^0*

Bending Stresses obtained at **20^0** pitch angle are listed in the Table 6.31.

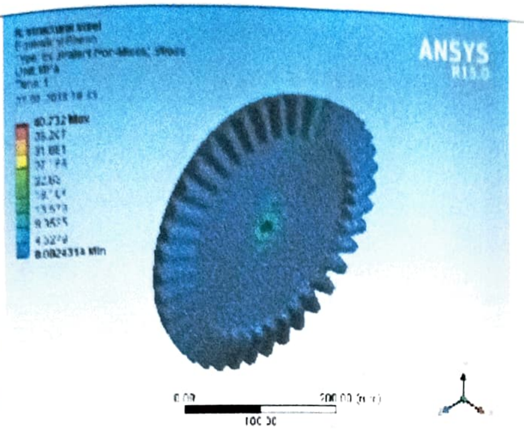


Figure 6.134 von –Mises stress at pitch angle 20^0

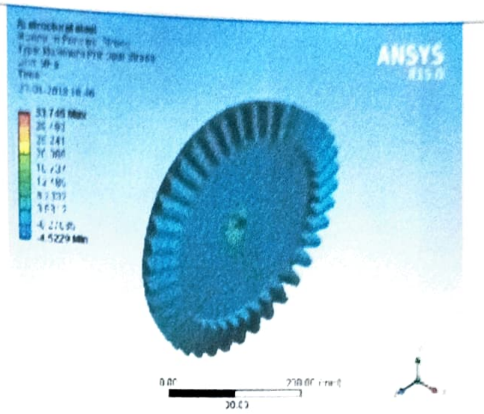


Figure 6.135 Max principal stress at pitch angle 20^0

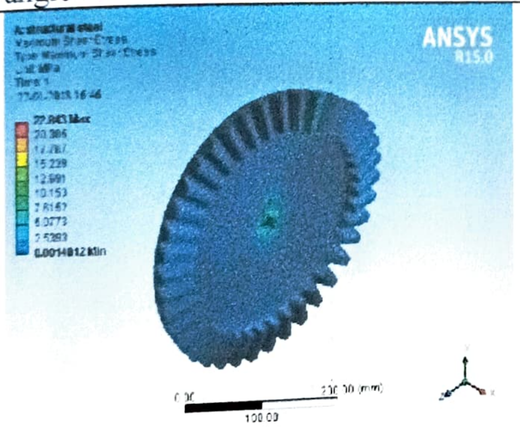


Figure 6.136 Max shear stress at pitch angle 20^0

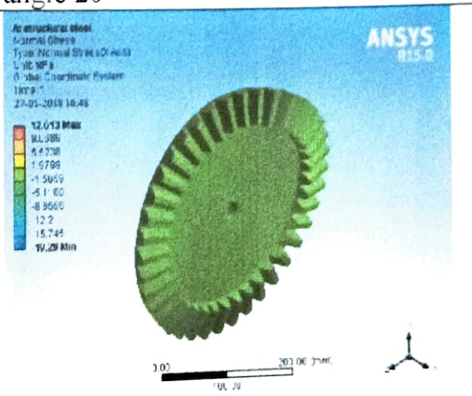


Figure 6.137 Normal stress at pitch angle 20^0

Table 6.31 Bending Stress at pitch angle 20^0

Stresses	**Value in N/mm^2**
von mises stress	40.73
Max principal stress	33.74
Max shear stress	22.83
Normal stress	12.61

6.1.4.2 *Contact stress at pitch angle 20⁰*

Contact Stresses obtained at **20⁰** pitch angle are listed in the Table 6.32

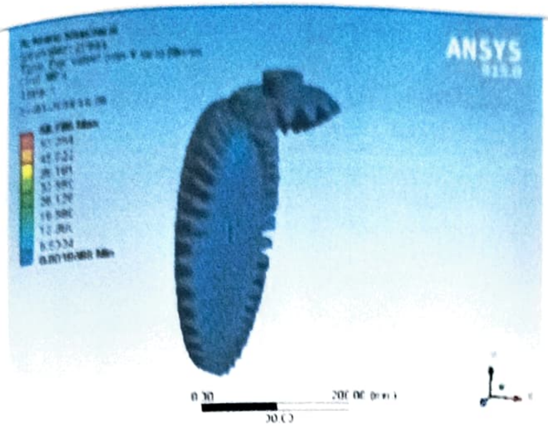


Figure 6.138 von –Mises stress at 20^0

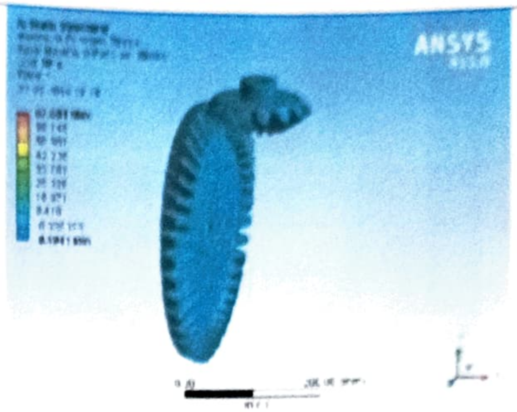


Figure 6.139 Max principal stress at 20^0

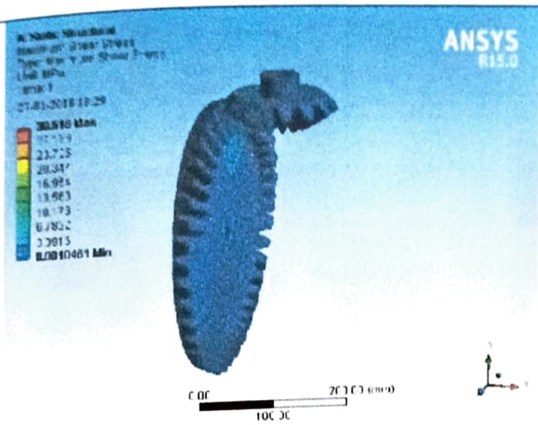


Figure 6.140 Max shear stress at 20^0

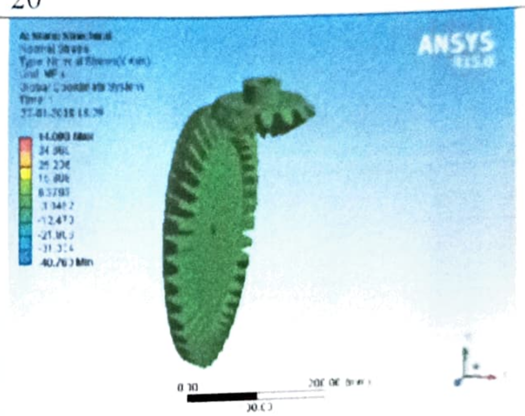


Figure 6.141 Normal stress at 20^0

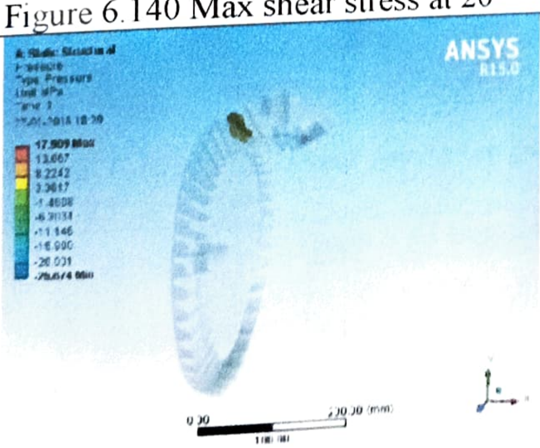


Figure 6.142 Contact Pressure at 20^0

Table 6.32 Bending Stress at pitch angle 20^0

Stresses	obtained value in N/ mm^2
von mises stress	58.78
Max principal stress	67.60
Max shear stress	30.51
Normal stress	44.09
Contact Pressure	17.90

6.1.4.3 Bending Stress at pitch angle 25⁰

Bending Stresses obtained at **25⁰** pitch angle are listed in the Table 6.33

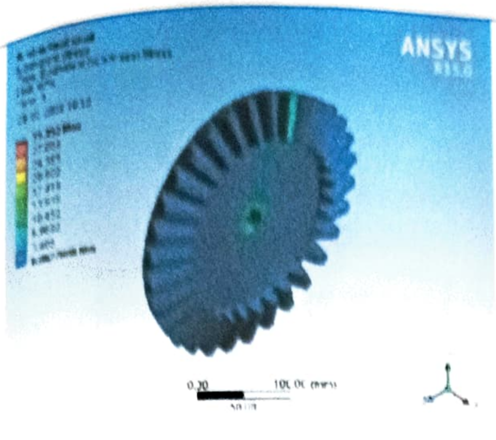


Figure 6.143 von –Mises stress at pitch angle 25^0

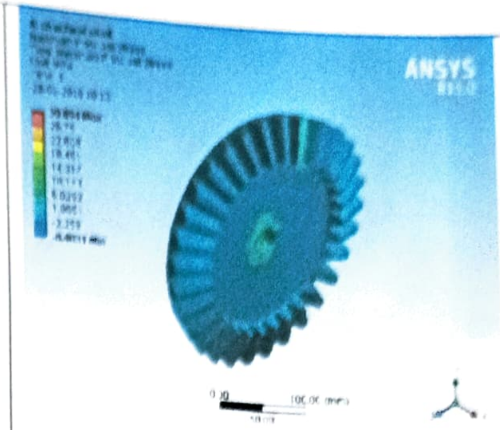


Figure 6.144 Max principal stress at pitch angle 25^0

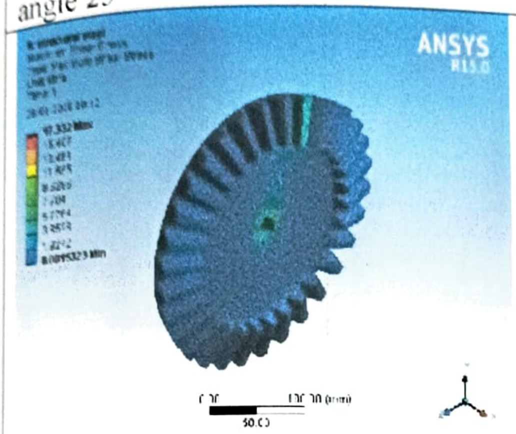


Figure 6.145 Max shear stress at pitch angle 25^0

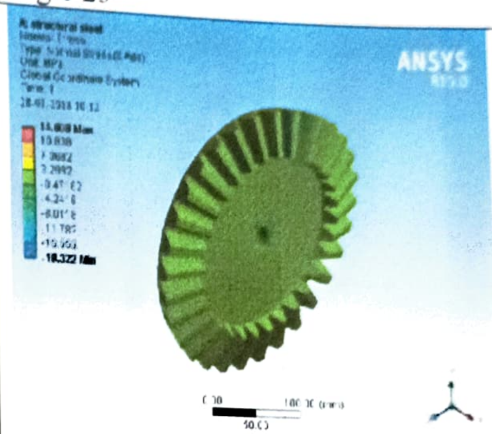


Figure 6.146 Normal stress at pitch angle 25^0

Table 6.33 Bending Stress at pitch angle 25^0

Stresses	**obtained value in N/ mm^2**
von mises stress	31.35
Max principal stress	30.89
Max shear stress	17.33
Normal stress	14.60

6.1.4.4 Contact stress at pitch angle 25°

Contact Stresses obtained at **25⁰** pitch angle are listed in the Table 6.34

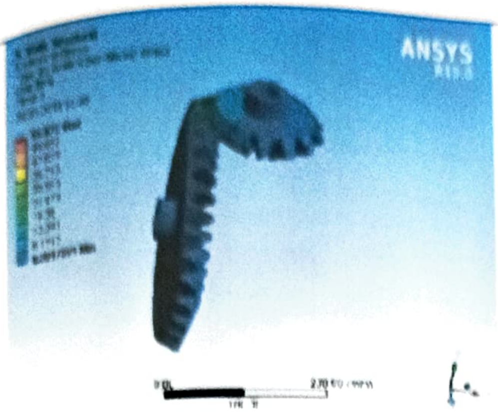


Figure 6.147 von –Mises stress at 25^0

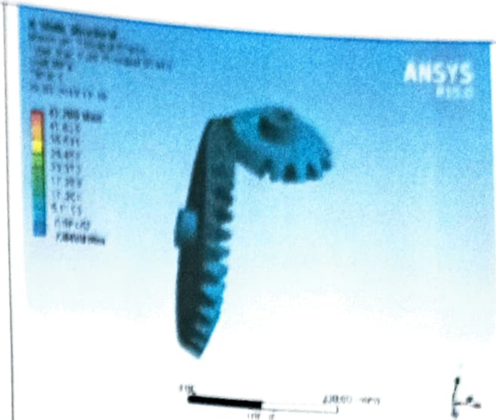


Figure 6.148 Max principal stress at 25^0

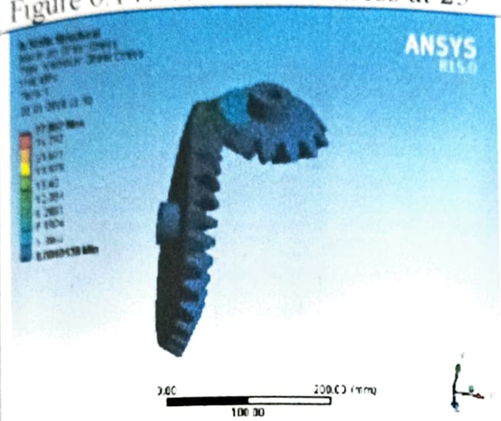


Figure 6.149 Max shear stress at 25^0

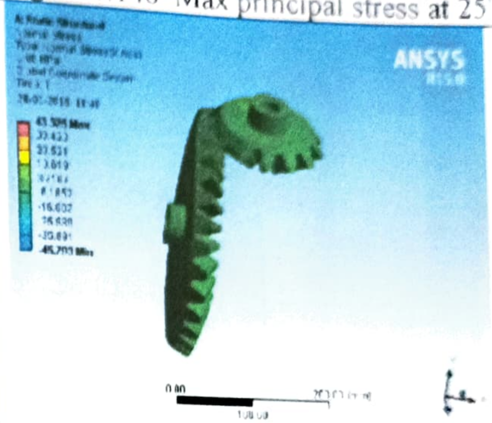


Figure 6.150 Normal stress at 25^0

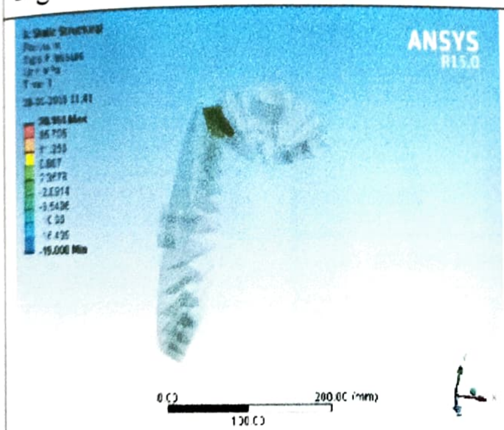


Figure 6.151 Contact Pressure at 25^0

Table 6.33 Contact stress at pitch angle 25^0 .

Stresses	**obtained value in N/ mm^2**
von mises stress	58.78
Max principal stress	67.60
Max shear stress	30.51
Normal stress	44.09
Contact Pressure	17.90

6.1.4.5 Bending Stress at pitch angle 30°

Bending Stresses obtained at **30**° pitch angle are listed in the Table 6.35

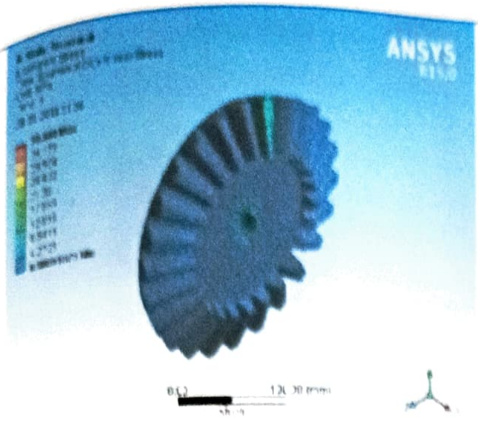


Figure 6.152 von –Mises stress at 30°

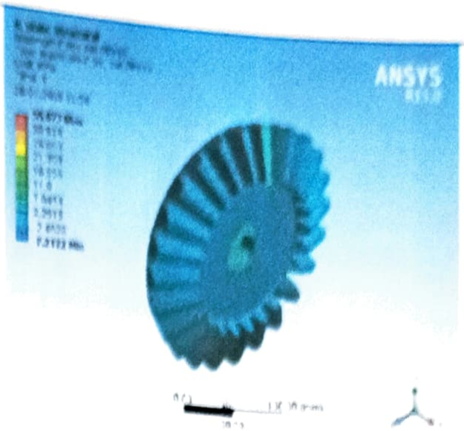


Figure 6.153 Max principal stress at 30°

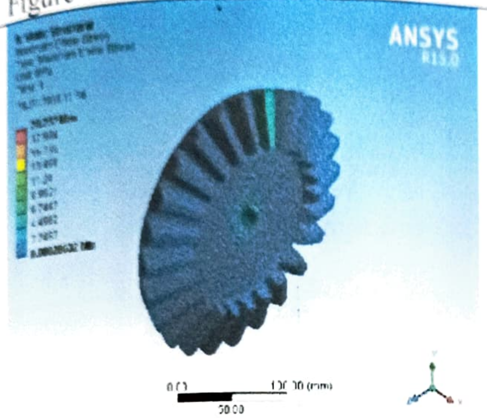


Figure 6.154 Max shear stress at 30°

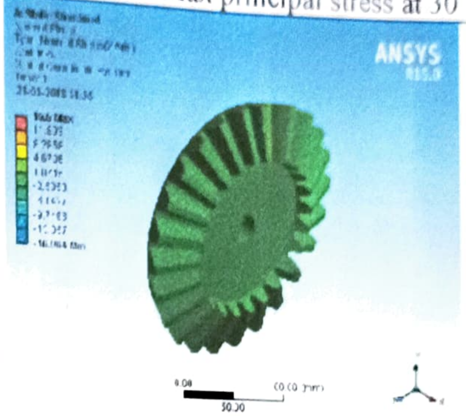


Figure 6.155 Normal stress at 30°

Table 6.34 Bending Stress at pitch angle 30°

Stresses	**obtained value in N/ mm^2**
von mises stress	38.44
Max principal stress	35.57
Max shear stress	20.23
Normal stress	15.05

6.1.4.6 Contact stress at pitch angle 30⁰

Contact Stresses obtained at **30^0** pitch angle are listed in the Table 6.36

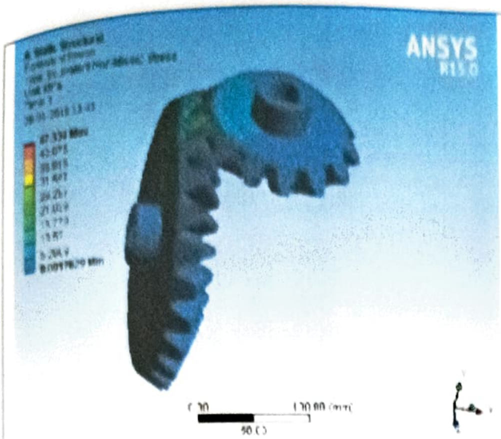


Figure 6.156 von –Mises stress at pitch angle 30^0

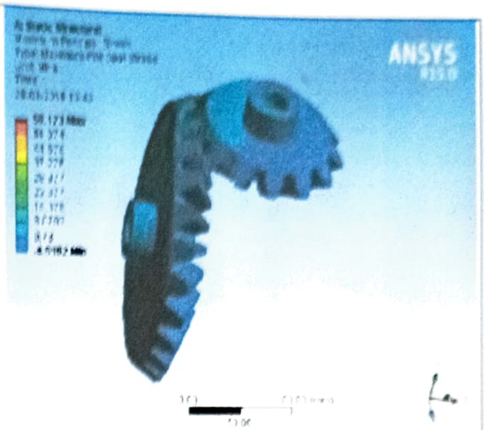


Figure 6.157 Max principal stress at pitch angle 30^0

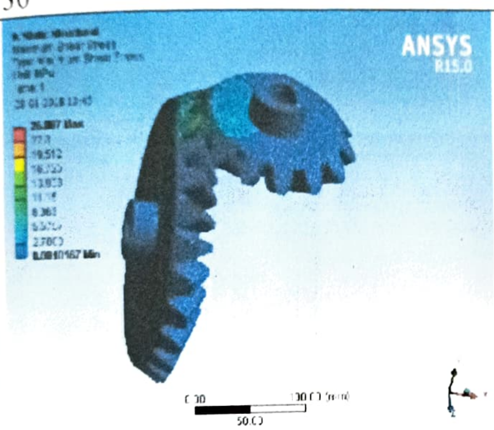


Figure 6.158 Max shear stress at pitch angle 30^0

Figure 6.159 Normal stress at pitch angle 30^0

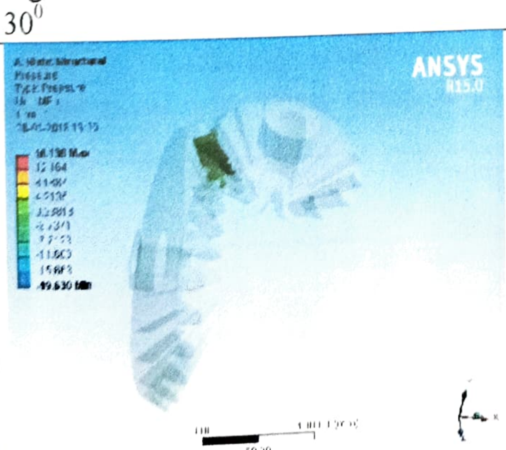


Figure 6.160 Contact Pressure at pitch angle

Table 6.35 Contact stress at pitch angle 30^0

Stresses	**obtained value in N/*mm*^{2}**
von mises stress	47.33
Max principal stress	59.17
Max shear stress	25.08
Normal stress	43.15
Contact Pressure	16.13

6.10.7 Bending Stress at pitch angle 35^0

Bending Stresses obtained at 35^0 pitch angle are listed in the Table 6.36

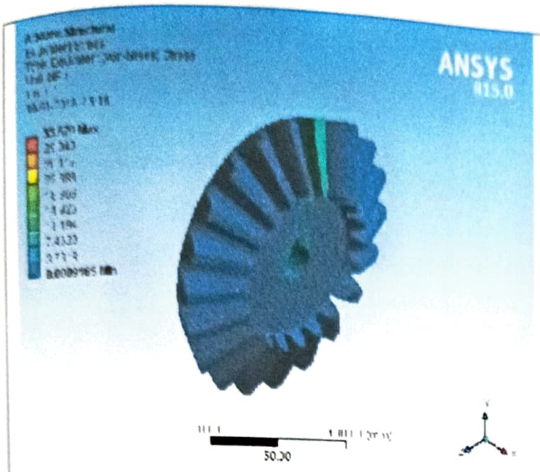


Figure 6.161 von –Mises stress at pitch angle 35^0

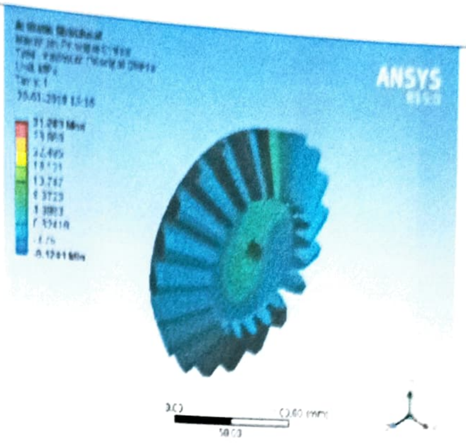


Figure 6.162 Max principal stress at pitch angle 35^0

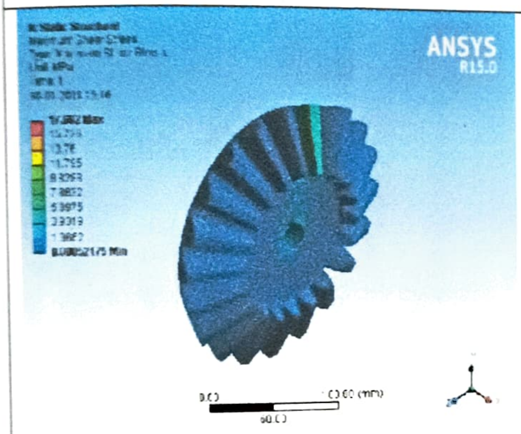


Figure 6.163 Max shear stress at pitch angle 35^0

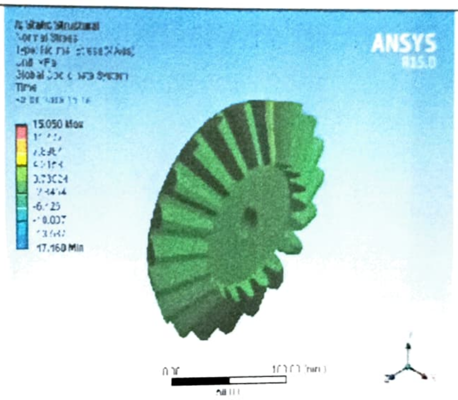


Figure 6.164 Normal stress at pitch angle 35^0

Table 6.36 Bending Stress at pitch angle 35^0

Stresses	**obtained value in N/ mm^2**
von mises stress	33.57
Max principal stress	31.24
Max shear stress	17.69
Normal stress	15.05

6.10.8 Contact stress at pitch angle 35^0.

Contact Stresses obtained at $\mathbf{35^0}$ pitch angle are listed in the Table 6.38

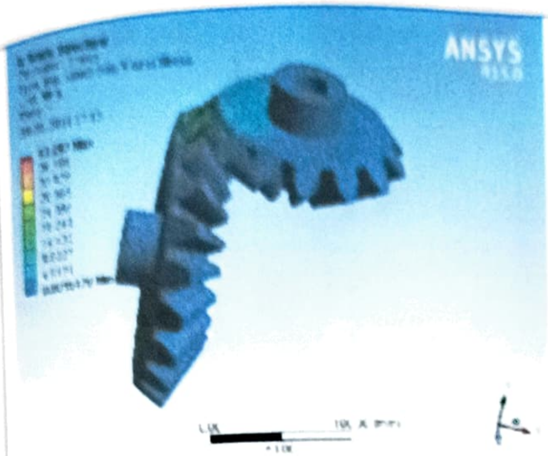


Figure 6.165 von –Mises stress at pitch angle 35^0

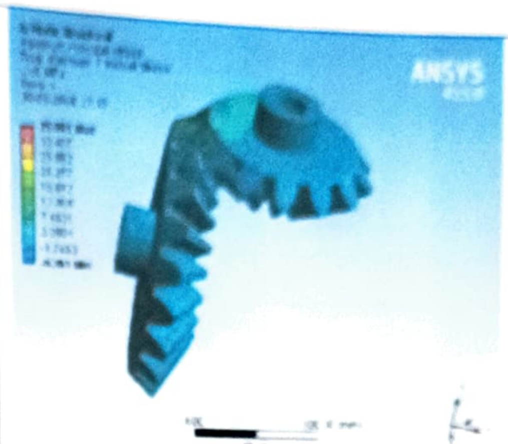


Figure 6.166 Max principal stress at pitch angle 35^0

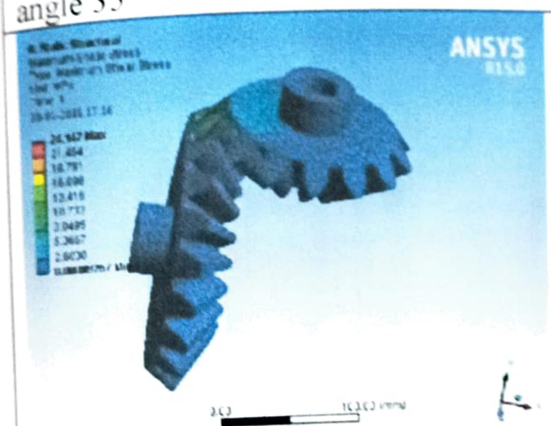


Figure 6.167 Max shear stress at pitch angle 35^0

Figure 6.168 Normal stress at pitch angle 35^0

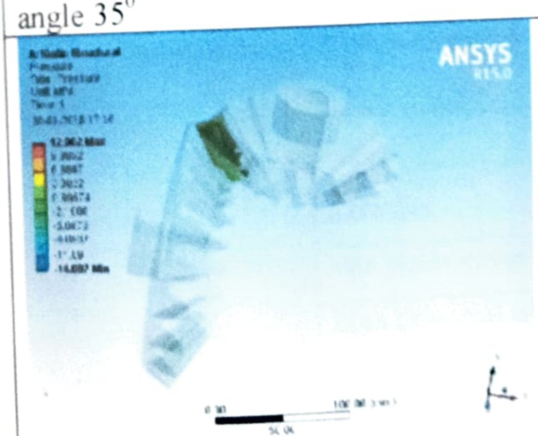


Figure 6.169 contact pressure at 35^0

Table 6.37 Contact stress at pitch angle 35^0

Stresses	**obtained value in N/ mm^2**
von mises stress	43.29
Max principal stress	35.09
Max shear stress	24.14
Normal stress	24.85
Contact Pressure	12.88

6.10.9 Bending Stress at pitch angle 40^0.

Bending Stresses obtained at **40^0** pitch angle are listed in the Table 6.39

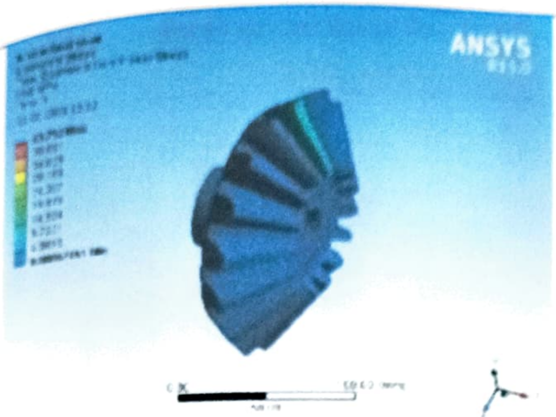
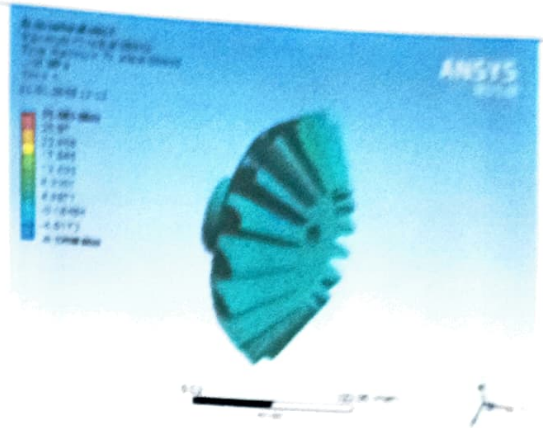
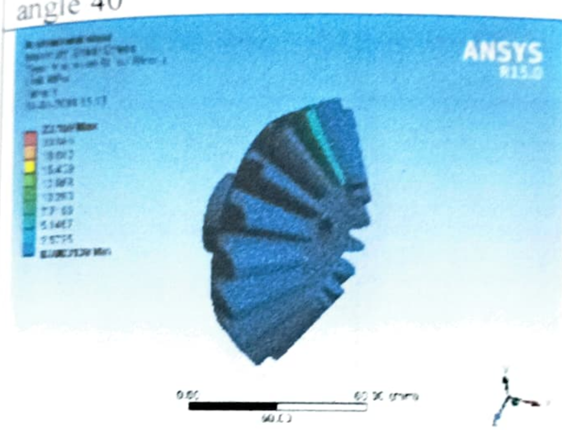
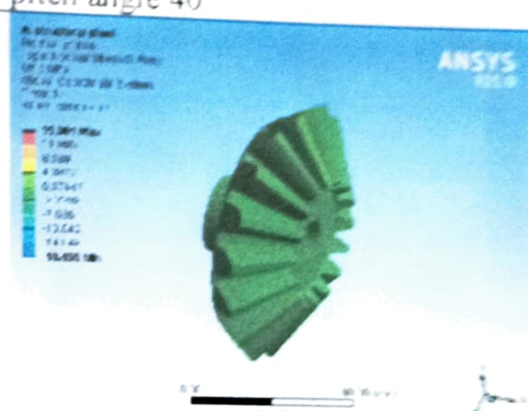
 Figure 6.170 von –Mises stress at pitch angle 40^0	 Figure 6.171 Max principal stress at pitch angle 40^0
 Figure 6.172 Max shear stress at pitch angle 40^0	 Figure 6.173 Normal stress at pitch angle 40^0

Table 6.38 Bending Stress at pitch angle 40^0

Stresses	**obtained value in N/ mm^2**
von mises stress	43.75
Max principal stress	31.48
Max shear stress	23.15
Normal stress	15.80

6.10.10 Contact stress at pitch angle 40^0.

Contact Stresses obtained at 40^0 pitch angle are listed in the Table 6.40

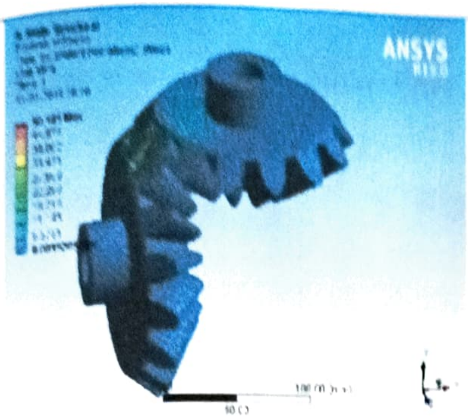


Figure 6.174 von –Mises stress at pitch angle 40^0

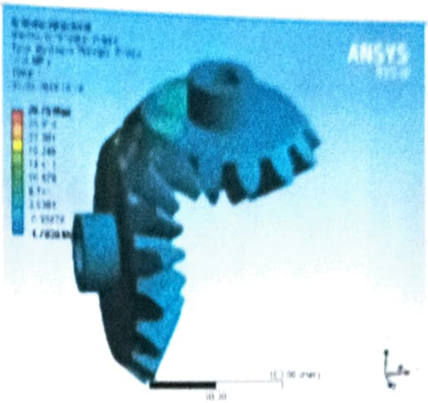


Figure 6.175 Max principal stress at pitch angle 40^0

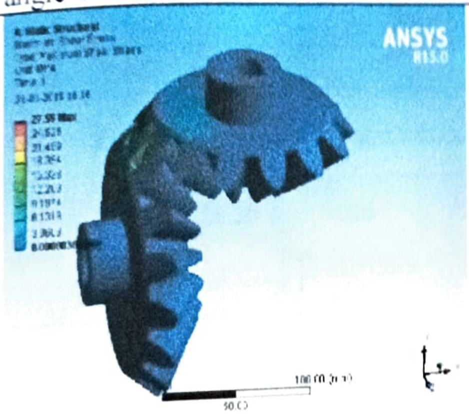


Figure 6.176 Max shear stress at pitch angle 40^0

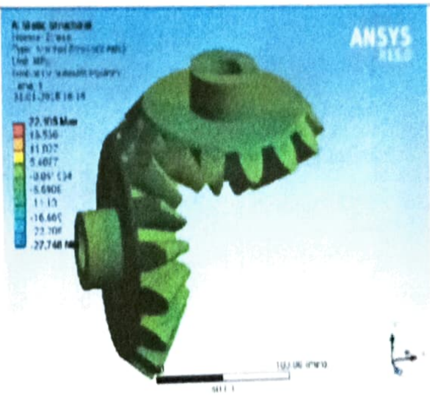


Figure 6.177 Normal stress at pitch angle 40^0

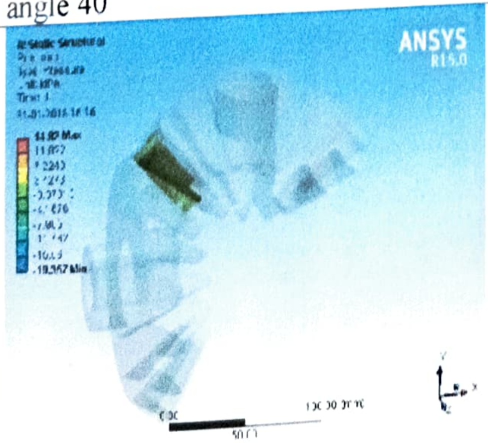


Figure 6.178 contact pressure at 40^0

Stresses	obtained value in N/ mm^2
von mises stress	50.14
Max principal stress	29.75
Max shear stress	27.59
Normal stress	22.10
Contact Pressure	14.82

Table 6.39 Contact stress at pitch angle 40^0

6.2 Variation of Bending Stresses With Five Pitch Angles and For Four Materials

Variation of bending stresses with variation in pitch angle for the materials Structural steel, Phospor bronze PB102, Cr-Ni Steel and Cast Iron were shown below

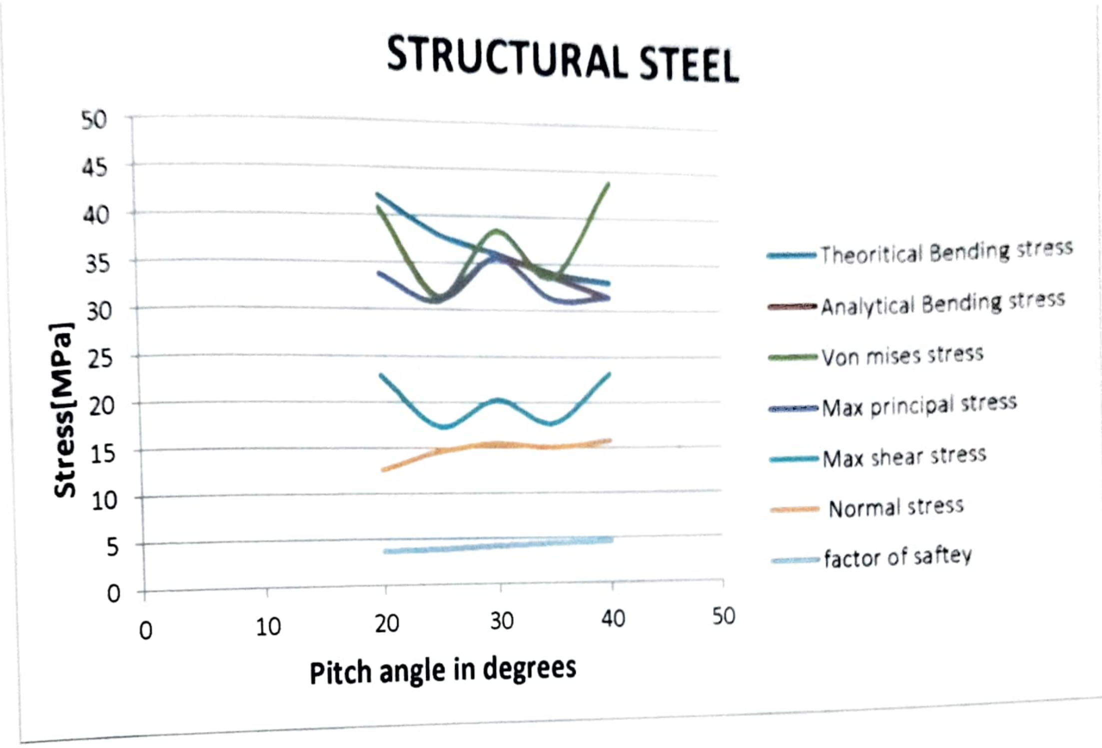


Figure 6.179 Variation of stresses with pitch angle for material Structural Steel

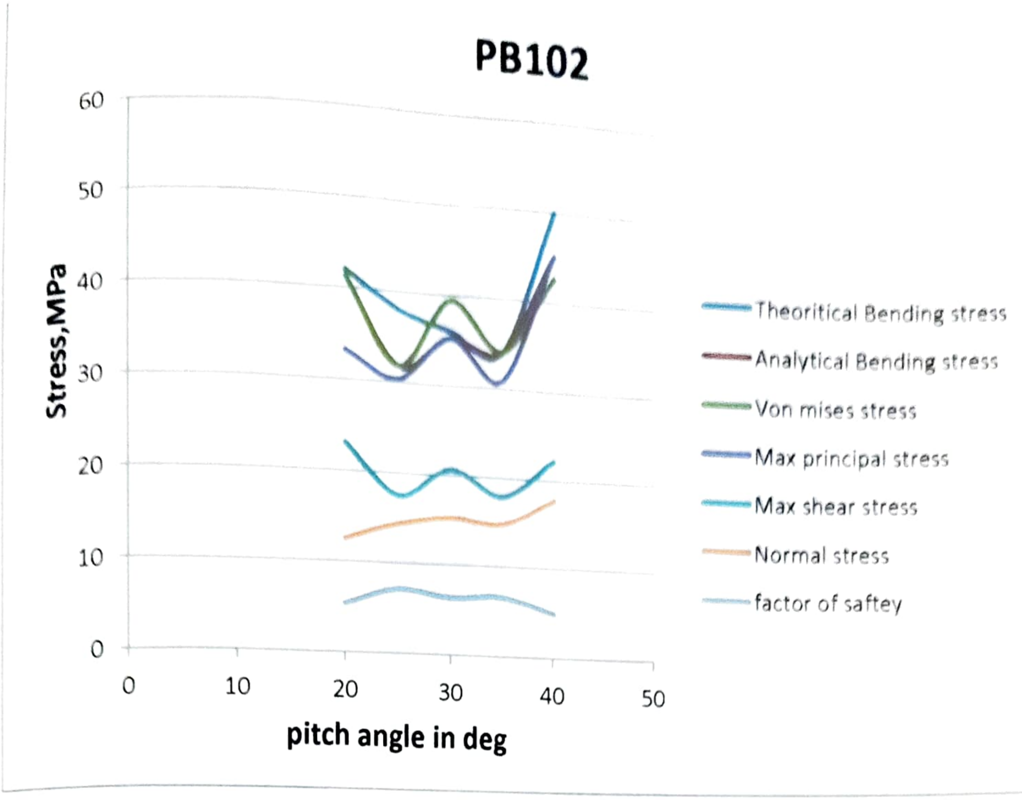


Figure 6.180 Variation of stresses with pitch angle for material PB 102.

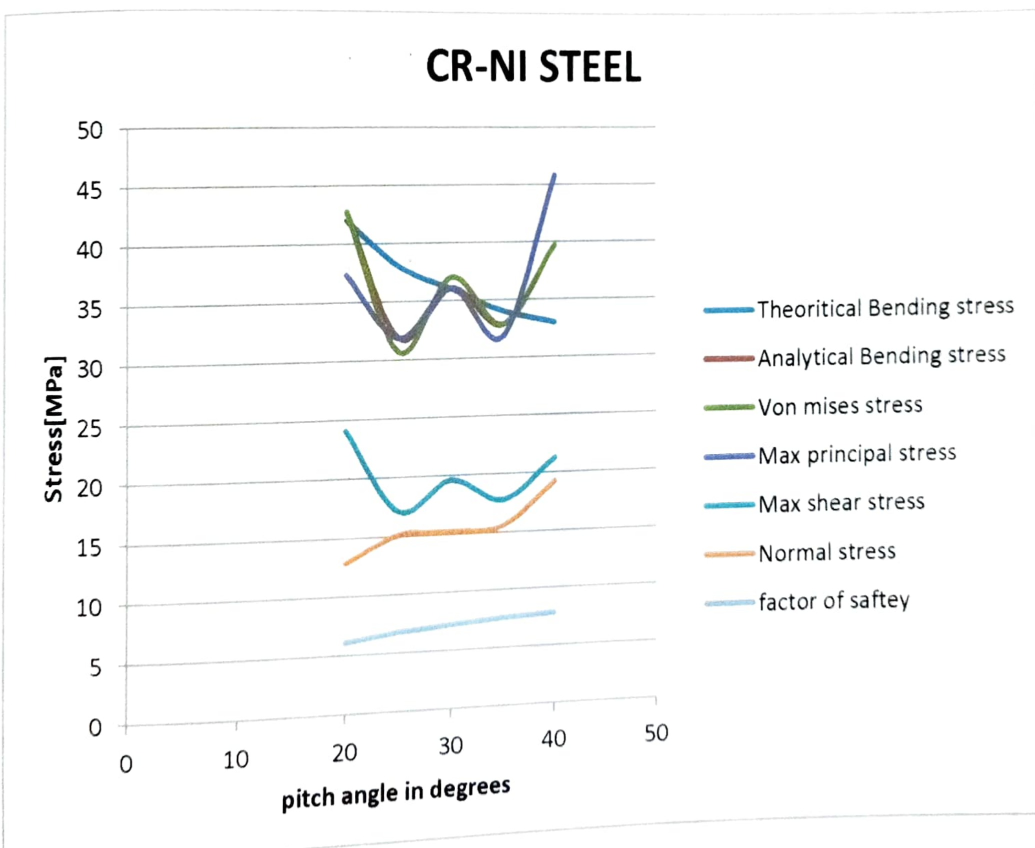


Figure 6.181 Variation of stresses with pitch angle for material Cr-Ni steel.

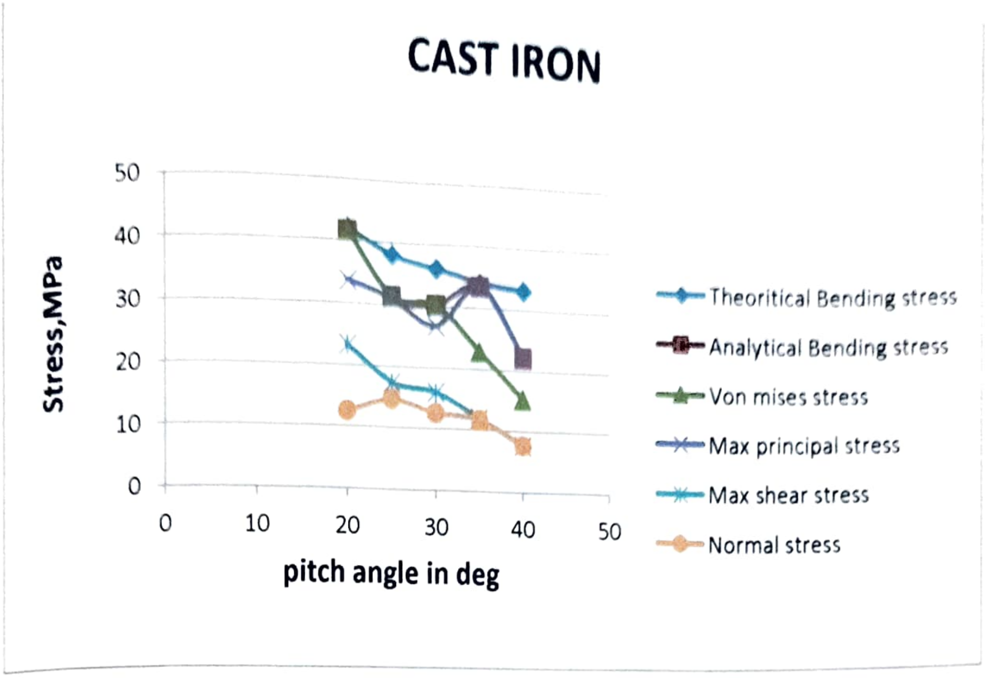


Figure 6.182 Variation of stresses with pitch angle for material Cast Iron.

6.3 Variation of Contact Stresses with Five Pitch Angles and For Four Materials

Variation of contact stresses with variation in pitch angle for the materials Structural steel, Phospor bronze PB102, Cr-Ni Steel and Cast Iron were shown below.

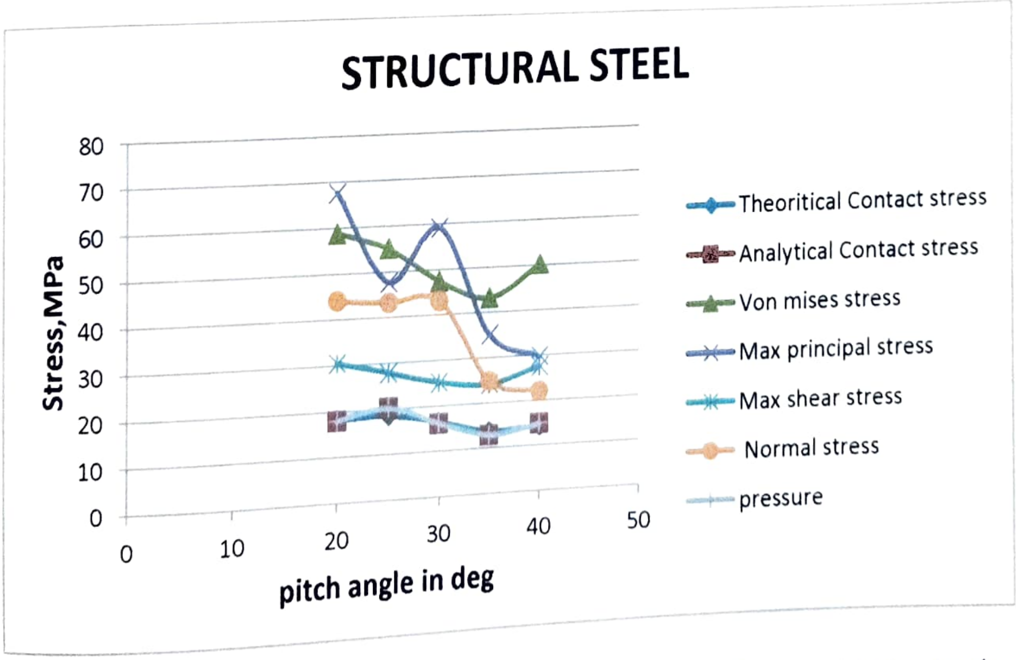


Figure 6.183 Variation of contact stresses with pitch angle for material Structural Steel.

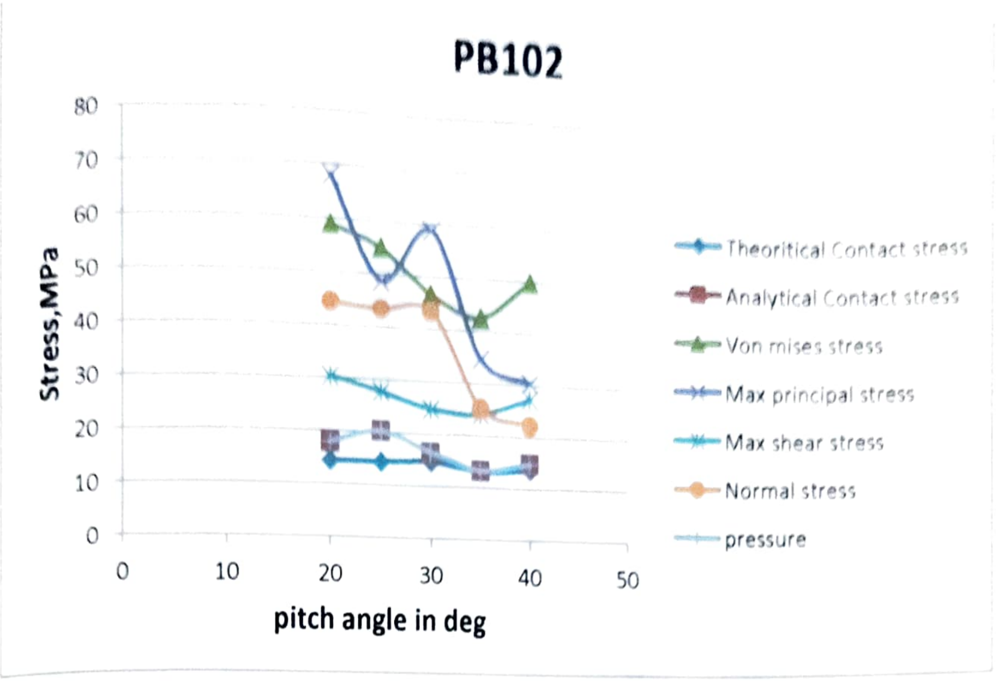


Figure 6.184 Variation of contact stresses with pitch angle for material PB 102

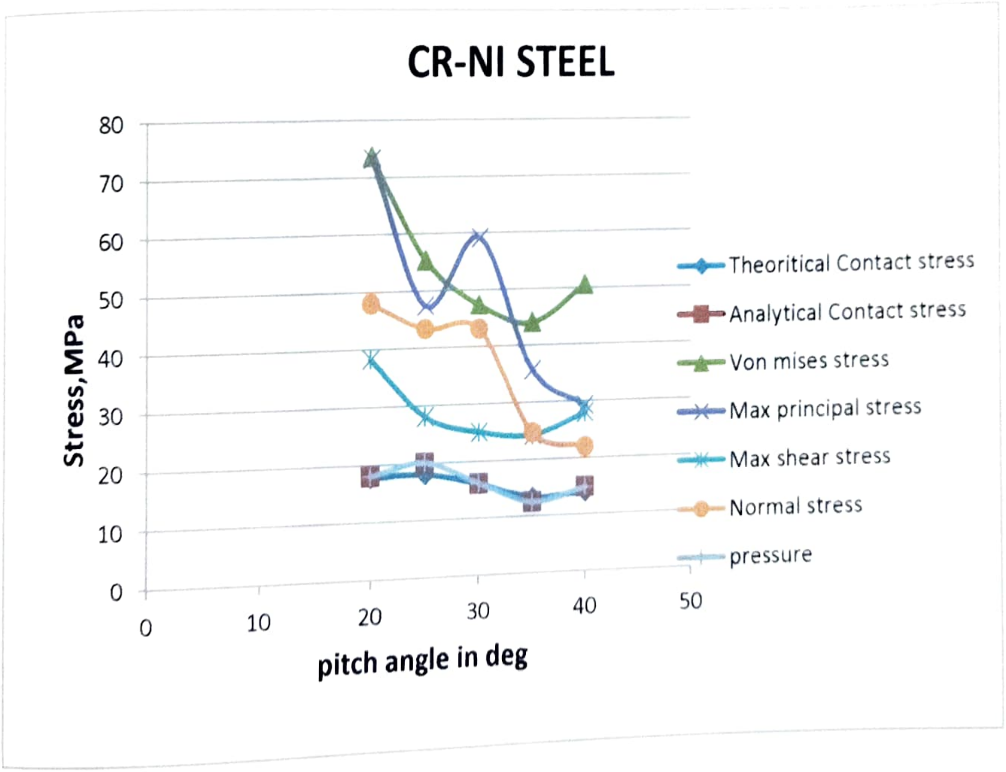


Figure 6.185 Variation of contact stresses with pitch angle for material Cr-Ni steel

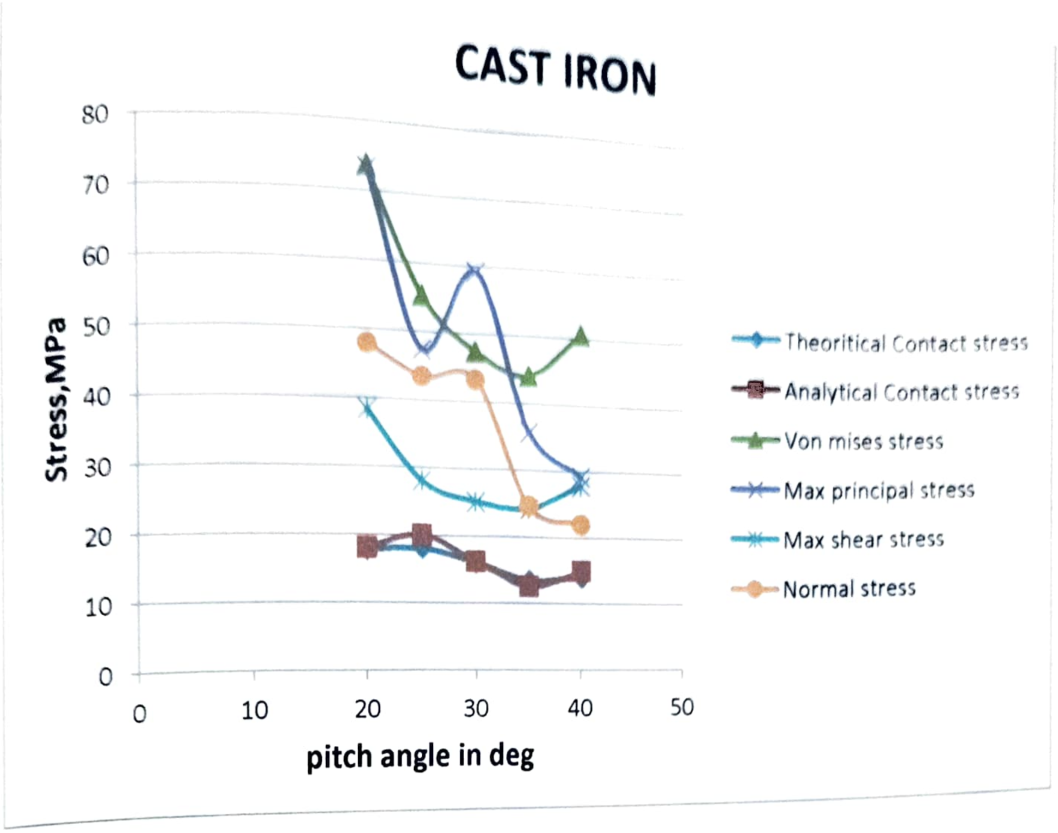


Figure 6.186 Variation of contact stresses with pitch angle for material Cast Iron

6.4 Variation of Factor of Safety for Four materials at Five pitch angles.

Variation factor of safety based on contact stresses had been obtained. At 35° pitch angle factor of safety is maximum for all the four materials.

Figure 6.187 factor of safety is increasing from pitch angle 20° to 35° and after 35° it starts decreasing.

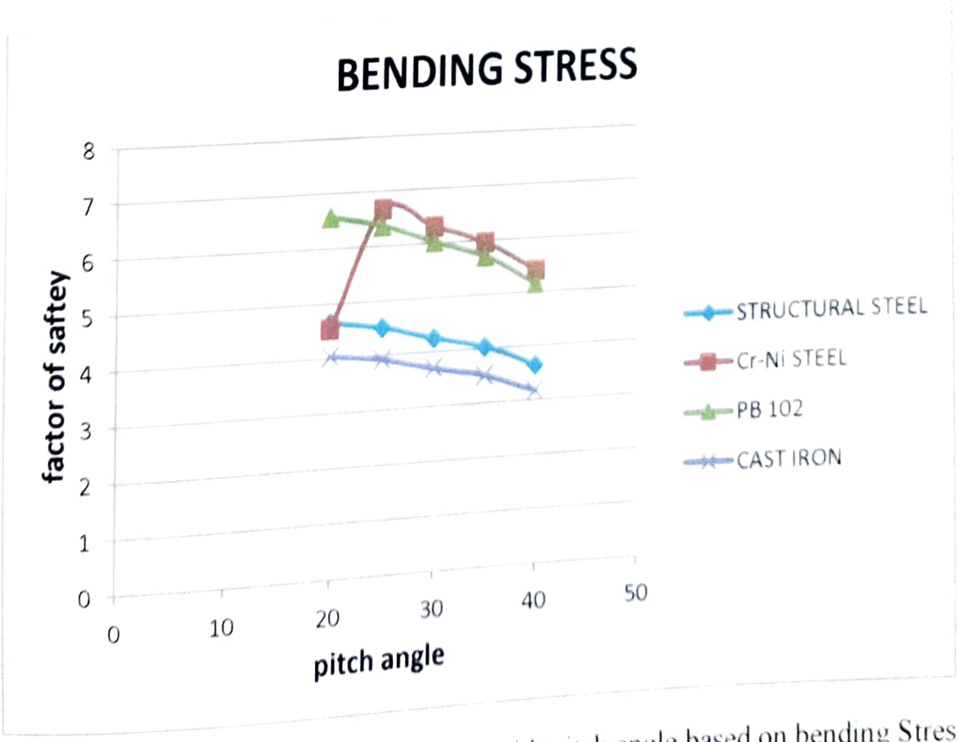


Figure 6.188 Variation of factor of safety with pitch angle based on bending Stress

7 CONCLUSIONS

The present work deals with evaluating the bending and contact stresses in a pair of bevel gears for five pitch angles and four different materials. The following conclusions were drawn from the study:

(1) It was observed that the bending stress are predominant and govern over contact stresses.

(2) It was observed that von-Mises stresses were decreasing with the pitch angle from 20^0 to $35^0$and there after increases.

(3) At 35^0 pitch angle, the minimum von-Mises stresses are in the range of 40-45 MPa.

(4) Factor of safety was observed to be minimum at 20^0 pitch angle and maximum at 35^0 in Contact stress analysis.

(5) It was observed that factor of safety was highest for Cr-Ni STEEL among all the materials chosen based on both bending and contact stresses analysis. phosphorous bronze102 stands the second best.

(6) The results obtained in ANSYS for bending and contact stresses are good in agreement with theoretical results.

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