

# Effect of Pitch angle on Bending Stresses of Bevel Gears

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**Abstract:** 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 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 stresses for three different materials and five 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.

**Keywords:** Pitch angle, Bevel gears, PHP, ANSYS.

## I. INTRODUCTION

Gears are toothed members which transmit power or motion between two shafts by meshing without any slip. Hence, gear drives are also called positive drives. In any pair of gears, the smaller one is called pinion and the larger one is called gear immaterial of which is driving the other. When pinion is the driver, it results in step down drive in which the output speed decreases and the torque increases. On the other hand, when the gear is the driver, it results in step up drive in which the output speed increases and the torque decreases.

**Bevel gears:** Bevel gears are gears where the axes of the two shafts intersect and the tooth of the gears are conical in shape. Bevel gears are most often mounted on shafts which are at  $90^{\circ}$ . The pitch surface of bevel gears is a cone. In a pair of gears, the larger is often called the GEAR and, the smaller one is called the PINION.

**Bending Stress:** Tangential component of gear tooth force induces the bending stress which tend to break the tooth. Hence bending stress is the basis for design of bevel gears.

## II. LITERATURE REVIEW

This section presents the literature review of similar works done previously in the area of bevel gears.

**Abhijeet.v.patil et al.[1]** 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 as 36.38N/mm<sup>2</sup>. By analysis the

bending strength value is 36.17N/mm<sup>2</sup> There is fairly good agreement between experimental and finite element results. The error in maximum bending stress is found to be 10%. They found that In bevel gear the bending stresses produced at critical section (root of tooth) are maximum as compared to spur gear.

**Alfosno Fuentes et al.[2]** In this project they prepared computerized design of advanced straight and skew bevel gears produced by precision forging is proposed. Modifications of the tooth surfaces of one of the members of the gear set are proposed in order to localize the bearing contact and pre design a favorable function of transmission errors. The proposed modifications of the tooth surfaces will be computed by using a modified imaginary crown-gear and applied in manufacturing through the use of the proper die geometry. The geometry of the die is obtained for each member of the gear set from their theoretical geometry obtained considering its generation by the corresponding imaginary crown-gear. Two types of surface modification, whole and partial crowning, are investigated in order to get the more effective way of surface modification of skew and straight bevel gears. A favorable function of transmission errors is pre-designed to allow low levels of noise and vibration of the gear drive. Numerical examples of design of both skew and straight bevel gear drives are included to illustrate the advantages of the proposed geometry.

**Emre turkoz et al.[3]** studied the problem that the static application of a moment of 600000 N-mm on the pinion, which tries to rotate but is hindered by the grounded gear. The torque is transferred to the gear through contact faces on tooth pairs. The moment causes on these pairs a contact force to be generated. Apart from the contact stress this

force forms, roots of the contact teeth also suffer from tooth root bending stress. In this paper the aim of the work is the evaluation of this root bending stress generated during the static application of the moment. The numerical 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.

**B. Venkatesh et al.** [4], 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 the 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.

**III. MATERIALS SELECTION**

The materials that are under consideration for this work are Phosphor bronze 102(Pb102) and chromium Nickel steel (Cr-Ni) alloy whose mechanical properties are given below in TABLE 1

TABLE 1 Material properties

Property	Phosphor Bronze	Chromium Nickel steel
Density (Kg/m <sup>3</sup> )	8850	7800
Young's modulus (GPa)	121	200
Poisson's ratio	0.33	0.28
Ultimate Tensile Strength (MPa)	650	680

Yield Tensile Strength (MPa)	276	280
Bulk modulus (GPa)	83.3	69.6

**Specifications used:**

Maximum Power: - 46.97KW  
Maximum Torque: - 140165N/mm  
Maximum Speed: - 3200 rpm

**IV. THEORETICAL CALCULATIONS**

**A. Calculation of Bending Stress**

The Bending Stress of the Bevel gears is calculated using lewis equation.

POWER=46.97KW  
SPEED=3200RPM

$$\text{Moment (M}_t) = \frac{60 \times 10^6 \times 46.97}{2\pi \times 3200} = 140165.76 \text{ N/mm}$$

$$\text{Diametral pitch (D}_p) = M \times Z_p = 140 \text{ mm}$$

$$\text{Tangential force (P}_t) = \frac{2M_t}{D_p} = \frac{2 \times 140165.76}{140} = 2002.3 \text{ N}$$

$$\text{Effective force (P}_{eff}) = \frac{C_s}{C_v} \times P_t$$

Where,

C<sub>s</sub> = service factor

C<sub>v</sub> = velocity factor

$$V = \frac{\pi \times D_p \times N_p}{60 \times 10^3} = \frac{\pi \times 140 \times 3200}{60 \times 10^3} = 23.45 \text{ m/s}$$

If V > 20 then,

$$C_v = \frac{5.6}{5.6 + \sqrt{V}}$$

$$C_v = 0.53$$

$$P_{eff} = \frac{1.5}{0.53} \times 2002.3$$

$$P_{eff} = 5601.23$$

Let P<sub>eff</sub> = S<sub>b</sub>

$$P_{eff} = m \times b \times \sigma_b \times \pi \times Y \left[ 1 - \frac{b}{A_0} \right]$$

From the above equation bending stress is calculated as

$$\sigma_{bw} = \frac{P_{eff}}{m \times b \times \pi \times Y \left[ 1 - \frac{b}{A_0} \right]} = \frac{5601.23}{10 \times 50 \times \pi \times 0.1049 \times 0.52}$$

$$\sigma_{bw} = 64.30 \text{ N/mm}^2$$

$$\text{Ultimate tensile stress (S}_{ut}) = 650 \text{ N/mm}^2$$

$$\text{Permissible Bending Stress} = 40\% \text{ of } S_{ut}$$

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

$$\text{Factor of safety} = 2.2$$

As the design calculations for two materials at five pitch angles takes lot of time. Hence a Graphical user Interface (GUI) is developed to calculate the bending stress using PHP: Hypertext Pre-processor web scripting.

**B. GUI developed using PHP hypertext preprocessor**

The Interface of the PHP hypertext processor is shown the Fig1 below

The typical calculations obtained for Phosphor bronze material at 20° pitch angle is shown in Fig-1.

Design of Bevel Gears	
Power [KW]	46.97
Speed [RPM]	3200
Module [mm]	10
No. of Teeth in Pinion	14
No. of Teeth in Gear	38
Pressure Angle [Degrees]	20
Face width [mm]	50
Ultimate Tensile Stress [N/mm <sup>2</sup> ]	650
Service Factor [Cs]	1
Modulus of Elasticity for Pinion [E N/mm <sup>2</sup> ]	121
<input type="button" value="Submit"/>	
<b>Strength Based Design</b>	
Pitch Angle	20 Degrees
Formative No. of Teeth [Z]	15
Lewis Form Factor [Y]	0.0932
Dp and Dg	140 mm
Cone Distance [A0]	380 mm
Pitch line Velocity [v]	202 mm
Velocity Factor [Cv]	23 m/sec
Moment [Mt]	0.54
Tangential Component [Pt]	140165 N-mm
Effective Load [Peff]	2002 N
Bending Stress	3716 N
Factor of safety based on Bending	33 N/mm <sup>2</sup>
<b>Wear Based Design</b>	
Ratio Factor-Q	6.57
Contact Stress [N/mm <sup>2</sup> ]	1.76
Factor of safety based on Wear	9.97 N/mm <sup>2</sup>
	65.19

Fig-1. Bending Stress for Phosphor Bronze PB102

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	

### V. MODELLING USING SOLIDWORKS

The bevel gear was modeled using SOLIDWORKS software by taking the specifications of a bevel gear used in automobile differential. Specifications of the bevel gear were listed in Table-2. The model was exported in IGES format which is compatible for ANSYS software.

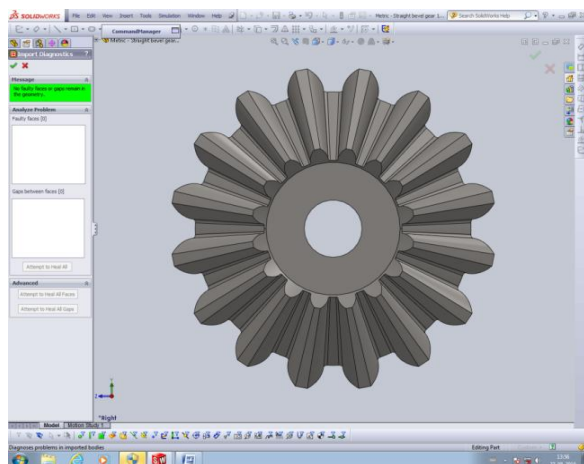


Fig 2 Modeled Gear

### VI. ANALYSIS USING ANSYS

The finite element analysis of the bevel gear was done by using ANSYS workbench software. The model from the solid works software was imported into ANSYS workbench. Assigning engineering data such as Density, Young's modulus, Poisson's ratio for the materials is shown in Fig-3.

Properties of Outline Row 3: Structural Steel			
	A	B	C
	Property	Value	Unit
1			
2	Density	7850	kg m <sup>-3</sup>
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		

Fig-3 Assigning Engineering Data in ANSYS

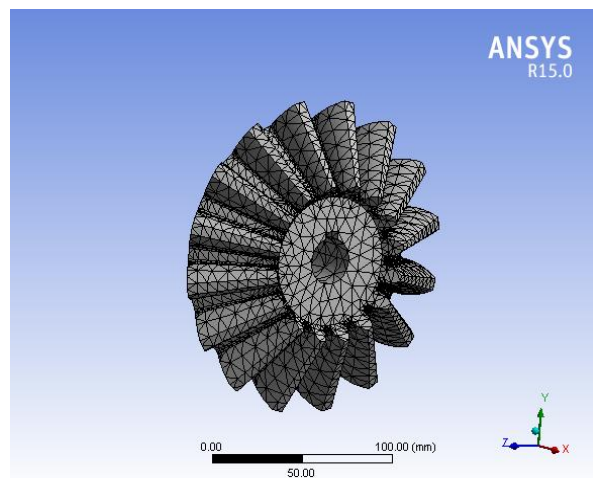


Fig -4 Model with fine Mesh

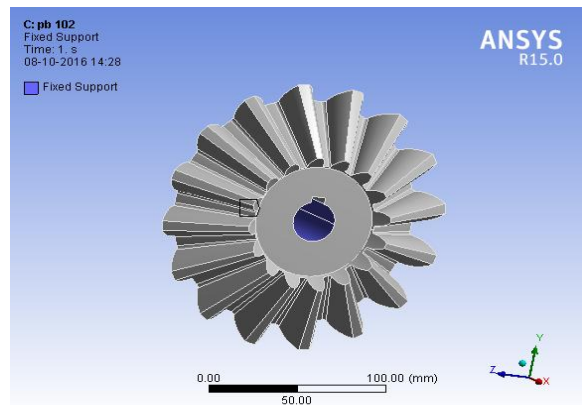


Fig -5. Supports given at the Centre of the gear

Fine Meshing was done as shown in Fig 4. Fixed support was given to the hub and a tangential force of 2002.01N was given to one of the tooth as shown in Fig- 5 and Fig -6 respectively. The bending stresses for PB102 and Cr-Ni Steel at different pitch angles ( $20^{\circ}$ ,  $25^{\circ}$ ,  $30^{\circ}$ ,  $35^{\circ}$ ,  $40^{\circ}$ ) were found using ANSYS software.

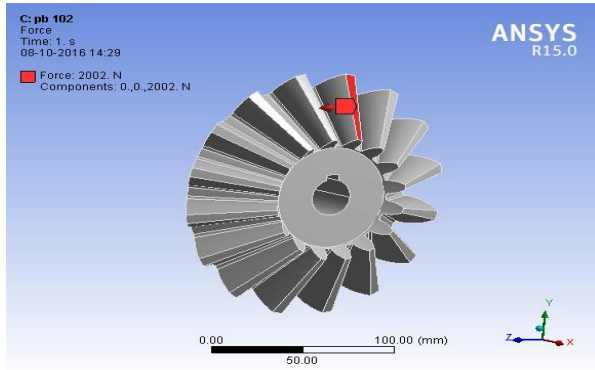


Fig -6. Tangential Force applied on the tooth

### VII. RESULTS AND DISCUSSIONS

The bending stresses results for PB102 and Cr-Ni Steel at five pitch angles ( $20^{\circ}$ ,  $25^{\circ}$ ,  $30^{\circ}$ ,  $35^{\circ}$ ,  $40^{\circ}$ ) which were found theoretically and using ANSYS software.

#### Bending stresses induced in Phosphor bronze 102

Stresses induced at  $20^{\circ}$ ,  $25^{\circ}$ ,  $30^{\circ}$ ,  $35^{\circ}$ ,  $40^{\circ}$  pitch angles were shown in Fig-7, Fig-8, Fig-9, Fig-10 and Fig-11.

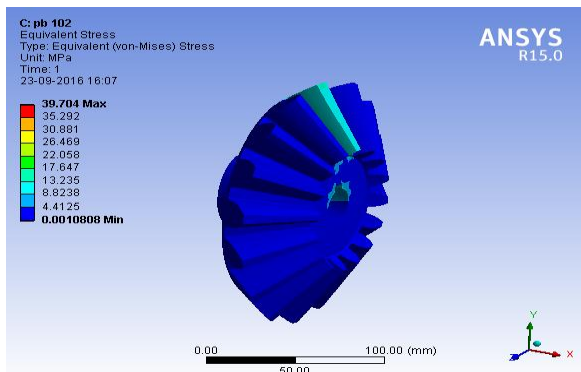


Fig-7. Bending stress for PB 102 at  $20^{\circ}$  pitch angle

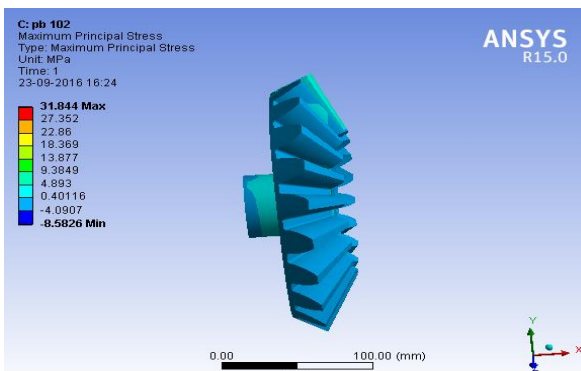


Fig-8. Bending stress for PB 102 at  $25^{\circ}$  pitch angle

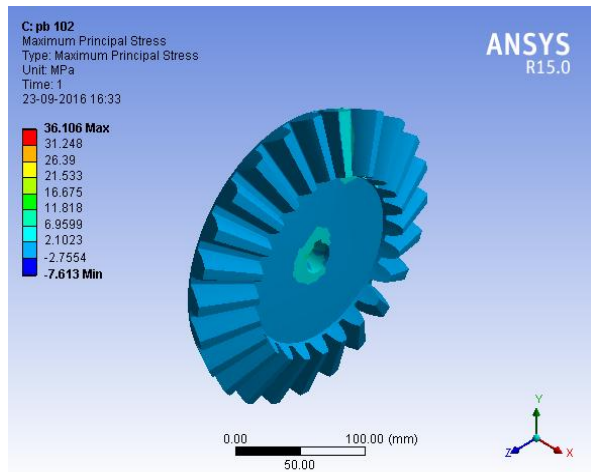


Fig-9. Bending stress for PB 102 at  $30^{\circ}$  pitch angle

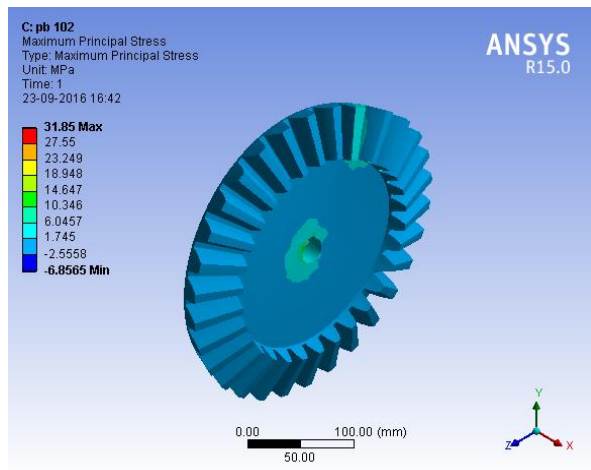


Fig-10. Bending stress for PB 102 at  $35^{\circ}$  pitch angle

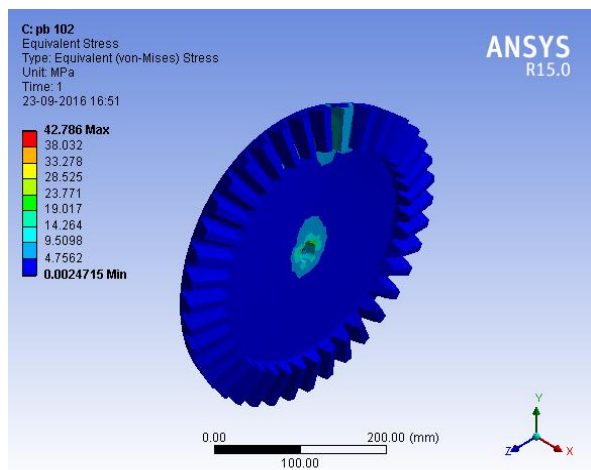


Fig-11. Bending stress for PB 102 at  $40^{\circ}$  pitch angle

#### Bending stresses induced in Cr-Ni Steel

The variation of Bending stress at different pitch angles ( $20^{\circ}$ ,  $25^{\circ}$ ,  $30^{\circ}$ ,  $35^{\circ}$ ,  $40^{\circ}$ ) Cr-Ni steel is shown in Fig-12, Fig-13, Fig-14, Fig-15 and Fig-16.

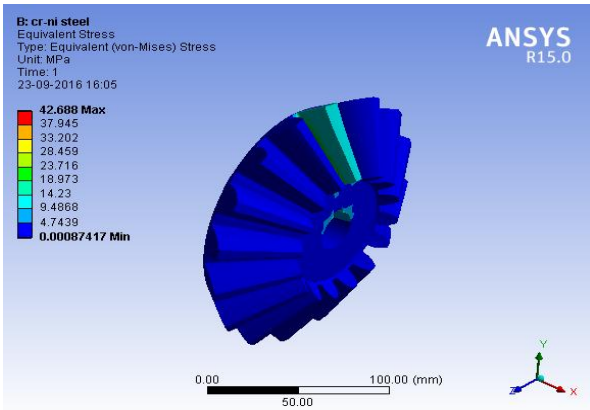


Fig-12. Bending stress for Cr-Ni at 20° pitch angle

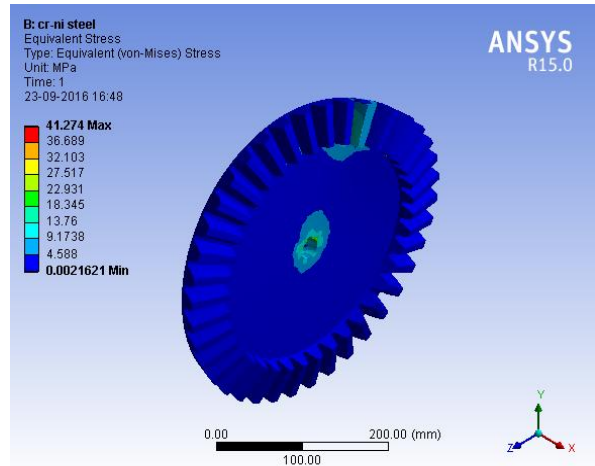


Fig-16. Bending stress for Cr-Ni steel at 40° pitch angle

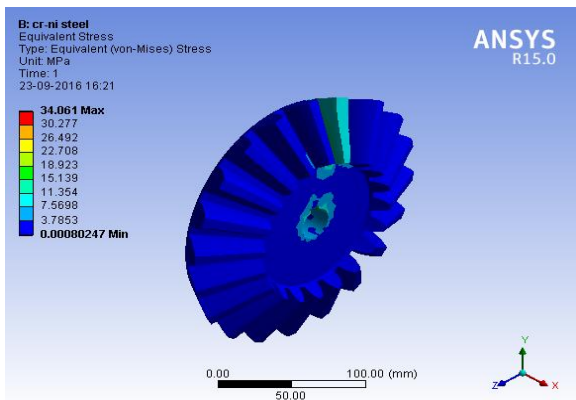


Fig-13. Bending stress for Cr-Ni at 25° pitch angle

Variation of Stresses with change in pitch angle was shown in Fig-17 and Fig-18.

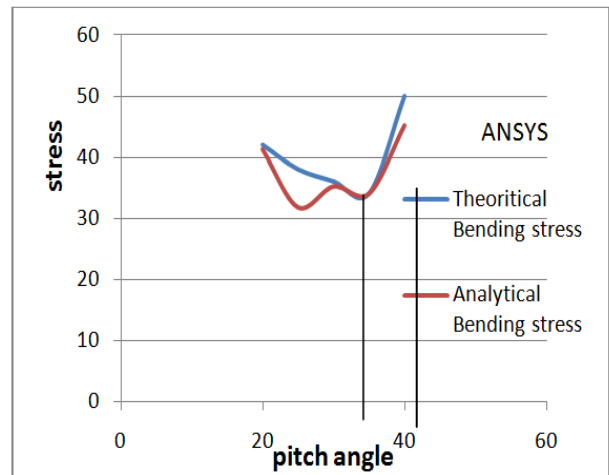


Fig-17. Variation of Bending stress for Pb 102

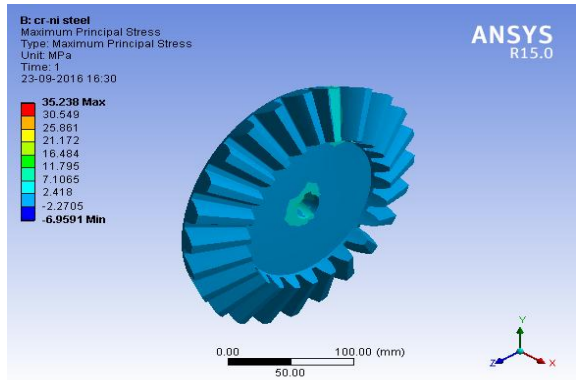


Fig-14. Bending stress for Cr-Ni at 30° pitch angle

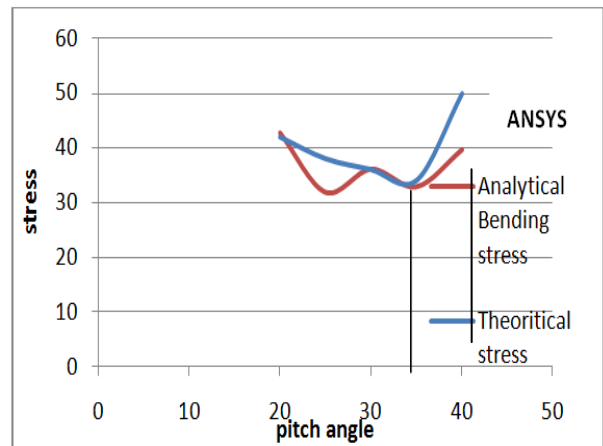


Fig-18. Variation of Bending stress for Cr-Ni steel

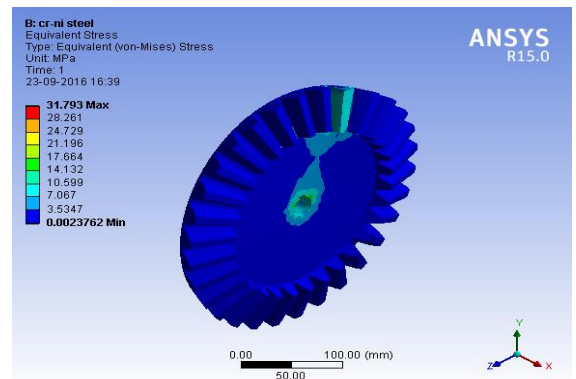


Fig-15. Bending stress for Cr-Ni at 35° pitch angle

The results of theoretical and analytical Bending stresses for Pb 102, Cr-Ni steel are shown in TABLE 2 and TABLE 3 respectively.

TABLE 2 Bending Stresses for Pb 102

Pitch angle in Degrees	Theoretical Bending Stress (MPa)	Bending Stress(MPa) Obtained in ANSYS	Factor of Safety
20	33	39.32	6.5
25	34	31.85	6.3
30	36	36.1	6.02
35	38	31.86	5.7
40	42	42.15	5.3

TABLE 3 Bending Stresses for Cr-Ni steel

Pitch angle in Degrees	Theoretical Bending Stress(MPa)	Analytical Bending Stress(MPa)	Factor of Safety
20	42	41.27	5.20
25	38	34.79	5.30
30	36	35.23	6.30
35	34	31.06	6.67
40	50	31.86	4.53

### VIII. CONCLUSION

The bending stresses for Pb 102, Cr-Ni steel at different pitch angles such as 20<sup>0</sup>, 25<sup>0</sup>, 30<sup>0</sup>, 35<sup>0</sup>, 40<sup>0</sup> were calculated theoretically and using ANSYS software. From the results, it was concluded that

1. The analysis results for bending stresses obtained in ANSYS and theoretical results are good in agreement.
2. The factor of Safety increases up to 35<sup>0</sup> pitch angle and then it decreases from 40<sup>0</sup> pitch angle.
3. Cr-Ni steel is considered as the Best material as compared PB102 based on Factor of Safety.

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