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DESIGN AND COMPARISON OF THE NITRIDED STEELS SPUR GEAR WITH AL 5050, AL-LI ALLOY AND COMPACTED GRAPHITE IRON

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ABSTRACT

In the present study the researchers aim to design and analyses the metallic spur gears using four different materials and figure out which material would be best suited for manufacturing of gears that have enough resilience for their intended use. The researchers have made use of Ansys R-24 software to create virtual models of the gears and simulate their behavior under different conditions. In this connection the authors are made an attempt to compare the results of four different materials considered such as Aluminium alloy 5050, Aluminium-Lithium alloys, Compacted Graphite Iron and Nitride- Steels. The outcome of the analysis for best performance in terms of stress distribution, strain deformation has been presented. This study provides information that could help to choose best material to design and manufacturing of spur gears.

Keywords: Spur gear, Ansys, Composite, analysis.

I. Introduction

Figure 1: Spur Gear (Coustry Google)

With the moving wheel of science and technology, the use of gears has become more and more common in all future industries. The advantages of spur gears are simplicity of design, economical production, low maintenance and absence of end thrust. A gear is a component of a transmission device that transmits rotational torque by applying a force to the teeth of another gear or device. P.B. Pawara, Abhay A Utpat b [1] et.al. explores the use of Metal Matrix Composite (MMC) materials, particularly Al-SiC composite, for manufacturing gears. These materials offer advantages like lightweight, high strength, and corrosion resistance, making them ideal for power transmission gears. Al-SiC composite is produced using methods like powder metallurgy or stir casting, enhancing hardness and tensile strength while reducing weight.

II. Literature

Nair Ajit V. et.al. [2] proposed the use of Aluminum-Titanium in the production of spur gears. The study the structural analysis of Model design of gears was observed with Ansys software Finally, comparing the results for Ansys software results with experimental test of the composite gears. D. Apparao et.al.[3] worked on the spur gear of the TATA super ACE vehicle model in mint color is included. A 3D model of the spur gear is generated using SolidWorks software, taking into account the design parameters of the spur gear and the model imported into ANSYS software for analysis. The fabrication of spur gear is done by using DMLS machine. Maraging steel material is chosen according to its properties for making of spur gear. Structural analysis is performed to investigate the bending stresses and deflections in the spur gear tooth. Ram Kumar Kunjam et.al. [4] proposed on the modification of spur gear design and explain the design the spur gear and dimension specification. K Vigneshwaran et.al. [5] Explained on his study on analyzed a Spur gear used in a stone crusher machine. They're using two methods: the theoretical Lewis equation and Finite Element Analysis (FEA). Specifically, they're looking at bending stress on the gear because it's crucial for gear durability. They're comparing two materials: C15 steel/CI 30 and C45 steel/CI 30. The C45 steel is better in terms of mechanical properties. The analysis shows that using C45/CI30 results in lower bending stress compared to the existing material. Module, which is a key factor in gear modelling, is varied in the analysis. S Rajeshkumar and R Manoharan et.al. [6] focused on the analysis of composite spur gears through numerical methods. Composite gears offer a good balance of strength and weight, along with increased hardness, durability, and lower maintenance costs. Using Ansys software, the researchers developed a Finite Element model to simulate spur gears. They looked at factors like stress distribution, strain, and deformation to compare composite gears with both steel and polymer gears. To evaluate and compare different designs, they developed an APDL (Ansys Parametric Design Language) gear model. This allowed them to assess the performance of composite gears against steel and polymer alternatives. Pinaknath Dewanji et.al. [7] proposed on the Designing the Spur gears, with the Finite Element Analysis (FEA). It's like putting the gears under a microscope, allowing us to see how they behave under different conditions. In the past, analysing gears meant diving into complex calculations. Tanuj Srivastava et.al. [8] explained about the Gears to analysed the Static behavior of spur gears found in automobile gearboxes, using standard torque specifications. Understanding how stress and deflection affect gear teeth is crucial for designing efficient power. Saleem, M. et.al. [9] expressed the Design of spur gear model with mathematical approach to standard design procedure has described and CATIA V5 R20 modeling software was used and properties are examined using CAE software (ANSYS).

Nomenclature of Gear:

1. Pitch Diameter (D): The pitch diameter is the diameter of the imaginary circle around which the gear teeth are spaced. It's a fundamental parameter used in gear design and is essential for calculating gear ratios and tooth dimensions.
2. Pitch Circle (PC): The pitch circle, also known as the pitch diameter, represents the circle on which the gear teeth are theoretically located. It's the basis for determining the size and spacing of the gear teeth.
3. Number of Teeth (N): The number of teeth on the gear determines its size and meshing characteristics. It directly influences the gear ratio and the smoothness of motion in gear systems.

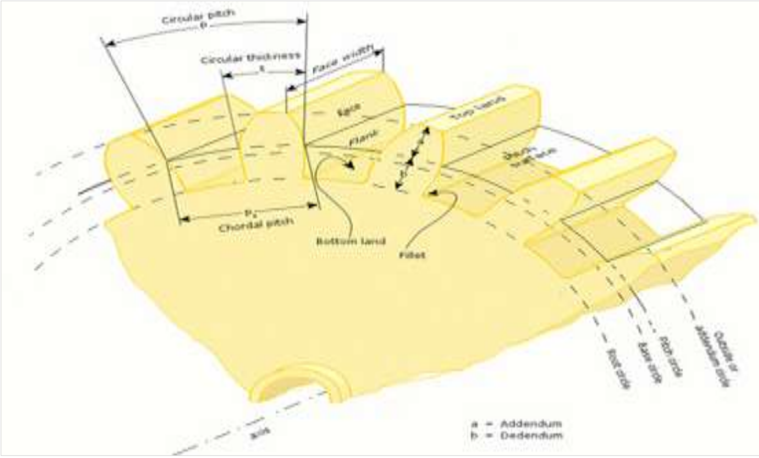

Figure 2: Involute of Spur gear (courtesy: SDP)

4. Pitch (P): The pitch is the distance between corresponding points on adjacent teeth along the pitch circle. It's often expressed as the reciprocal of the diametral pitch and is used to calculate tooth dimensions.
5. Diametral Pitch (Pd): The diametral pitch is the number of teeth per inch of the pitch diameter. It's a measure of the size of the gear teeth and is commonly used in gear design and manufacturing.
6. Pressure Angle (ϕ): The pressure angle is the angle between the line of action (the line along which the force between meshing gears acts) and the tangent to the pitch circle. It determines the shape of the gear teeth and affects the load-carrying capacity and efficiency of the gear system.
7. Addendum (a): The addendum is the radial distance from the pitch circle to the top of the gear tooth. It represents the height of the tooth above the pitch circle and is essential for determining the clearance and engagement of meshing gears.
8. Dedendum (b): The dedendum is the radial distance from the pitch circle to the bottom of the gear tooth space. It represents the depth of the tooth space and is critical for ensuring proper clearance and meshing between gears.
9. Clearance (c): Clearance is the difference between the dedendum of one gear and the addendum of its mating gear. It provides space for lubrication and prevents interference between meshing gears.

Table1: Specifications of Spur Gear

S.no	Parameter	Formula	Value
1	Number of teeth(Z)	z	26
2	Module (m)	m	4.5
3	Pitch circle radius(R)	m× $N/2$	58.2
4	Clearance circle radius(R)	0.94× R_p	54.99
5	Addendum circle radius(r)	R_p+m	63
6	Dedendum circle radius	R_p-1.25×m	52.875
7	Pressure angle	θ	20°

2.1 Objectives

The intention of this paper is to consider four materials to investigate working of Spur gear. Comparative study was performed on spur gear with Nitrided Steel, Aluminium alloy 5050, Aluminium-Lithium alloys and Compacted Graphite Iron. This research was aimed at the distribution of stress, deformation, of all the above-mentioned materials using Catia V5 Software on the Spur Gear having standard specification. This includes:

- To select the different materials, such as AL 5050, AL-LI alloy, compacted graphite iron, Nitrided steel, etc., for analysis of spur gear.

- To analyze the spur gear to find the stress distribution and strain deformation study using FEM and to identify optimum material.
- To compare the obtained results and analyse for the different materials of Spur gears. Find out the optimum material for the design of the spur gears.

2.2 Material Selection for Spur Gear

Nitrided steel is the strongest and hardest, followed by compacted graphite iron, Aluminium-lithium alloys, and aluminium 5050. Nitrided steel is also the stiffest, providing stability. However, factors like weight and cost should be considered too. Overall, Nitrided steel might be the most suitable for demanding applications due to its superior mechanical properties, while Aluminium alloys could be suitable for lighter-duty applications.

2.2.1 Stress distribution analysis

By using FEA to analyze stress distribution in spur gears made of four different materials under various loads. Identify stress concentration areas to optimize gear design for uniform stress distribution, ensuring durability and reliability.

2.2.2 Strain deformation study

Finite element analysis (FEA) to understand stress distribution in spur gears of different materials under varying loads. Identify stress concentration areas to refine gear design for consistent stress distribution, ensuring durability and reliability.

2.3.1 Properties of Aluminium Alloy 5050

- Al alloys are well-known for being lightweight and easy to work with.
- They aren't very resistant to corrosion, meaning they can deteriorate when exposed to certain environments.
- Al alloys are great for machining, making them easy to shape and work with using various tools.
- Al 5050, in particular, is notable for its high strength and ability to withstand repeated stress without breaking easily.

2.3.2 Properties of Aluminium-Lithium Alloy

- They possess a high specific strength, meaning they're strong relative to their weight.
- AL-Li alloys are known for being lightweight due to their low density.
- AL-Li alloys are becoming more popular in aerospace and automotive sectors.
- These alloys enhance mechanical properties like stiffness, fatigue resistance, and damage tolerance, making them valuable in demanding applications.

2.3.3 Properties of Compacted Graphite Iron (CGI)

- It has better mechanical properties than regular gray iron and ductile iron.
- Its structure with connected graphite modules gives it strength, thermal conductivity, and ability to absorb vibrations.
- It's highly resistant to wear, stays stable under heat, and reduces noise.

2.3.4 Properties of Nitrided Steel

- Nitriding increases surface hardness, wear resistance, and fatigue strength.
- Gears made from Nitrided steels last longer and require less maintenance due to their superior hardness and toughness.
- Nitrided also improves resistance to corrosion and fretting fatigue, making it a viable choice for tough operating environments.

2.3.5 Strategy of the concept

The subsequent steps have been identified to attain the project objectives of designing and testing real spur gears with suitable properties as specified to develop a three-dimensional model of spur gear using CATIA V5.

- To develop a Finite Element prototype of spur gear and clarify the same make use of Ansys
- To intrigue the bending and contact stresses of different spur gears.
- Juxtapose the results of Nitrided Steel spur gear with Al alloy 5050, Al-Li alloys and Compacted Graphite Iron.

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- Summarize the findings and insights

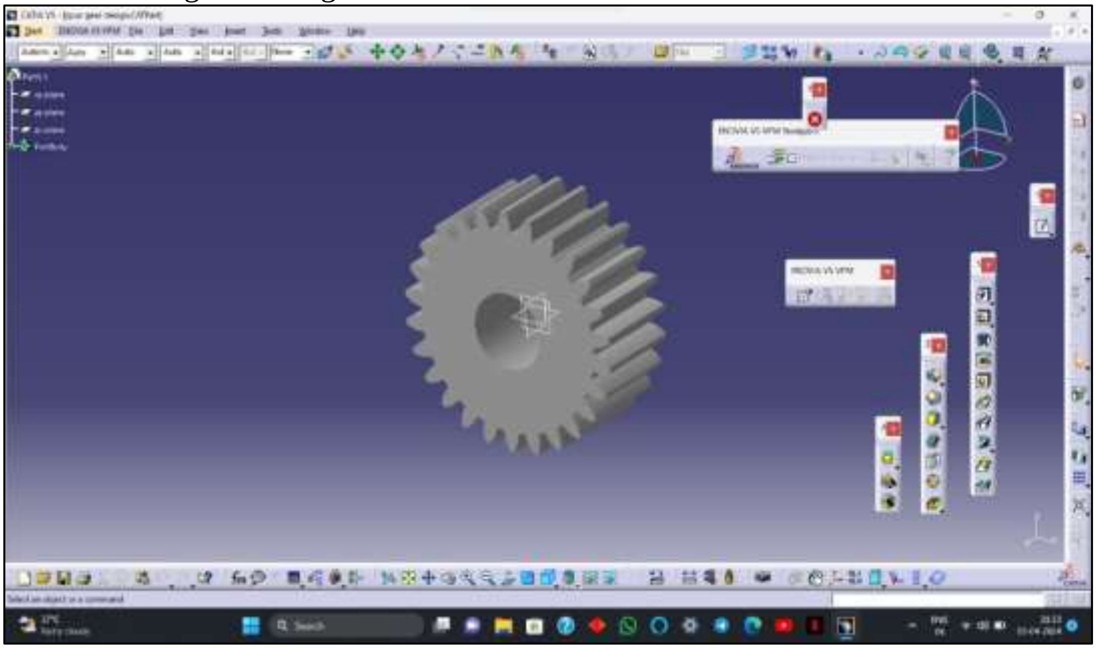

Figure 2: Design of Spur Gear with Meshing of Nodes 2104 of 7527 elements

2.4 Modeling

- The modeling approach for spur gear modeling executed using CATIA V5. The gear limiting factors are modelled as per the design calculation as shown in Figure 3.
- The Involute profiles are created using geometric construction techniques.
- The single involute creation is patterned using the circular array.
- The above created cross section was converted into a solid gear by extruding the gear to the face width calculated.
- The segment of the spur gear is terminated by a sketch circle

2.4.1 Design of spur gear using CATIA V5

Designing spur gears in CATIA V5, developed by Dassault Systems, based on specified dimensions. Created driver and driven gears according to provided specifications. Utilized CATIA V5's tools for accurate modelling and design. Ensured compatibility and functionality between driver and driven gears. Following industry standards and design guidelines for optimal gear performance. Prepared for further analysis and manufacturing processes.

2.4.2 Initiated steps in the Modelling of Spur Gear

The elaborated profile was generated using the dimensional setting up system as shown in the Figure3. The elaborated design was figured using the circular setup. The instance of the spur gear was completed in the Drawing mode. The above created cross section was converted into a solid gear by extruding the gear to the face width calculated above.

2.4.3 Initiated steps to resolve any Problem in Ansys

Like solving any problem analytically, we need to define follow as below

- Selecting the solution domain,
- Set the physical model,
- Select the boundary conditions and
- Set the pphysical properties.

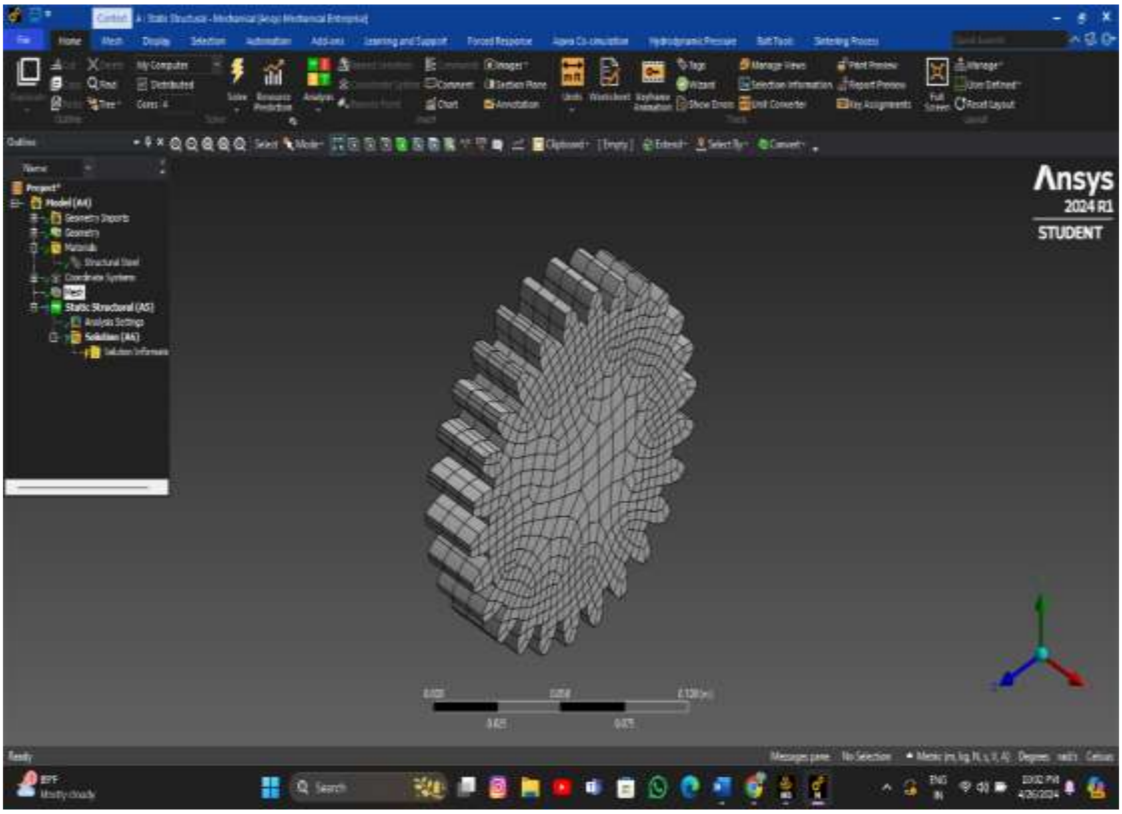

Figure 3: Generating the Mesh for Spur Gear

2.4.3.1 Build Geometry

Establish a two- or three-dimensional characterization of the article to be modelled and tested operate the work plane arrange order inside ANSYS

2.4.3.2 Define Material Properties

Now that the part is in place, define a library of important objects that list the objects (or functions) being modelled. This includes thermal and mechanical properties.

2.4.3.3 Generate Mesh

At this stage, ANSYS identifies the composition of the component. Subsequently, it is essential to outline the process of dividing the modelled configuration into finite elements.

2.4.3.4 Apply Loads

Upon the complete design of the system, the final step involves imposing constraints on the system, including physical loadings and boundary conditions.

2.4.3.5 Obtain Solution

This is undoubtedly a significant advancement, as ANSYS necessitates an understanding of the specific domain (such as steady state, transient, etc.) in which the problem exists.

2.4.3.6 Display the outcome

Once the response has been obtained, there are numerous methods to display the results from ANSYS. You may select from a variety of options, including tables, graphs, and contour plots.

2.4.4.1 Stress distribution in Ansys

Stress analysis plays a crucial role for engineers across various disciplines, including civil, mechanical, and aerospace engineering, among others. While commonly termed stress analysis, this process involves the evaluation of both stress and strain within a system to assess its response to external loads.

2.4.4.2 Strain distribution in Ansys

Strain is determined by taking the difference in directional displacements of paired nodes and subsequently dividing the change in length by the initial distance separating the nodes. The below-mentioned Table 2 is informing about the mechanical properties of Al 5050. Figure 4 explains about the Static case of the boundary condition of Al 5050. The below mentioned Figure 5 for Aluminium 5050 Von Mises stress values. The value of 2.42e+003 is minimal and maximum value for is 8.35e+006 of von mises stress. The Figure 6 explains about the Translation displacement vector values. The minimal value is '0' and maximum value is 5.74e+003 for Al 5050 spur gear.

2.4.5 Analysis of Aluminium 5050 materials

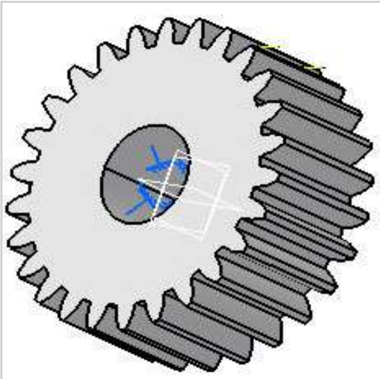

Figure 4: Static case of the boundary condition of Al 5050

Table 2: Mesh values with Mechanical Properties of AL5050.

Entity	**Size**
Nodes	2104
Element	7527
Young's Modulus	69000 N/m^2
Poisson's ratio	0.33
Density	2680 kg/m^3
Yield strength	105MPa
Coefficient of thermal expansion	140 W/m k

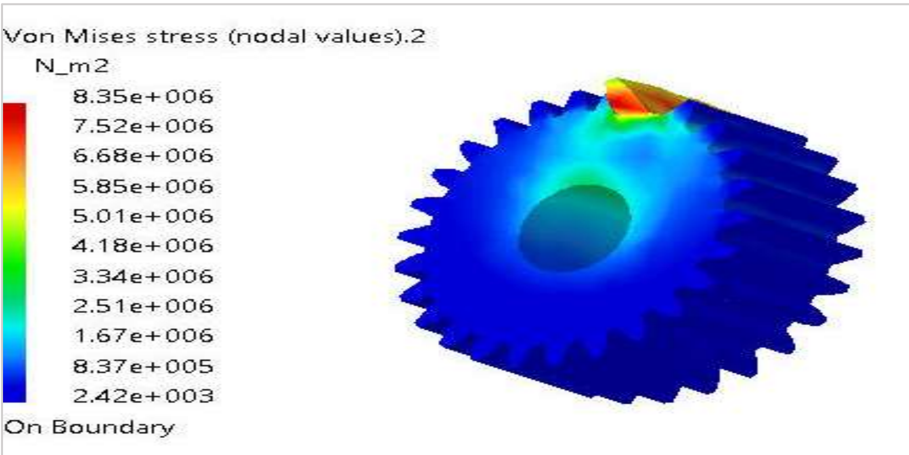

Figure 5: Von mises stress of Al 5050

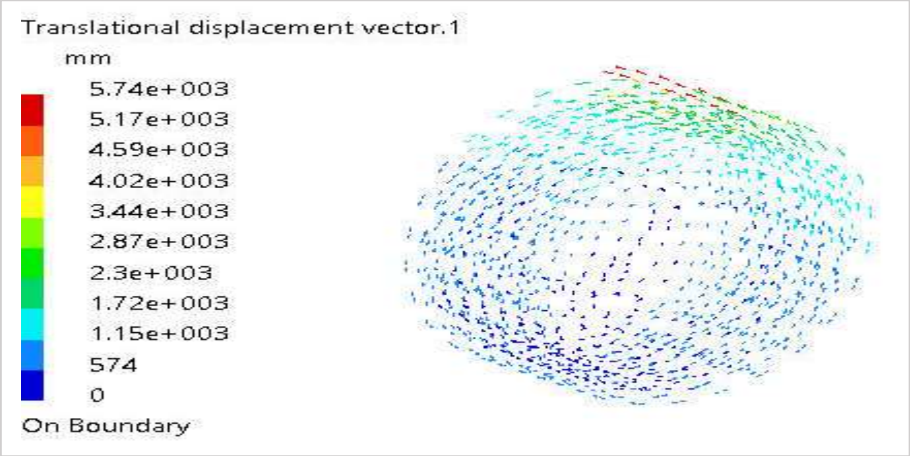

Figure 6: Translational displacement vector of Al 5050

2.4.6 Analysis of Nitrided Steels.

Figure 7: Static case of the boundary condition of NS

Table 3: Mesh values with Mechanical Properties of N S

Entity	Size
Nodes	2104
Element	7527
Young's modulus	2e+011N/m^2
Poisson's ratio	0.4
Density	0.00785kg/m^3
Yield strength	1000 MPa
Coefficient of thermal expansion	50 W/m k

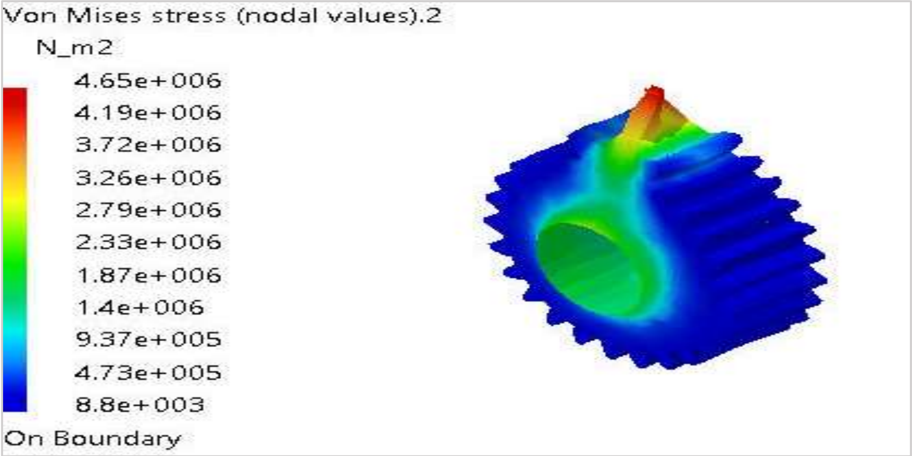

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Figure 8: Von mises stress of NS

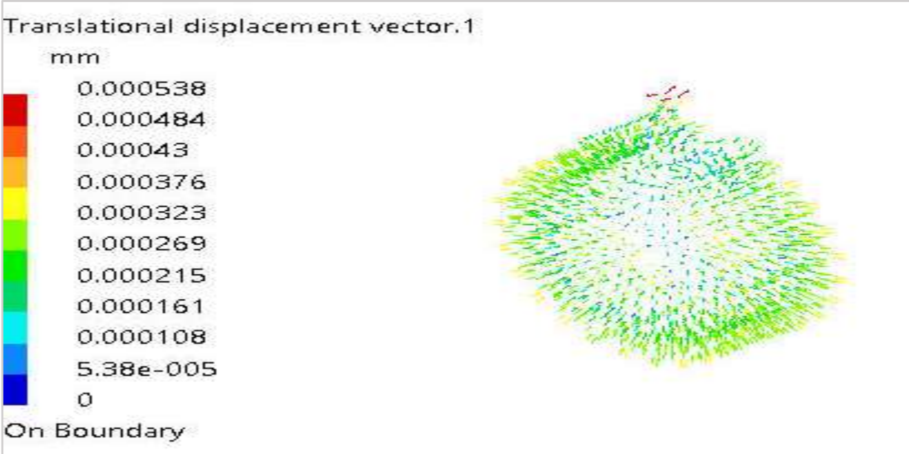

Figure 9: Translational displacement vectors of NS

The mentioned Table 3 is the information about the mechanical properties of Nitrated steel. Figure 7 explains about the Static case of the boundary condition of Nitrided Steel. Figure 8 explains about the Nitrated Steel Von Mises stress value is maximum as 4.65e+006 and the minimum stress value 8.8e+003 is observed. Figure 9 is explaining Translation displacement vector minimum value is recorded as 0 and maximum value recorded as 0.000538 for the above Nitrated Steel.

2.4.7 Analysis of Aluminium Lithium Alloy material Analysis

The mentioned Table 4. is informing about the mechanical properties of Al-Li alloy Spur Gear. Figure 10 explains about the Static case of the boundary condition of Al-Li alloy Spur Gear. The Figure 11 explains about the Al-Li stress Von Mises stress values. The obtained maximum and the minimum stress values are 2.42e+003 and 8.3e+006 recorded

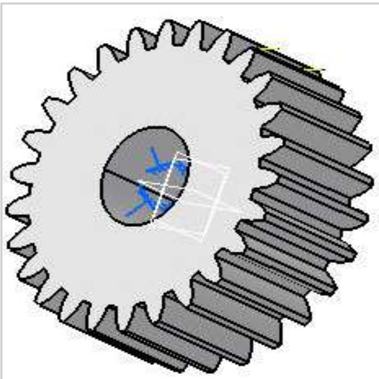

Figure 10: Static case of the boundary condition of Al-Li alloy.

Table 4: Mesh values with Mechanical Properties of Al-Li

Entity	Size
Nodes	2104
Element	7527
Young's modulus	96000 N/m^2
Poisson's ratio	0.33
Density	0.003kg/m^3
Yield strength	78 M pa
Coefficient of thermal expansion	150 W/m k

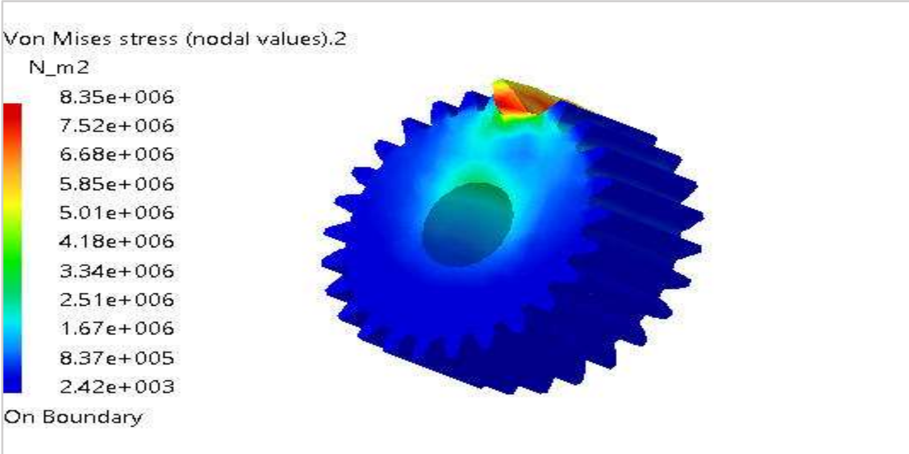

Figure 11: Von mises stress of Al-Li

2.7.4 Compacted Graphite Iron (CGI)

The mentioned Table 5 is informing about the mechanical properties of CGI Spur gear. Figure 12 explains about the Static case of the boundary condition of CGI Spur gear. The Figure 13 explains about the CGI Von Mises stress value 1.45e+003 is minimum and 3.33e+006 is maximum are recorded respectively. Figure 14 explaining about the Nitrated Steel Translation displacement vector values. The obtaining values of Translation displacement for Nitrated Steel observed minimum value as 0 and maximum value obtained as 0.000824 respectively.

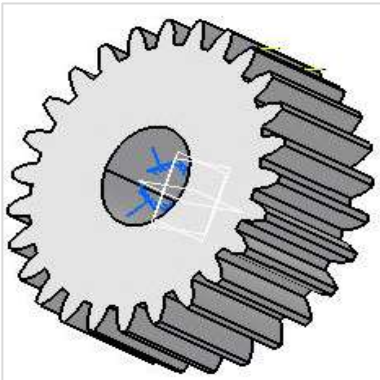

Figure 12: Static case of the boundary condition of CGI

Table 5: Mesh values with Mechanical Properties of CGI

Entity	Size
Nodes	2104
Element	7527
Young's modulus	150000 N/m^2
Poisson's ratio	0.4999
Density	$0.007 kg/m^3$
Yield strength	400 MPa
Coefficient of thermal expansion	60 W/m k

The above-mentioned Table 5 is informing about the mechanical properties of CGI Spur gear. Figure 12 explains about the Static case of the boundary condition of CGI Spur gear. The Figure 13 explains about the CGI Von Mises stress value 1.45e+003 is minimum and 3.33e+006 is maximum are recorded respectively. Figure 14 explaining about the Nitrated Steel Translation displacement vector values. The obtaining values of Translation displacement for Nitrated Steel observed minimum value as 0 and maximum value obtained as 0.000824 respectively.

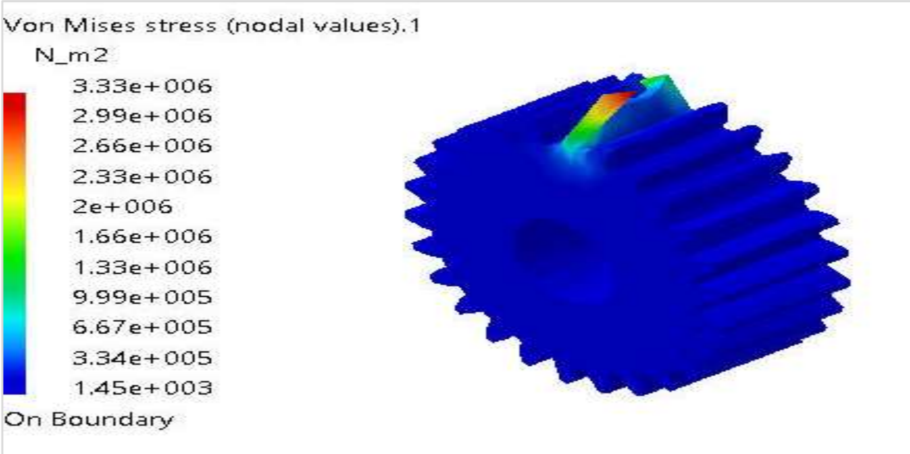

Figure 13: The above CGI stress value 1.45e+003 is min value and max value is 3.33e+006

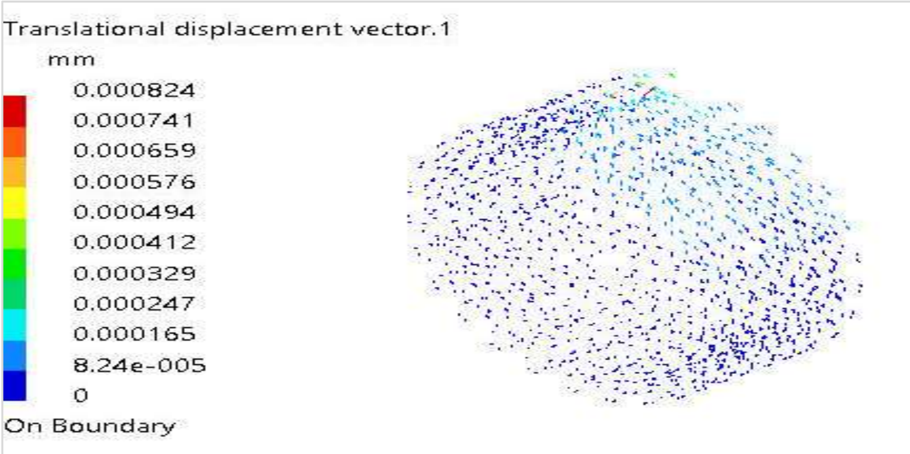

Figure 14: The above CGI Translation displacement vector

2.8 Direct Method computation

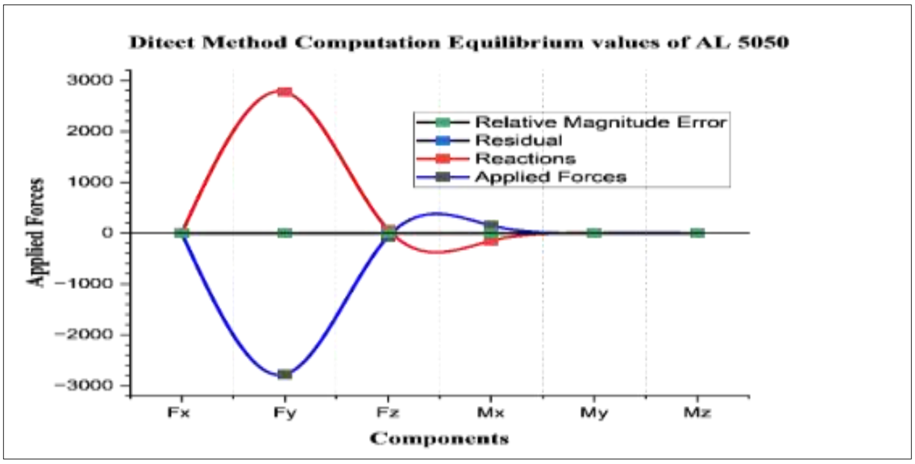

Figure 15: Direct method computation value for AL 5050 Spur Gears

In Ansys Fluent, the continuous method is a mathematical method for simulating sound waves by solving the fluid power equation. It is used to calculate how sound waves are generated and propagated. This free method is expensive and difficult because it requires: very accurate numbers, good computational meshes, and unpredictable boundary conditions. In this method, both the generation and propagation of sound waves are directly calculated by solving the appropriate water pressure equations.

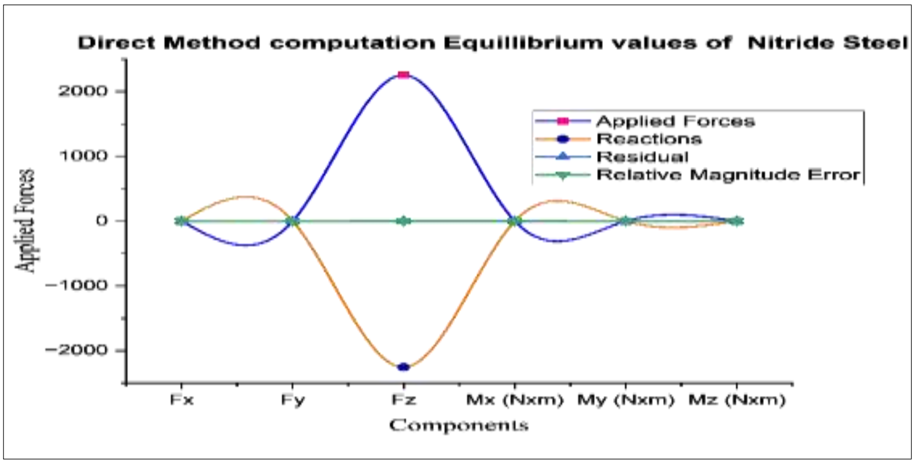

Figure 16: Direct method computation value for NS Spur Gears

The prognosticate of sound waves always requires an accurate solution for the design of the control system. Also, in many practical applications of this finite element method, one must use governing equations that can simulate viscous and turbulent effects, such as the unsteady Navier-Stokes equation (i.e., DNS)., RANS equations, and filtering equations used in DES and LES. The direct method computation values are simulated for the Al 5050, NS, CGI and Al-Li etc., material of spur gears for evaluating the accurate solutions for designing. In this direct method computation, the method of simulation to study on the Relative Magnitude error and Residual values, Reactions and Applied forces are considered for four mentioned materials of Spur gears.

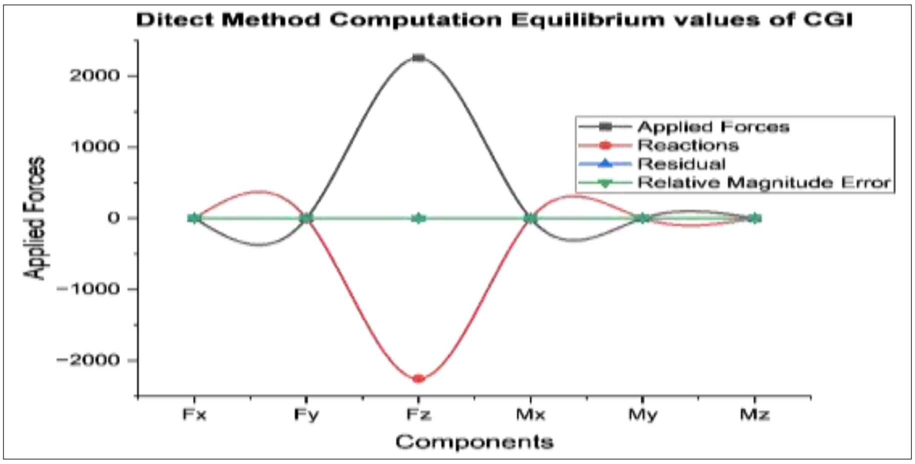

Figure 17: Direct method computation value for CGI Spur Gears

The mentioned, figures from 15 to 18 clearly shown about the Direct method computation values to evaluate the accurate solutions for the analysis on the selected material likewise AL 5050, NS, CGI and Al-Li materials for spur gears.In this computation results clearly mentioned in respective graphs are shown clearly. The Graphs are explaining about Components, Relative magnitude error, Applied Forces, residuals values, and Reactions values. Figure 19 clearly explained about the utmost and minimal values of the Von Mises Stresses for AL 5050, NS, CGI and Al-Li materials for spur gears. Figure 20 explains about the Youngs Modulus, Passions Ratio, density, Yield Strength and coefficient of thermal expansion values etc.,

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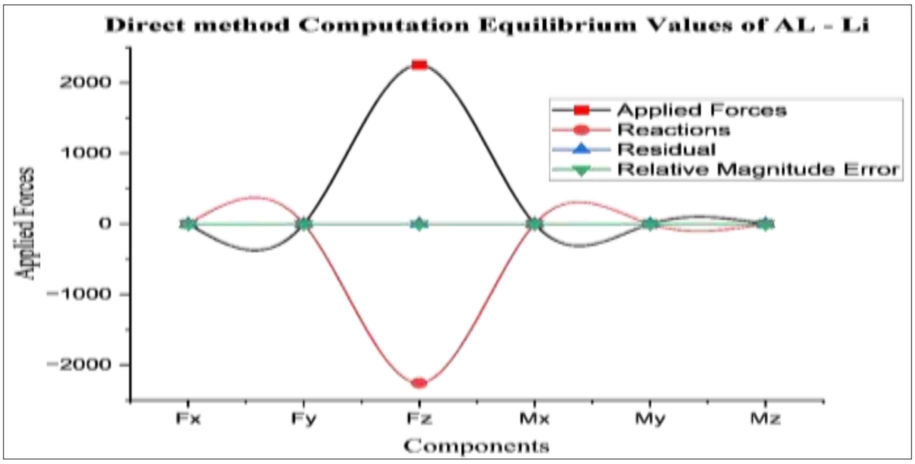

Figure 18: Direct method computation value for Al-Li Spur Gears

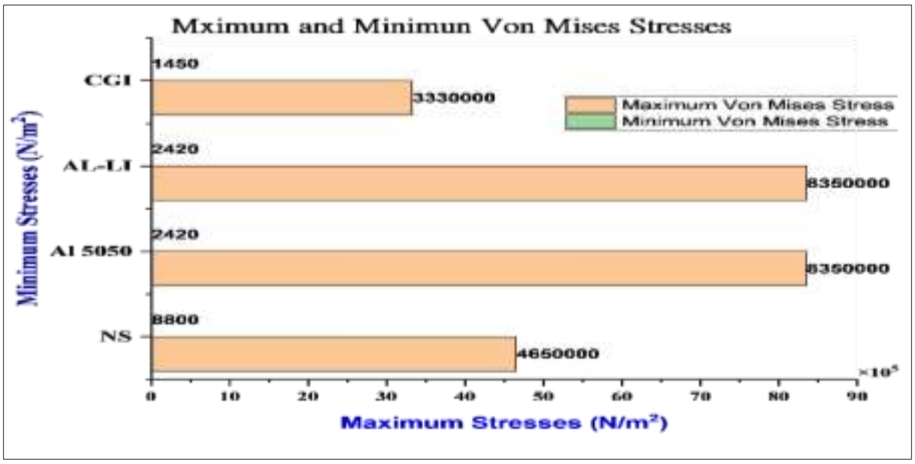

Figure 19: The utmost and minimal values of the Von Mises Stresses.

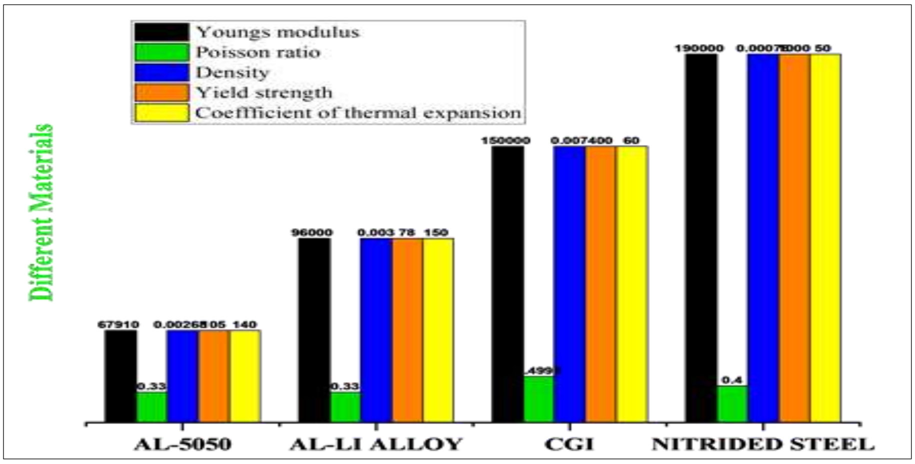

Figure 20: Comparison of different values for AL 5050, NS, CGI and Al-Li materials

III. Conclusions

After evaluating all the results carried out by Ansys R-24 software of four materials of

1. Stress distribution 2. Strain distribution 3. Co-efficient of thermal expansion

i. Stress distribution:

- For Al 5050 was obtained as maximum and minimum is 8300000 N/mm^2 and 2400 N/mm^2.
- For Al-Li alloy l is obtained as maximum and minimum is 8300000 N/mm^2 and 2400 N/mm^2.

- For CGI material is obtained as maximum and minimum is 3300 N/mm^2 and 1400 N/mm^2.
- For Nitrided Steel material is obtained as max and min is 4600000 N/mm^2 and 8800 N/mm^2.

ii. Strain deformation:

- For Al 5050 material is obtained as 5.517×103J
- For Al-Li alloy material is obtained as 8.041×10-2J
- For CGI material is obtained as 2.67×10-4J
- For Nitrided Steel material is obtained as 1.798×10-2J

iii. Coefficient of thermal Friction:

- For Al 5050 material was obtained as 5516.15J
- For Al-Li alloy material is obtained as 0.86J
- For CGI material is obtained as 2.678×10-4J
- For Nitrided Steel material was obtained as 0.018J

➢ From the Stress distribution effect that the NS material was obtained as 1.798×10^{-2}J is minimum.

➢ From the Strain deformation effect, it is evident that for NS material was obtained as 8800 N/mm^2 is minimum.

➢ From the Coefficient of thermal expansion results it is evident that for NS material spur gear was obtained as 0.018J is minimum.

Finally, after looking at the simulation results on the distribution of Stress, Strain Deformation, and Coefficient of Thermal Expansion for all materials, it is clear that the best material is Nitrided steel.

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