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FEA FOR STRESS REDUCTION AT THE ROOT OF THE SPUR GEAR

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Abstract: **This study presents a comprehensive analysis of spur gear roots employed in a shredder machine, utilizing Ansys Workbench for design and Finite Element Analysis (FEA) Static Structural analysis. The investigation focuses on the comparative performance of three materials: carbon steel, copper alloy, and cast iron. Through meticulous examination, the study evaluates the stress distribution and deformation patterns in the gear teeth under operating conditions, assessing the potential for fatigue failure. Furthermore, model analysis is conducted to measure vibration characteristics, providing insights into the dynamic behavior of the gears. By scrutinizing these aspects, the research aims to identify the most suitable material for the gear application, considering both structural integrity and vibrational stability, thereby enhancing the overall performance and longevity of the shredder machine.**

1. INTRODUCTION

This study presents a comprehensive investigation into the design and Finite Element Analysis (FEA) Static Structural analysis of spur gear roots utilized in a shredder machine, employing Ansys Workbench. The primary objective is to assess the structural integrity and performance of the gear teeth under operational loads. By comparing three different materials—carbon steel, copper alloy, and cast iron—the study aims to identify the most suitable material for the application. Additionally, model analysis is conducted to measure vibration characteristics, providing crucial insights into the dynamic behavior of the gears. Through meticulous examination of stress distribution, deformation patterns, and vibrational stability, this research seeks to enhance the durability and efficiency of the shredder machine, contributing to its optimal performance in industrial applications.

1.1Importance of Gear Root Analysis:

Gear root analysis holds significant importance in ensuring the reliability, safety, and efficiency of gear systems across various applications. Here are some key reasons why gear root analysis is important:
Fatigue Failure Prevention: The gear root is a critical area prone to fatigue failure due to cyclic loading. Analysing the stress distribution and fatigue life of the gear root helps in identifying potential failure points and implementing design improvements to enhance durability.
Optimization of Gear Design: By understanding the stress distribution and deformation patterns at the gear root, engineers can optimize the gear geometry, material selection, and manufacturing processes to minimize stress concentrations and improve performance.

Enhanced Reliability: Gear root analysis ensures that the gear teeth can withstand the operational loads and environmental conditions without premature failure. This enhances the reliability of gear systems, reducing downtime and maintenance costs.
Safety Assurance: Failure of gears in critical applications can lead to catastrophic consequences, including equipment damage, production losses, and even personnel injury. Gear root analysis helps in identifying potential failure modes and implementing preventive measures to ensure safety.
Performance Improvement: By analysing the structural behaviour of gear roots, engineers can identify opportunities for performance improvement, such as reducing weight, increasing load-carrying capacity, and minimizing noise and vibration levels.
Material Selection: Gear root analysis facilitates the comparison of different materials for gear construction. By evaluating factors such as strength, fatigue resistance, and cost, engineers can select the most suitable material that balances performance requirements with economic considerations.
Validation of Design Standards: Gear root analysis helps in validating design standards and guidelines, ensuring compliance with industry regulations and standards such as AGMA (American Gear Manufacturers Association) and ISO (International Organization for Standardization).

1.2 FEA Static structural analysis:

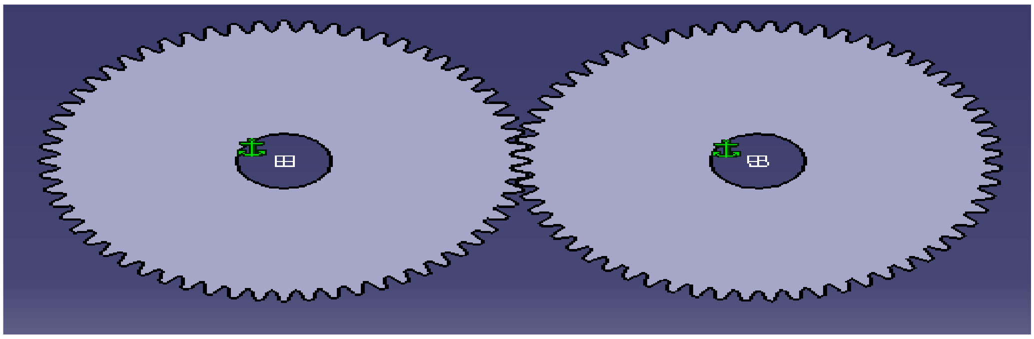
Finite Element Analysis (FEA) Structural analysis of spur gears using Ansys Workbench is a sophisticated engineering tool aimed at comprehensively evaluating the root causes, pressure distribution, stress levels, and deformation behaviour of gears under various loading conditions. By simulating real-world operating conditions, FEA enables engineers to identify potential failure modes and optimize gear designs for enhanced performance and reliability.
This analysis involves modelling the gear geometry, applying appropriate boundary conditions and loads, and utilizing advanced numerical techniques to solve the governing equations of structural mechanics. Moreover, FEA facilitates material comparison among steel, copper alloy, and cast iron, considering their physical properties such as tensile strength,
modulus of elasticity, yield strength, and density. Each material's suitability for gear applications can be assessed based on factors like wear resistance, fatigue behaviour, and cost-effectiveness, allowing engineers to make informed decisions in gear material selection.
Through this holistic approach, FEA Structural analysis serves as a powerful tool in the design and optimization of spur gears, ensuring they meet the stringent performance requirements of diverse industrial applications while maximizing operational efficiency and longevity.

FEA Here's a step-by-step methodology for solving a spur gear using static structural analysis in Ansys Workbench, along with material comparison between steel 4140, copper alloy, and cast iron, and modal analysis of steel 4140 material:

1. Import Geometry
   - Import the 3D model of the spur gear into Ansys Workbench.
2. Material Assignment
   - Define the material properties for steel 4140, copper alloy, and cast iron.
   - Input the appropriate material properties such as Young's modulus, Poisson's ratio, and density for each material.
3. Mesh Generation
   - Generate a finite element mesh on the spur gear geometry.

- Ensure that the mesh is refined in critical areas such as the gear teeth and root.

4. Boundary Conditions
   - Apply boundary conditions to simulate the loading and constraints on the spur gear.
   - Fix the bottom face of the gear to represent the mounting surface.
   - Apply torque or rotational displacement to simulate the gear's operating conditions.
5. Static Structural Analysis
   - Set up the static structural analysis in Ansys Workbench.
   - Define the analysis settings, such as the solver type, convergence criteria, and solution controls.
   - Run the static structural analysis to calculate the stress distribution, deformation, and safety factors in the spur gear.
6. Material Comparison
   - Analyse the results of the static structural analysis for each material (steel 4140, copper alloy, and cast iron).
   - Compare the stress levels, deformation characteristics, and safety factors to assess the performance of each material under the given loading conditions.
7. Modal Analysis (Steel 4140)
   - Set up a modal analysis for the steel 4140 material to analyse its vibration characteristics.
   - Define the analysis settings, such as the frequency range, mode extraction method, and boundary conditions.
   - Run the modal analysis to determine the natural frequencies and mode shapes of the steel 4140 spur gear.
8. Result Interpretation
   - Interpret the results of the static structural analysis and modal analysis to assess the performance and behaviour of the spur gear and steel 4140 material.
   - Identify any areas of concern such as high stress concentrations, excessive deformation, or resonance frequencies.
9. Optimization and Design Improvement
   - Use the analysis results to optimize the spur gear design and material selection.
   - Make design improvements to mitigate potential failure modes and enhance the performance and reliability of the spur gear.



Front View of 3D Model of Spur gear

Top View of 3D Model of Spur gear

2.PROPOSED SYSTEM

2.1 Introduction to 1st iteration:

The static structural analysis of a spur gear with steel 4140 material involves evaluating its response to external loading conditions to ensure reliability and performance. In this analysis, a loading moment of 79500 N-mm is applied to simulate the torque transmitted by the gear during operation. The gear is supported with frictional contact constraints to mimic its mounting and engagement within the machinery. Additionally, a remote displacement boundary condition is imposed to represent the gear's interaction with surrounding components, ensuring realistic behaviour under operational conditions. Through this analysis, engineers can assess the stress distribution, deformation, and safety factors within the gear to optimize its design for durability and efficiency in practical applications.

Material Data
Steel 4140
TABLE 1
Steel 4140 > Constants

Density	7.85e-006 kg mm^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	4.34e+005 mJ kg^-1 C^-1
Thermal Conductivity	6.05e-002 W mm^-1 C^-1
Resistivity	1.7e-004-ohm mm

TABLE 2
Steel 4140 > S-N Curve

Alternating Stress MPa	Cycles	Mean Stress MPa
3999	10	0
2827	20	0
1896	50	0
1413	100	0
1069	200	0
441	2000	0
262	10000	0
214	20000	0
138	1.e+005	0
114	2.e+005	0
86.2	1.e+006	0

2.1.1 Model Analysis:

In the model analysis of a spur gear using Ansys Workbench, the gear's natural frequencies and mode shapes are investigated to understand its dynamic behaviour in free conditions.

This analysis aims to identify the fundamental vibration modes of the gear without any external constraints applied. By conducting this model analysis, engineers can determine the critical resonant frequencies and corresponding mode shapes, which are essential for assessing the gear's structural integrity and potential vibration-induced failures.

The model analysis is performed for nine modes, capturing a comprehensive understanding of the gear's dynamic response.

Additionally, a frictionless support condition is applied to accurately simulate the gear's behaviour in a free state, ensuring realistic results for further analysis and optimization.

Through this model analysis, engineers can make informed decisions to enhance the design and performance of the spur gear, ultimately improving its reliability and efficiency in practical applications.

The following bar chart indicates the frequency at each calculated mode.

FIGURE 1

Model (B4) > Model (B5) > Solution (B6)

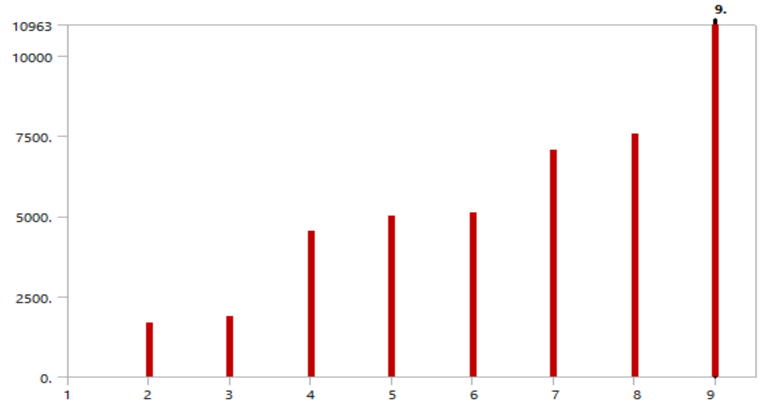


TABLE 3

Model (B4) > Model (B5) > Solution (B6)

Mode	Frequency [Hz]
1.	0.
2.	1692.2
3.	1892.1
4.	4550.6
5.	5009.3
6.	5119.8
7.	7071.2
8.	7570.9
9.	10963

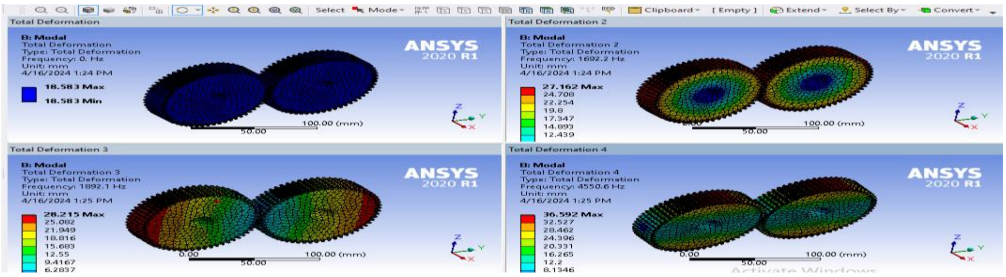


Figure Model analysis modes from 0-4

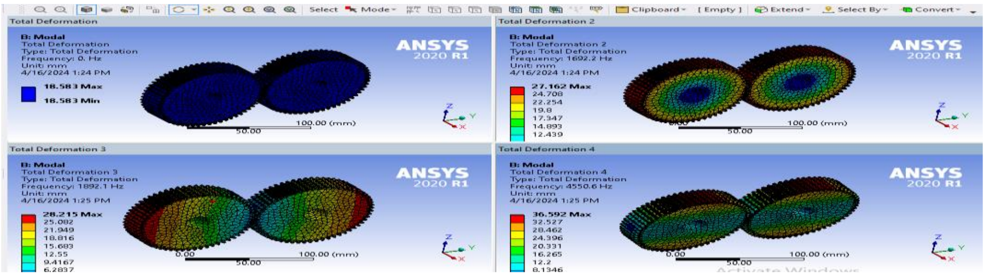


Figure Model analysis modes from 4-8

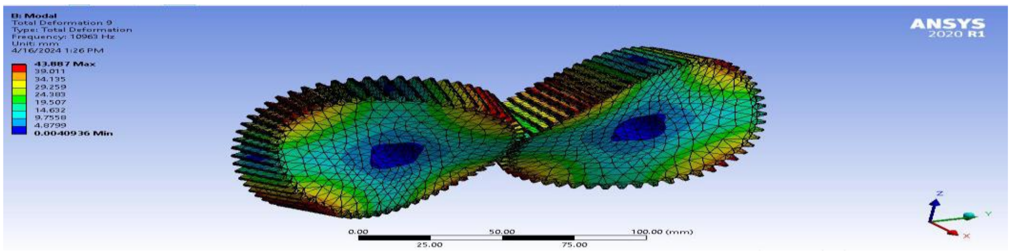


Figure Model analysis mode 9

2.1.2 Discussion:

The static structural analysis of the spur gear with Steel 4140 material, subjected to a loading moment of 79500 N-mm and frictional support with remote displacement boundary conditions, provides valuable insights into its performance and structural response. The total deformation of 0.017309 mm indicates the extent of displacement experienced by the gear under the applied load. This deformation, although minimal, signifies the gear's ability to withstand the load without undergoing significant deflection or distortion, ensuring its structural integrity during operation. Concurrently, the stress distribution within the gear material, measured at 168.19 MPa, reflects the internal forces induced by the applied loading conditions. This stress level falls within the material's allowable limits, indicating that the gear can effectively handle the applied load without risking failure. Moreover, the observed frictional stress of 122.74 MPa emphasizes the importance of considering frictional effects in gear design, underscoring the need for proper lubrication and surface treatments to minimize friction-induced wear and ensure efficient gear operation over time. Overall, these analysis results provide critical insights into the behavior of the Steel 4140 spur gear under operational conditions, guiding informed design decisions and ensuring reliable performance in practical applications.

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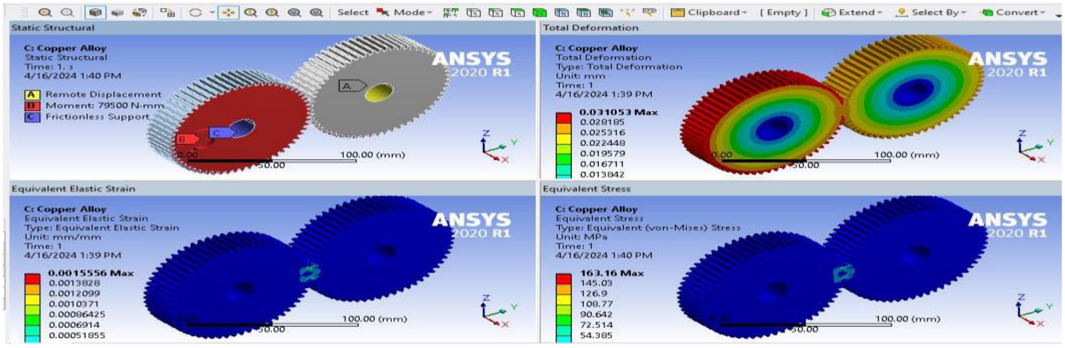
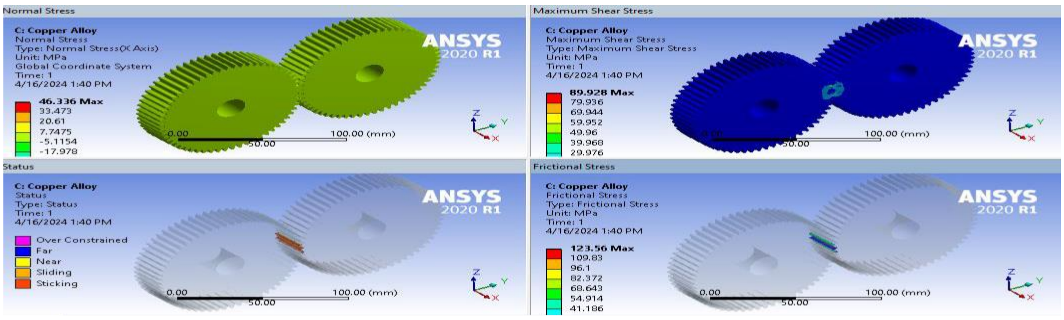
2.2 Iteration 2 - Copper Material:

The static structural analysis of a spur gear with copper alloy material aims to examine its response to external loading conditions for ensuring robustness and operational reliability. In this analysis, a loading moment of 79500 N-mm is applied to simulate the torque exerted on the gear during its operation within a shredder machine or similar equipment. The gear is supported with frictional contact constraints to emulate its mounting and engagement within the machinery. Furthermore, a remote displacement boundary condition is implemented to model the gear's interaction with surrounding components, thus capturing its realistic behavior under operational scenarios. Through this analysis, engineers can evaluate the stress distribution, deformation, and safety factors within the gear, facilitating the optimization of its design for enhanced durability and performance in practical applications.

Results					
Minimum	5.2367e-003 mm	1.85e-009 mm/mm	1.1937e-004 MPa	-69.43 MPa	6.8862e-005 MPa
Maximum	3.1053e-002 mm	1.5556e-003 mm/mm	163.16 MPa	46.336 MPa	89.928 MPa
Average	2.0705e-002 mm	1.4871e-005 mm/mm	1.5493 MPa	1.0574e-003 MPa	0.85212 MPa



a) Boundary Condition (b) Total Deformation (c) Strain & (d) Stress on Spur gear for copper material



(a) Normal Stress (b) Maximum shear stress (c) Status & (d) Frictional Stress on Spur gear for copper material

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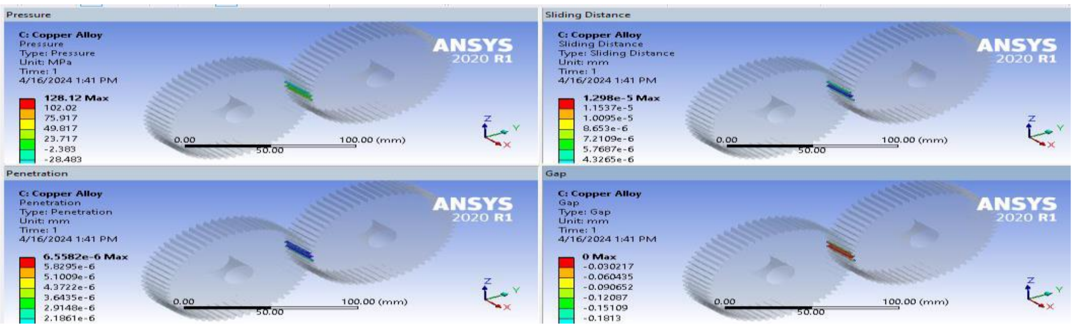

a) Pressure (b) Sliding Distance (c) Penetration & (d) Gap on Spur gear for copper material

Bounding Box	
Length X	25. mm
Length Y	204.54 mm
Length Z	107.83 mm
Properties	
Volume	3.6906e+005 mm³
Mass	3.0632 kg

2.2.1 Discussion:

The static structural analysis of the spur gear with a copper alloy material, subjected to a loading moment of 79500 N-mm and frictional support with remote displacement boundary conditions, offers valuable insights into its performance and structural response. The total deformation obtained, measuring 0.031053 mm, signifies the extent of displacement experienced by the gear under the applied load. This deformation, although small, indicates the gear's ability to withstand the applied load without experiencing excessive deflection or distortion, ensuring its structural integrity during operation. Concurrently, the stress distribution within the gear material, measured at 163.16 MPa, reflects the internal forces induced by the applied loading conditions. This stress level falls within the material's allowable limits, suggesting that the gear can effectively handle the applied load without risking failure. Moreover, the observed frictional stress of 123.56 MPa underscores the significance of considering frictional effects in gear design, highlighting the need for proper lubrication and surface treatments to minimize friction-induced wear and ensure efficient gear operation over time. Overall, these analysis results provide critical insights into the behavior of the copper alloy spur gear under operational conditions, facilitating informed design decisions and ensuring reliable performance in practical applications.

2.3 Iteration 3 Cast iron Material:

The static structural analysis of a spur gear with Gray Cast Iron material under a loading moment of 79500 N-mm and frictional support with remote displacement boundary conditions serves as a critical step in understanding the gear's behavior and ensuring its reliability in practical applications. Gray cast iron, known for its excellent wear resistance and damping properties, presents unique challenges and opportunities in gear design. By subjecting the gear to simulated loading conditions and incorporating frictional support with remote displacement boundary conditions, engineers can accurately assess factors such as stress distribution, deformation, and mode of failure, enabling informed design decisions and optimization strategies. This analysis aims to validate the gear's structural integrity, mitigate potential failure modes, and enhance its performance under operating conditions, ultimately contributing to the development of robust and efficient gear systems.

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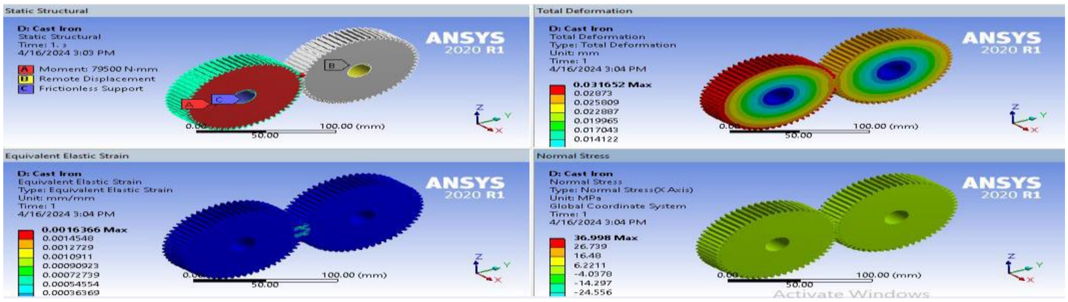
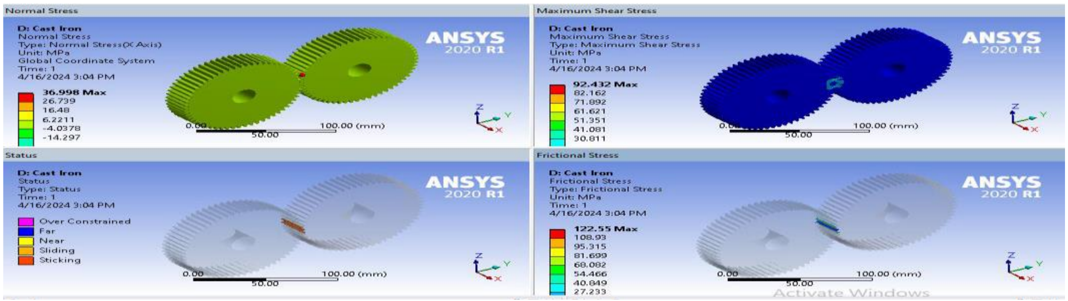
Bounding Box	
Length X	25. mm
Length Y	204.54 mm
Length Z	107.83 mm
Properties	
Volume	3.6906e+005 mm^3
Mass	2.6572 kg

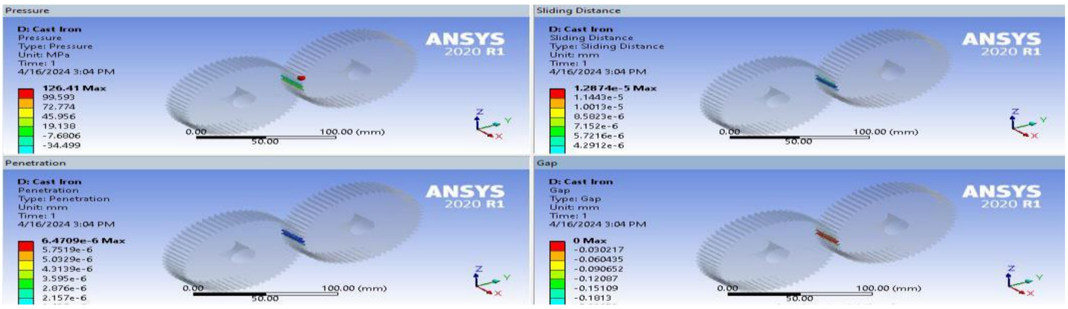
Table gray Cast Iron alloy bounding box for created geometry



(a) Boundary Condition (b) Total Deformation (c) Strain & (d) Stress on Spur gear for copper material



(a) Normal Stress (b) Maximum shear stress (c) Status & (d) Frictional Stress on Spur gear for copper material



(a) Pressure (b) Sliding Distance (c) Penetration & (d) Gap on Spur gear for copper material

Results					
Minimum	5.3562e-003 mm	1.2619e-009 mm/mm	1.1014e-004 MPa	-55.332 MPa	6.2012e -005 MPa
Maximum	3.1652e-002 mm	1.6366e-003 mm/mm	170.6 MPa	36.998 MPa	92.432 MPa
Average	2.1146e-002 mm	1.4885e-005 mm/mm	1.5468 MPa	8.9115e-004 MPa	0.84841 MPa

2.3.1 Discussion:

The static structural analysis of a spur gear with Gray Cast Iron material, subjected to a loading moment of 79500 N-mm and frictional support with remote displacement boundary conditions, yields crucial insights into the gear's performance and structural response. The total deformation obtained, measuring 0.031652 mm, indicates the extent of displacement experienced by the gear under the applied load. While this deformation is minimal, it highlights the gear's ability to withstand the load without significant deflection or distortion, ensuring its structural integrity during operation. Additionally, the stress distribution within the gear material, measured at 36.998 MPa, reflects the internal forces induced by the applied loading conditions. This stress level falls within the material's allowable limits, suggesting that the gear can effectively handle the applied load without risking failure. However, the observed frictional stress of 122.55 MPa emphasizes the influence of frictional forces on the gear's performance, underscoring the need for proper lubrication and surface treatments to minimize friction-induced wear and ensure efficient gear operation over time. Overall, these analysis results provide critical insights into the behavior of the Gray Cast Iron spur gear under operational conditions, guiding informed design decisions and ensuring reliable performance in practical applications.

RESULT

Sr.No	***Material***	***Total Deformation mm***	***Stress in MPa***	***Frictional Stress in Mpa***
1.	*Steel alloy* 4140	0.017309	168.19	122.74
2.	*Copper alloy*	0.031053	163.16	123.56
3.	*Gray Cast Iron*	0.031652	36.998	122.55

CONCLUSION

In conclusion, the design and static structural analysis of spur gear root tooth analysis, along with the comparison of results between Steel 4140, Copper Alloy, and Gray Cast Iron materials, provide valuable insights into material behaviour and gear performance under applied loads. The examination of deformation and stress characteristics reveals noteworthy findings that guide informed design decisions.

Among the materials analysed, Steel 4140 exhibits the lowest deformation, indicating its superior stiffness and resistance to bending under the applied load. This suggests that Steel 4140 may be the preferred material for applications where minimal deflection and precise gear meshing are critical factors.

Conversely, Copper Alloy demonstrates moderate deformation, highlighting its ability to withstand loading conditions while offering good formability and machinability advantages. This makes Copper Alloy a viable option for applications where a balance between mechanical performance and manufacturing ease is desired.

Remarkably, Gray Cast Iron exhibits lower stress levels compared to the other materials, despite experiencing slightly higher deformation. This suggests that Gray Cast Iron offers excellent ductility and damping properties, allowing it to absorb and distribute load-induced stresses more effectively. Consequently, Gray Cast Iron may be well-suited for applications where noise reduction and vibration damping are significant considerations.

Overall, while Steel 4140 excels in minimizing deformation, Gray Cast Iron stands out for its ability to maintain lower stress levels. Copper Alloy, on the other hand, presents a balanced performance profile. By carefully considering these material characteristics in conjunction with specific application requirements, engineers can optimize gear design for enhanced reliability, longevity, and performance in diverse industrial settings.

REFERENCES

[1] Seok-Chul Hwanga, Jin-Hwan Lee b, Dong-Hyung Lee c, Seung-Ho Hana, Kwon Hee Lee,Contact stress analysis for a pair of mating gears, Mathematical and Computer Modelling 57 (2013) 40–49 .

[2] Prashant Kumar Singh, Siddhartha, Akant Kumar Singh An investigation on the thermal and wear behaviour of polymer based spur gears, Tribology International 118 (2018) 264–272.

[3] R. Prabhu Sekar and R. Sathishkumar, Enhancement of Wear Resistance on Norma Contact Ratio Spur Gear Pairs through Non-standard Gears, Wear, http://dx.doi.org/10.1016/j.wear.2017.03.022.

[4] I.S. Al-Tubi, H.Long, J. Zhang, B.Shaw, Experimental and analytical study of gear micro pitting initiation and propagation under varying loading conditions, Wear328 329(2015)8–16 .

[5] Xiang Daia, Christopher G. Cooleyb, Robert G. Parkera,Dynamic tooth root strains and experimental correlations in spur gear pairs, Mechanism and Machine Theory 101 (2016) 60– 74 .

[6] Shutting Li et al. Centrifugal load and its effects on bending strength and contact strength of a high speed thin-walled spur gear with offset web, Mechanism and Machine Theory 43 (2008) 217–239.

[7] Xihui Liang, Hongsheng Zhang, LibinLiu , MingJ.Zuo, The influence of tooth pitting on the mesh stiffness of a pair of external spur gears, Mechanism and MachineTheory106(2016)1–15 .

[8] T. Osman, Ph. Velex et al, A model for the simulation of the interactions between dynamic tooth loads and contact fatigue in spur gears, Tribology International 46 (2012) 84–96.

[9] Santosh S. Patil, Saravanan Karuppanan, Ivana Atanasovska, Experimental measurement of strain and stress state at the contacting helical gear pairs, Measurement 82 (2016) 313–322.

[10] Ankur Saxena, Anand Parey, Manoj Cooksey, Effect of shaft misalignment and friction force on time varying mesh stiffness of spur gear pair, Engineering Failure Analysis 49 (2015) 79–91.

[11] Miriam B. Sánchez, Miguel Pleguezuelos, José I. Pedrero, Calculation of tooth bending strength and surface durability of internal spur gear drives, Mechanism and Machine Theory 95 (2016) 102–113.