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Ansys Simulations for Comparative Analysis of Structural Integrity in Differential Gearbox Materials

[1]Shimpi Saurabh Suresh, [2]Dr.Mayank Ladha, [3]Dr. Rahul Joshi

[1]Research Scholar, Dept. of Mechanical Engineering, Swami Vivekanand College of engineering, Indore (M.P.)

[2]Asscociate prof., Dept. of Mechanical Engineering, Swami Vivekanand College of engineering, Indore (M.P.)

[3]Asscociate prof., Dept. of Mechanical Engineering, Swami Vivekanand College of engineering, Indore (M.P.)

Abstract

This abstract provides a concise overview of a study focused on utilizing Ansys simulations to conduct a comparative analysis of structural integrity in differential gearbox materials. Differential gearboxes are critical components in various mechanical systems, including automotive transmissions. Ensuring the durability and reliability of these gearboxes is paramount for the overall performance and safety of the systems they are integrated into.In this study, we employ advanced finite element analysis techniques using Ansys software to evaluate and compare the structural integrity of different materials commonly used in manufacturing differential gearboxes. The materials under investigation include various metals and alloys, each with unique mechanical properties.

The simulations involve subjecting these materials to various mechanical loads, including torque, stress, and vibration, replicating real-world operating conditions. By analyzing the stress distribution, deformation, and fatigue characteristics of each material, we aim to identify the most suitable material for enhancing the longevity and performance of differential gearboxes.The outcomes of this research have broad implications for industries reliant on differential gearboxes, such as automotive, aerospace, and industrial machinery. The findings will contribute to informed material selection and design improvements, ultimately enhancing the structural integrity and durability of these critical components, leading to increased operational reliability and safety.

Introduction

Gears play an omnipresent role in diverse machinery, comparable to fundamental components like springs, nuts, and bolts. The evolution of gears in terms of materials and design has undergone substantial transformations over time. The origins of understanding gear rotation trace back to the 4th century B.C., notably attributed to Aristotle, who observed the reversal of gear rotation in interconnected gear wheels. Initially applied in contexts such as water wheels and clocks, the essential nature of gears remained relatively static until the 17th century. This period witnessed a surge in demand for conjugate profiles, with the significance of involute profiles taking center stage. Professor Robert Willis from Cambridge University revolutionized contemporary gear toothing by introducing hobbing machines and hob cutters, marking a pivotal juncture in gear technology. Subsequent advancements have continued to shape and refine the field.

Gears, which are broadly defined as toothed components designed to transmit or receive motion through the engagement of interlocking teeth, excel in comparison to friction-based drives like friction drums and belts when it comes to ensuring reliable motion transfer. Gears have a wide range of applications across various machinery, including automobiles, tractors, rolling mills, naval engines, lifting and hauling equipment, and metal-cutting machine tools. They are highly valued for their efficiency, compact design, dependable performance, and ease of use. However, the manufacturing of gears requires specialized machinery and tools, and any inaccuracies in the tooth milling process can lead to operational vibrations and noise.Whenever possible, the preference is for gears to be mounted on shafts with parallel axes or on shafts that intersect at right angles. One specific type of cylindrical gear, known as a spur gear, is characterized by teeth that create straight-line paths along the gear's surface

Advantages of Gears:

A wide range of machinery, including rolling mills, automobiles, material handling equipment, maritime power plants, and metal-cutting machine tools, incorporates gear drives for the following reasons

Fundamental Law of Gearing

The Fundamental Law of Gearing is a foundational principle in the realm of mechanical engineering and gear design. It articulates a crucial relationship between the number of teeth on gears and their angular velocities within a gear system. Essentially, it states that the product of the number of teeth on one gear and its angular velocity is equal to the product of the number of teeth on the other gear and its angular velocity. This law is expressed as $N1 * \omega1 = N2 * \omega2$, where N1 and N2 represent the number of teeth on the respective gears, while ω1 and ω2 denote their angular velocities. This law is of paramount importance in gear design as it allows engineers to predict and calculate the behavior of gear systems accurately. It plays a vital role in ensuring that gears mesh correctly, transmit power efficiently, and maintain the desired speed and torque ratios in a wide range of mechanical applications, spanning from the intricate transmissions of automobiles to the complex machinery used in various industrial processes. A solid grasp of the Fundamental Law of Gearing is indispensable for the design of reliable and effective gear systems in engineering and manufacturing, contributing to the efficiency and functionality of countless mechanical devices and systems.

Literature Review

Congfang Hu et. al. (2021) This study focused on dynamic load-sharing and random errors. Initially, a stochastic multi-body dynamics model was created for a planetary transmission with closed differentials. Next, the study compared the Taguchi method to the generated sampling and stochastic load-sharing behavior. It also examined how load-sharing performance is influenced by assembly and manufacturing tolerances. Finally, the results were validated through experiments on the main gearbox of a MW wind turbine.

Mehmet Sarıtaşet. al. (2021) In this study, a three-stage gearbox is subjected to stress analysis using the finite element analysis technique with the commercial software Ansys. The gearbox, which features triple reduction helical gears, is constructed using two types of steel, namely AISI 8620 and AISI 5115, both of which include 16MnCr5 steel. The research encompasses both dynamic and static structural analyses.

Prasad Matamet. al. (2021) This study paper summarized the findings of many investigations. The differential gearbox should be constructed from a mix of aluminum and other materials to save weight, while the gear design should make use of steel for its strength. A unique design might be used to construct a differential gearbox that has been changed. By modifying and incorporating a third inclination gear shift onto the crown wheel, we may potentially get one piece of information and three yields from the differential, as opposed to the prior one piece of information and two yields.

Prathamesh Patil et. al. (2021) The major purpose of this study is to examine the design of the gear assembly in an LMV's differential gearbox at 2000 RPM and 4400 RPM while the vehicle is transmitting power. The analysis also covers several gear materials, including cast iron, cast steel, and aluminum alloy. For the most part, gears and gear shafts are made of cast iron or steel. Aluminum alloy and nickel chromium alloy are two of the materials tested in this article for their potential to reduce the weight of the differential gearbox. As the speed increases, the displacement and stress analyses account for the weight loss in the gearbox. For the analysis, a program named Ansys is used.

SumeetShindeet. al. (2021) Determining the types and basics of the differential mechanism is the goal of this study. The many types of limited slip differentials and how they function are also the subject of the study. The automotive industry is one of the most cutthroat in modern times, with each month seeing the release of a brand-new model boasting state-of-the-art conveniences and performance features. The vehicle's performance is greatly affected by the research and development of automotive differentials.

Ravi et. al. (2019) This research delves into the examination of bending and contact stresses within an involute helical gear system, utilizing both analytical methods and finite element analysis. The aim is to enhance gear durability and ensure optimal design by reducing gear failure rates. The Lewis stress formula is employed in this study, simplifying certain calculations and making assumptions to identify peak stress concentrations in the assessment of equipment.

ShubhamPalveet. al. (2019) conducted a study on transmission errors produced by properly meshing gears, as well as contact stresses and bending stresses that occur in gear systems. When it comes to mechanical power transmission systems, wheel work is always considered a key component. A study of the contact stresses was carried out using finite element models. Placing a spring in the gap between the two contacting regions to generate a stiffness connection between them is a common technique that changes the FEM examination of contact concerns.

Methodology

General Procedure of Finite Element Method

The Finite Element Method (FEM) encompasses a systematic and comprehensive approach to solving complex engineering problems by dividing them into simpler, interconnected elements. The general procedure of the Finite Element Method involves several key steps, providing a structured framework for numerical analysis.

Problem Definition:

The first step involves clearly defining the problem to be analyzed. This includes specifying the physical geometry, material properties, loading conditions, and any applicable constraints or boundary conditions. A precise problem definition lays the foundation for the subsequent stages of the FEM.

Discretization:

The physical domain of the problem is discretized into smaller, geometrically simple elements. These elements collectively represent the entire structure or system under consideration. Common types of elements include triangles and quadrilaterals in 2D problems and tetrahedra and hexahedra in 3D problems.

Elemental Equations:

For each discretized element, the governing equations are established based on the physical laws governing the problem. These equations typically include equilibrium equations, compatibility conditions, and constitutive relations that define the material behavior.

Assembly:

The elemental equations are combined to form a comprehensive system of equations that represents the entire structure. This process involves aggregating the contributions from each element while ensuring the correct connectivity between nodes is maintained.

Application of Boundary Conditions:

Essential and natural boundary conditions are applied to the global system, reflecting the constraints and external forces acting on the structure. This step ensures that the analysis accurately represents the real-world scenario.

Solution of System Equations:

Numerical methods, such as matrix inversion or iterative solvers, are employed to solve the system of equations. The use of modern computational tools and software packages simplifies this process, enabling the handling of intricate calculations.

Post-Processing:

Once the solution is obtained, post-processing techniques are applied to extract relevant information. This includes visualizing stress distributions, deformation patterns, and other important parameters to gain insights into the behavior of the structure.

Validation and Verification:

The accuracy of the FEM analysis is validated by comparing the results with experimental data or analytical solutions, where available. Additionally, the numerical model is verified to ensure that it faithfully represents the physical system.

Optimization and Sensitivity Analysis:

The FEM can be employed for optimization studies and sensitivity analyses to explore different design scenarios and assess the impact of varying parameters on the system's performance.

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Results and Discussion

A mesh of few measurable components of the fundamental frame makes up the differential gear model that has to be studied. All segments are believed to use basic polynomial profile capabilities and nodal displacement to calculate the displacement distinction. Until the hidden nodal displacement is considered, the conditions for strains and stresses are not met. The resulting set of equilibrium conditions is presented in a highly modifiable grid.

Here we provide the findings of the simulation study obtained from Ansys, which is separated into three portions according to material-wise changes.

.Analysis of Differential gear with Copper Alloy material

This section presents the findings of an examination of a differential gear made of copper alloy. The results are plotted and photographs are obtained using an Ansys system. The chosen output parameters for this investigation are shear stress, equivalent stress, and deformation. Down below, you can see the figure displaying the differential analysis performed on Copper Alloy.

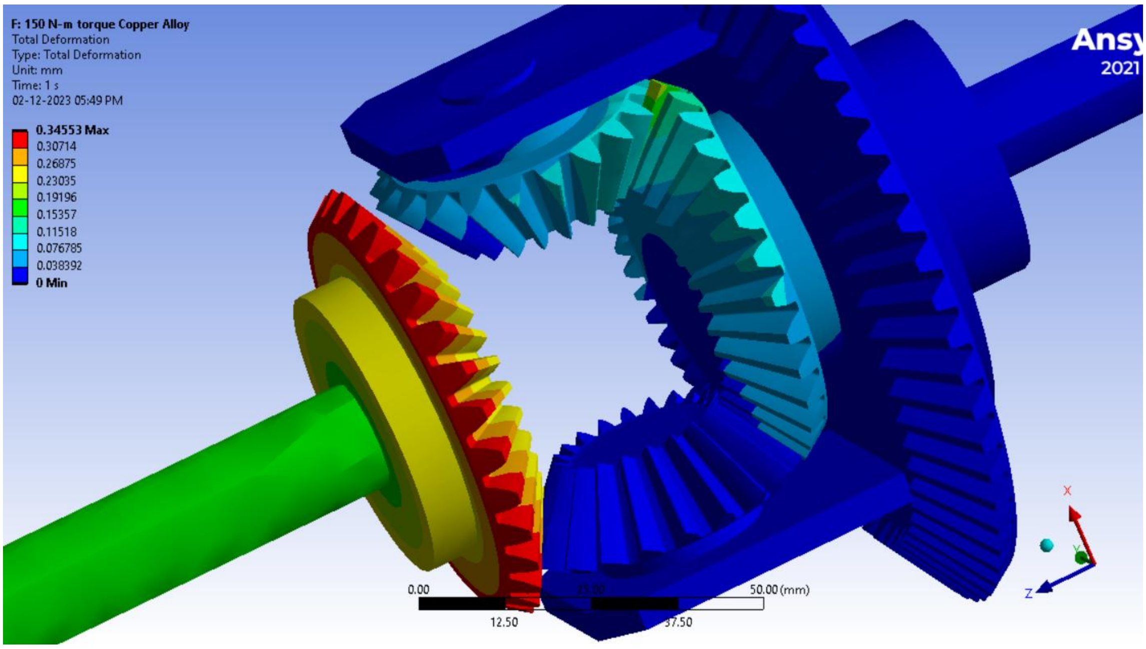

Figure 1: Total deformation of Gear assembly using Copper alloy material

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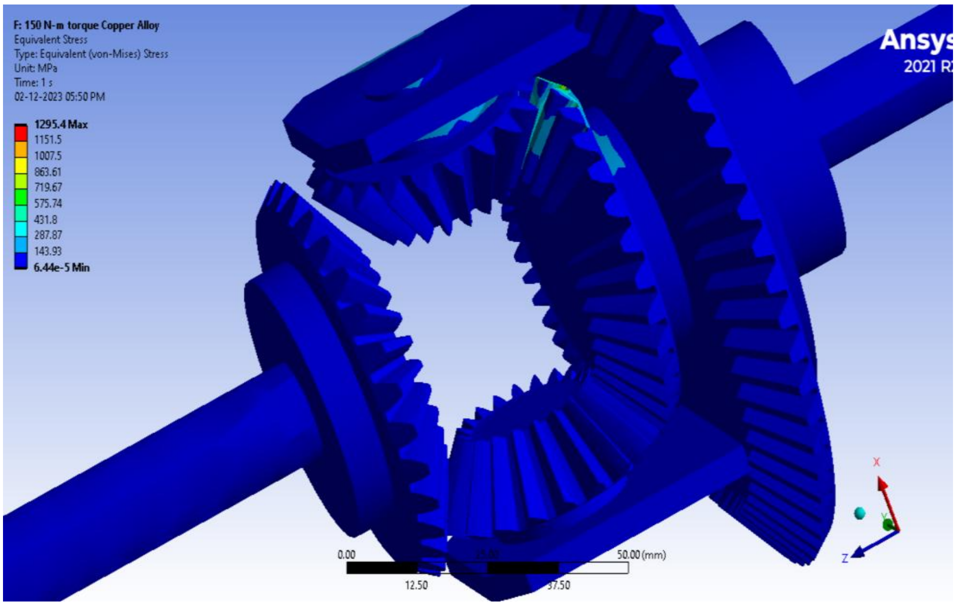

Figure 2:Equivalent Stress of Gear assembly using Copper alloy material

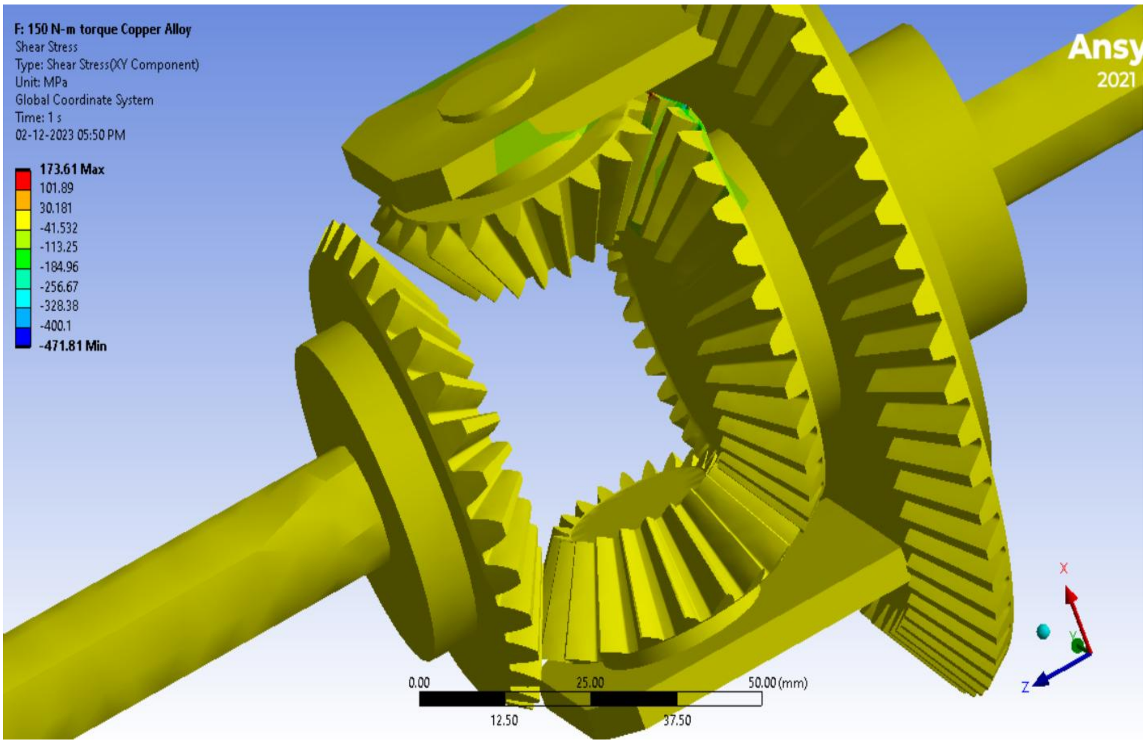

Figure 3: Shear Stressof Gear assembly using Copper Alloy alloy material

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Analysis of Differential gear with Cast iron material

The analysis of the differential gear that was carried out using cast iron material is shown in this part. All of the findings are plotted, and pictures are taken from Ansys as the analysis is being carried out.

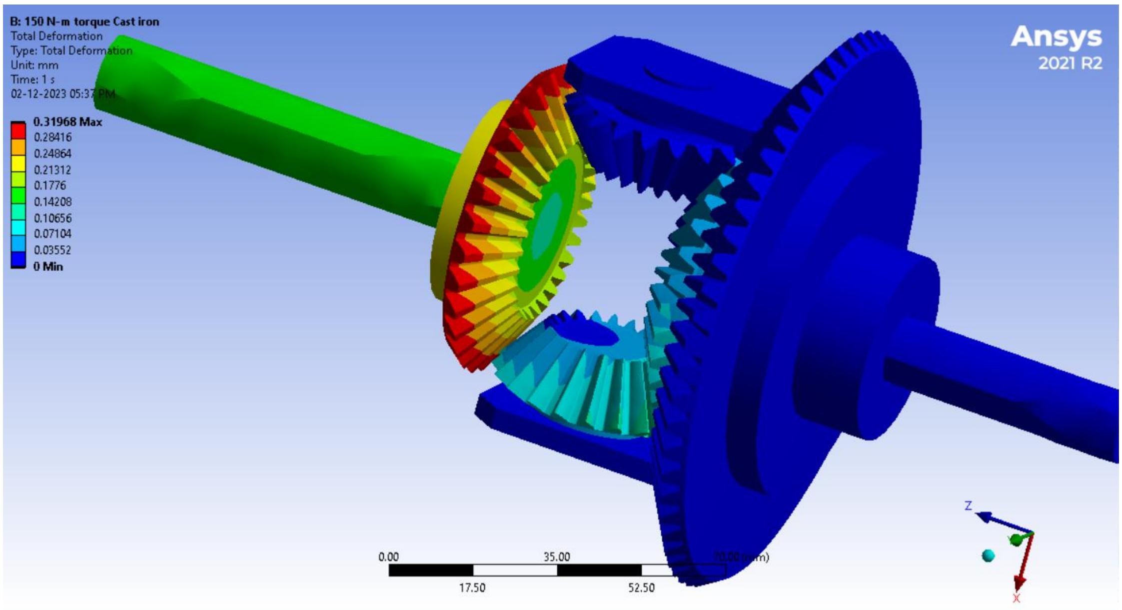

Figure 4: Total deformation of Gear assembly using Cast Iron material

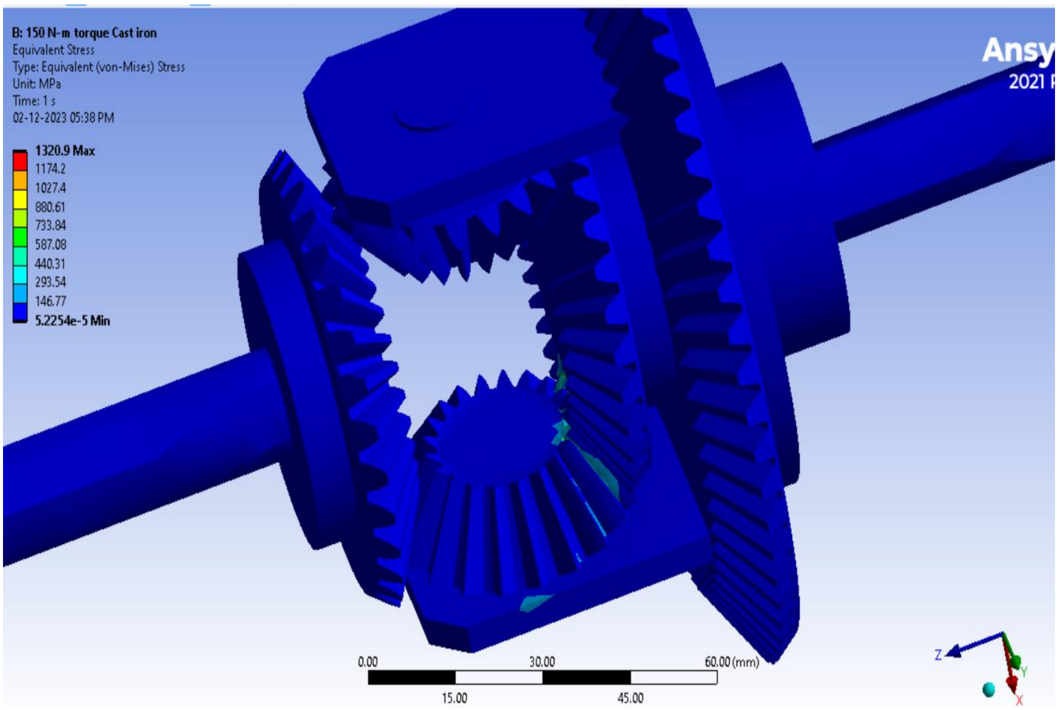

Figure 5: Equivalent Stress of Gear assembly using Cast Iron material

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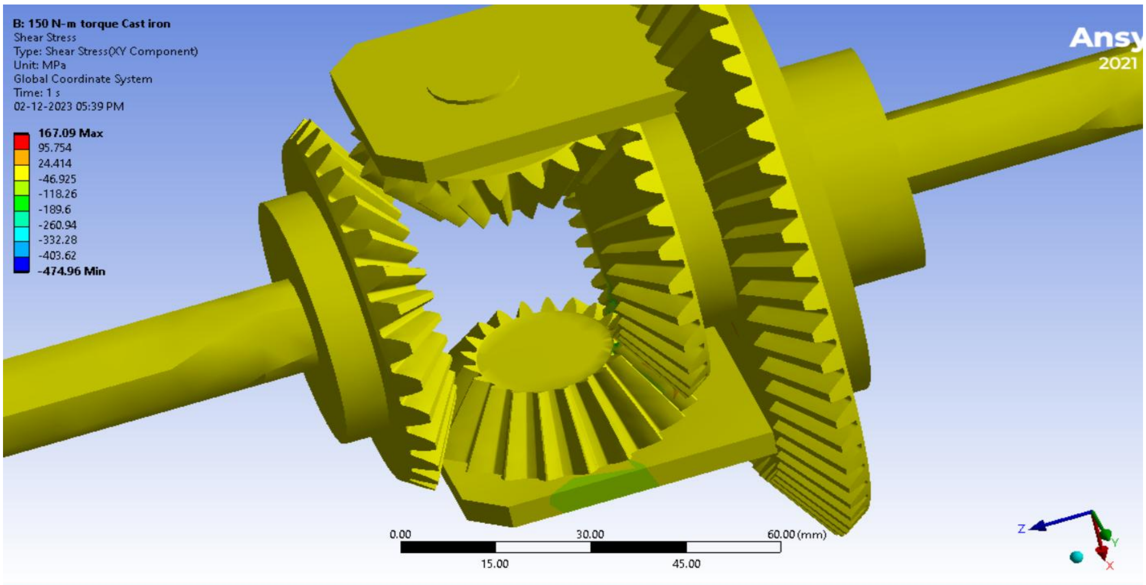

Figure 6: Shear Stress of Gear assembly using Cast Iron material

Analysis of Differential gear with Magnesium Alloy material

This article provides a comprehensive analysis of a differential gear constructed of magnesium alloy. Additionally, it includes graphs that illustrate the results and photographs that were taken by Ansys during the procedure.

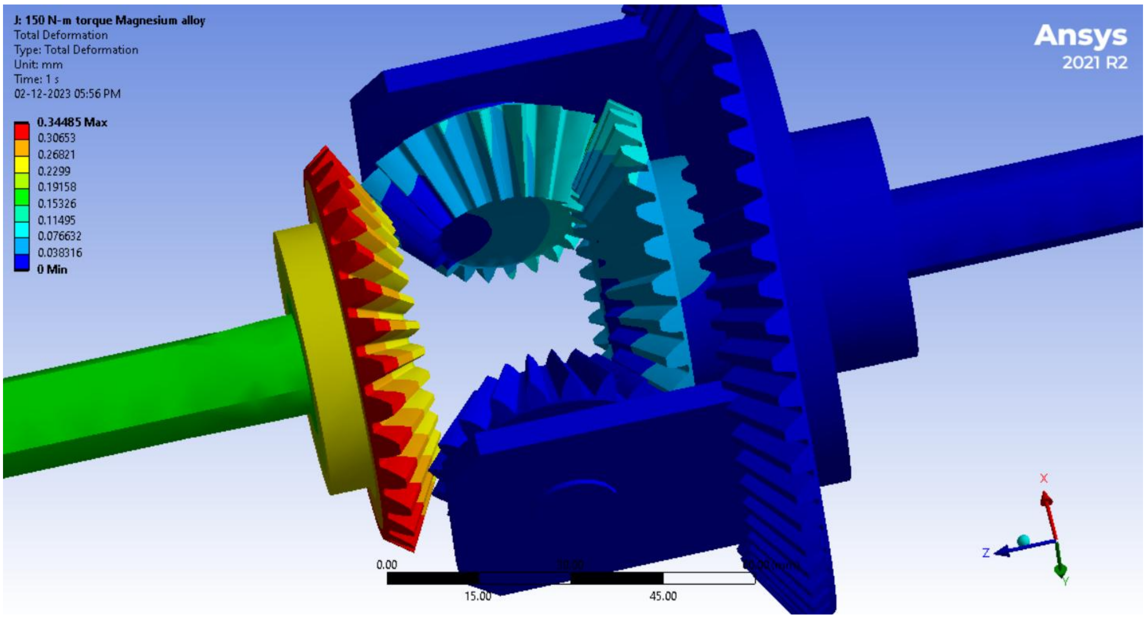

Figure 7**:** Total deformation of Gear assembly using Magnesium Alloy material

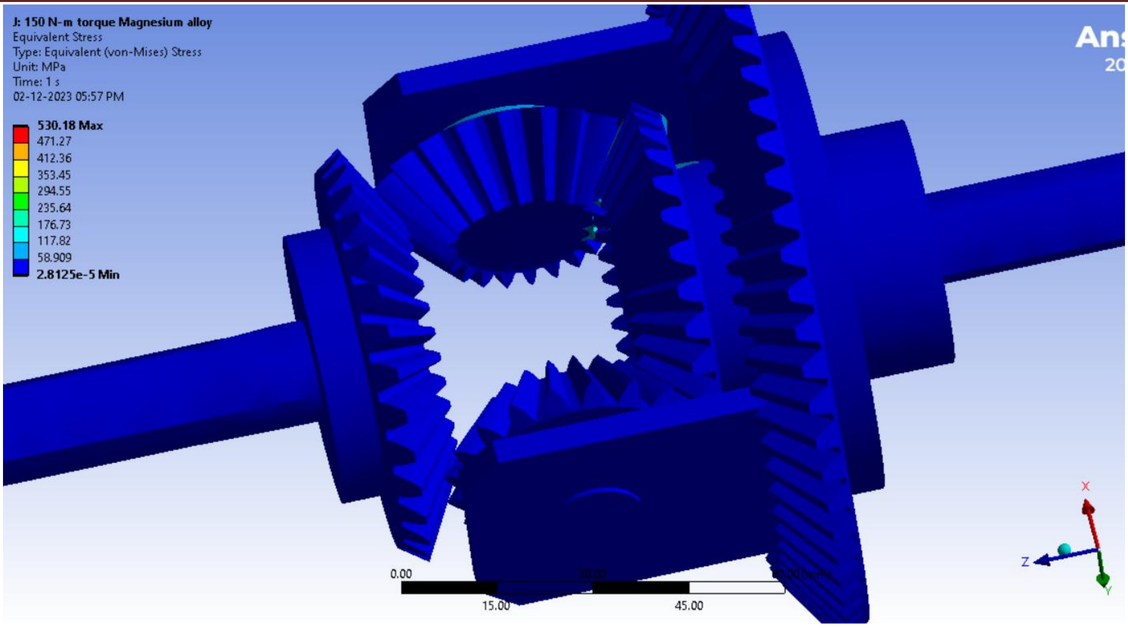

Figure 8:Equivalent stress of Gear assembly using Magnesium Alloy material

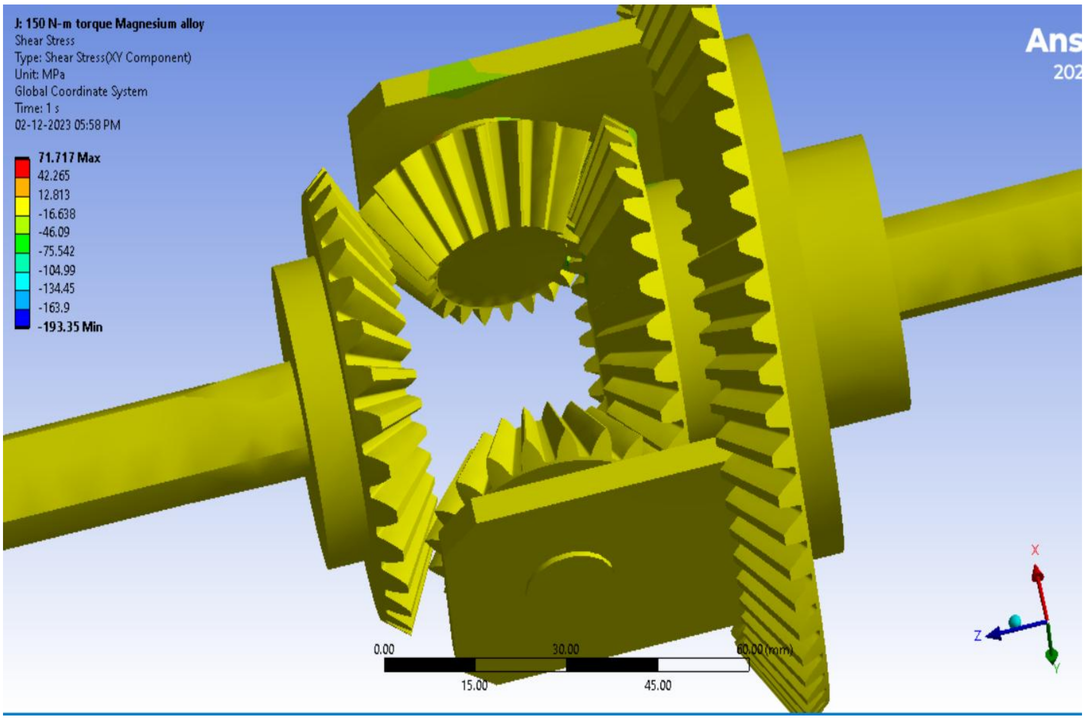

Figure 9:Shear stress of Gear assembly using Magnesium Alloy material

Figure 7 shows the overall deformation at 150 N-m torque, with a larger deformation of 0.3318 mm, as shown in the previous research. The highest equivalent stress was 2899.7 MPa in figure 8, while the maximum shear stress was 432.6 MPa in figure 9.

Total Deformations

A comparison of all of the deformations that were created in the differential gear model at different torques is shown in Table 1. The comparison is made using three different types of material variations.

Table 1: Total Deformations of Differential Gear model

Materials	Total Deformations (mm)			
	150 N-m	**500 N-m**	**1000 N-m**	**2000 N-m**
Cast Iron	0.3196	0.3197	0.31809	0.31653
Copper Alloy	0.3455	0.34502	0.34461	0.34351
Magnesium Alloy	0.3448	0.3439	0.313	0.339

The comparison of data is shown in Table 1, which reveals that the greatest deformation observed at Copper Alloy is 0.3455 mm when subjected to a torque of 150 N-m. There is a minimum deformation of 0.313 millimeters when the torque is 1000 N-m.

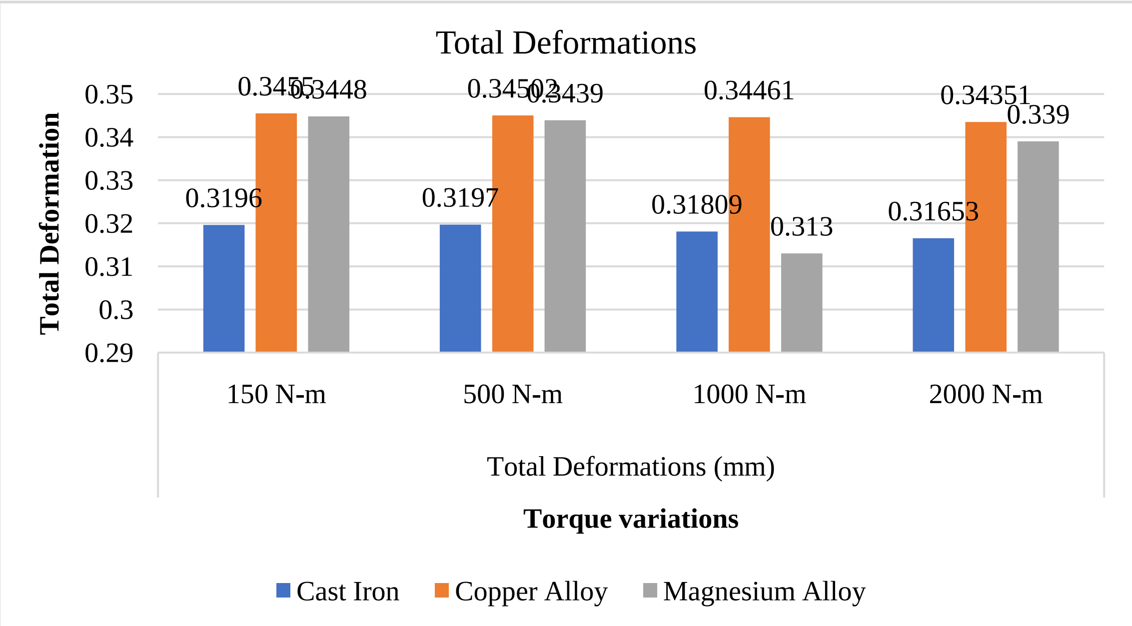

Figure 10: Comparison of Total Deformation of Differential Gear

Conclusion

In the findings of this analysis into the structural behaviors of differential gearbox materials, our exploration has traversed the intricate terrain of total deformations, equivalent stress (von Mises stress), and shear stress. As we navigate the realms of Cast Iron, Copper Alloy, and Magnesium Alloy under varying torque loads, the contours of their mechanical responses come into sharper focus. This journey has not only unravelled the material-specific intricacies but also laid the groundwork for informed decision-making in the realm of automotive engineering. In this conclusive chapter, we distill the essence of our findings, draw overarching implications for differential gearbox design, and envision pathways for future research and application. The revelations from the total deformations, stress distributions, and shear stress analyses converge to shape a narrative that advances our understanding of material dynamics within the critical components of automotive systems. As we traverse the key findings and their interconnections, the significance of this study becomes apparent in guiding the trajectory of future advancements and innovations within the automotive industry.

In this comprehensive study, we embarked on a detailed exploration of the structural behaviors exhibited by three distinct materials—Cast Iron, Copper Alloy, and Magnesium Alloy—within the context of a differential gearbox under varying torque loads. The investigation aimed to shed light on critical parameters, including total deformations, equivalent stress (von Mises stress), and shear stress, providing valuable insights for the design and selection of materials in automotive applications.

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