Comparative Static and Dynamic Analysis of Spur Gears Using Conventional and Advanced Materials in ANSYS

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***Abstract*—Gears are essential components in mechanical assemblies that transfer power and motion most effectively and efficiently from rotating shafts. The performance and service life of gear systems depend on the material used, particularly in applications that operate under high-load or high-speed conditions. In this paper, we conduct a comparison of spur gears, focusing on optimisation for mechanical efficiency and reduced weight through ANSYS-type analysis. The comparison is limited to the static and dynamic performance of spur gears, manufactured from conventional materials, Gray Cast Iron, and advanced materials, Bronze C51000 and Resin Polyamide / Nylon 66. Indicators to measure performance included stress contour maps, total deformation and directional deformation response of the gears, given the same set of boundary conditions. Based on the results of analysis, the conventional materials had greater stiffness where-as the advanced materials especially Bronze C51000 showed the best strength/weight ratio for gears or reasonable load-carrying capability with a huge weight reduction While the advanced materials used in flexible analysis show there may not be rigidly equivalent to conventional materials, its suitable for an application which requires a lightweight high-performance component. This study highlights the importance of material selection in developing durable, efficient, and lightweight components.**

***Index Terms*—Explicit Analysis, Gear Pair, Material Selection, Mechanical Strength, Nylon 66.**

I. INTRODUCTION

Gears are essential mechanical components used in many industries, playing a vital role in power transmission and motion conversion between parallel, intersecting and non-intersecting non-parallel shafts [1]. Among all gear types, spur gears are the most common, providing efficiency, ease of manufacturing, and high motion transfer on parallel shafts. When using gears such as spur gears, several performance-related factors should be considered, including external factors like geometry and operating conditions, as well as material selection, which affects strength, durability, and noise levels. Due to continuous progress in engineering, industries such as automotive and aerospace are increasingly seeking lighter and more diverse materials, thanks to new materials and manufacturing advancements. These industries focus on both static and dynamic analyses, emphasising the importance of accurately assessing critical factors such as stress, stress distribution, deformation, and vibration to ensure safety and enhance design, as well as component selection. Many researchers have utilised Finite Element Analysis (FEA) in ANSYS to investigate the static and dynamic performance of spur gears. In [2], a study provided evidence of high stress at the tooth root, which is consistent with Lewis Theory. In [3], it has been demonstrated that composite materials could potentially reduce weight while maintaining strength. In [4], the effect of tooth parameters of spur gears on contact stress using Hertzian contact theory has been alanysed. The impact of pitch deviation on the load-sharing capacity between tooth pairs of spur gears has been explored [5]. In [6], a multi-objective optimisation of gear pair parameters using genetic algorithms has been presented to minimise transmission volume and power losses. The importance of mesh design and material selection in spur gear analysis has been emphasised [7], while experiments were performed in [8] to validate their simulations. In [9], a study carried out a dynamic analysis of spur gears with a high contact ratio. Additionally, studies are focusing on the static and dynamic analysis of mechanical components made from composite materials. For instance, in [10-11], a fatigue analysis of connecting rods made from composite materials. This study performed static analysis to evaluate stress and deformation under steady loads, along with explicit dynamic analysis to assess behaviours under impact and time-dependent loading, simulating operational conditions. Three materials were selected to compare their performance in terms of shear stress, directional deformation, and total deformation across both simulation scenarios.

The rest of the paper is organised as follows. Section 2 covers the modelling of the spur gears, including material selection. Section 3 explains the detailed processes for both static and explicit dynamic analysis. Section 4 presents the simulation results in detail. The paper is summarised in Section 5.

II. DESIGN AND MODELLING OF SPUR GEAR

Spur Gear

Spur gears are common mechanical devices used for the efficient transmission of power and motion between parallel shafts. They have straight teeth parallel to the gear's axis, which makes them easy to design, produce, and simulate. During the design process, essential parameters such as module, number of teeth, pitch circle diameter, pressure angle, face width, and material choice are considered to ensure proper meshing, load transfer, and strength. Modelling spur gears with CAD tools enables the analysis of gear geometry, contact forces, and performance under various operating conditions. Their simple design also makes them suitable for high-efficiency, low-noise applications. The 3D model of the spur gear assembly was developed in the ANSYS Design Modeller, as shown in Fig. 1. The following dimensions were used to create the gear assembly model: number of teeth, 30; pitch circle diameter, 95 mm; inner circle diameter, 20 mm; pressure angle, 20°; and face width, 35 mm.

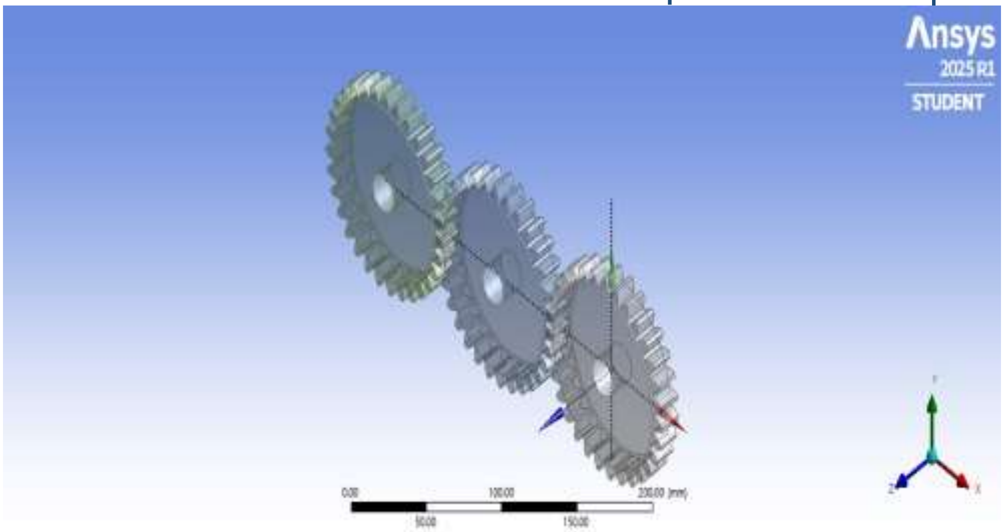

Figure 1. 3D Model development in ANSYS Design Modeller

Material Selection

Three materials were selected for comparison, each representing a range of engineering materials, from traditional to cutting-edge. The three materials chosen were Bronze C51000, Polyamide Resin (also known as Nylon 66), and Grey Cast Iron. Each material exhibited characteristics such as elasticity, density, and damping capacity, thereby demonstrating its suitability for performance purposes. The simulation conditions, including load and boundary conditions, were held constant to compare deformation and stress concentrations, primarily at the tooth root and to natural frequencies.

Bronze C51000 is the best choice among the three materials discussed earlier: Bronze C51000, Resin Polyamide (Nylon 66), and Gray Cast Iron, when considering mechanical properties. The material has a high tensile ultimate strength (5.745e+09 dyne/cm²) and excellent yield strength (5.05e+09 dyne/cm²). Bronze C51000 also exhibits high stiffness, allowing loads to be transmitted with minimal deformation, which helps it withstand forces in compression and tension while maintaining its shape. The material's high shear modulus is vital for durability during rotation, as in gear applications. Regarding ropes, while Gray Cast Iron can handle load in compression, it has no yield strength and is classified as a brittle material, making it ineffective under shock load failure. Nylon 66 is lighter, resistant to corrosion, and suitable for light loads and plastic gears, but it has very low strength and stiffness. Therefore, the series of Bronze materials offers the best balance of strength, wear resistance, and reliability, especially in industrial gear applications that require maximum mechanical performance over extended periods.

Table 1: Comparative Mechanical Properties of Bronze C51000, Nylon 66, and Gray Cast Iron for Engineering Applications

Properties / Material	**Bronze C51000**	**Nylon 66**	**Gray Cast Iron**
Density (g/cm^3)	8.715	1.14	7.2
Young's Modulus (dyne/cm$^{2)}$	1.077e+12	1.62e+10	1.1e+12
Poisson's Ratio	0.345	0.41	0.28
Bulk Modulus (dyne/cm^2)	1.1581e+12	3e+10	8.3333e+11
Shear Modulus (dyne/cm^2)	4.0037e+11	5.7447e+09	4.2969e+11
Isotropic Secant Coefficient (1/°c)	1.675e-05	0.00013	1.1e-05 1
Tensile Ultimate Strength (dyne/cm^2)	5.745e+09	-	5.4e+09
Tensile Yield Strength (dyne/cm^2)	5.05e+09	-	0
Compressive Ultimate Strength (dyne/cm^2)	-	-	8.2e+09

III. SIMULATION FRAMEWORK AND METHODOLOGY

To accurately estimate the physical behaviours of the system, implementing a systematic numerical modelling and simulation method is essential. This section outlines the key steps in finite element analysis (FEA), such as mesh generation, application of boundary conditions, setting convergence criteria, and running the simulation. A well-designed mesh ensures geometric accuracy and solution reliability, while appropriately applied boundary conditions replicate actual loads and constraints. Convergence criteria are established to produce stable and dependable results. Overall, this approach provides a comprehensive framework for evaluating system performance and verifying design assumptions.

Mesh Generation

Mesh generation is essential for analysing spur gears in ANSYS. It involves breaking down the gear shape into small finite elements to simulate stress, deformation, and contact precisely. A finer mesh is typically applied to gear teeth, as shown in Fig. 2, and contact areas to capture stress concentrations and enhance accuracy more effectively. ANSYS offers both automatic and manual mesh refinement options, allowing users to adjust element size, type, and quality as needed. The details of mesh generation with adaptive sizing are as follows; Nodes: 18888, Elements: 9810, Mesh Defeaturing: Yes, Defeature Size: Default, Transition: Fast, Span Angle Centre: Coarse, Initial Size Seed: Assembly, Error Limits: Aggressive Mechanical, Target Element Quality: Default (5.e-002), and Smoothing: Medium.

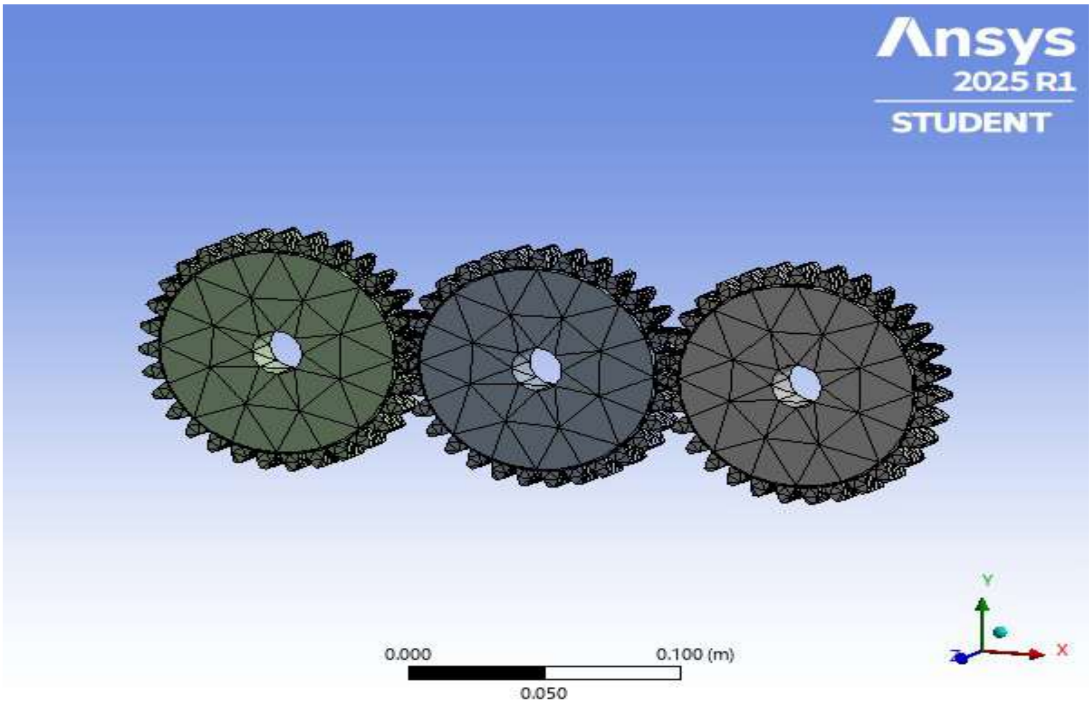

Figure 2. Mesh generated through the automatic refinement process

Boundary Conditions

In ANSYS, boundary conditions for static and explicit dynamic analysis of spur gear assemblies are set to ensure precise and efficient simulations. In static analysis, gear shafts are fixed to limit motion, with frictionless or symmetric supports used to simplify calculations. Torque is applied through remote displacement, and bearing effects are modelled with cylindrical supports. In dynamic analysis, initial angular velocity simulates sudden loading, with contact pairs using penalty-based friction. Non-reflective boundaries and damping manage stress waves and energy loss. These conditions help predict stress, deformation, and fatigue life under actual loading conditions.

Convergence Criteria

A convergence study was performed by adjusting the mesh element size in the simulation. Larger mesh elements decrease the number of equations that ANSYS must solve, reducing computational time, especially on less powerful systems. However, bigger elements can decrease result accuracy, especially for complex geometries, as they can't fully represent detailed surface features, causing deviations from the precise solution. Although this project utilises the student version of ANSYS, which has some restrictions for advanced analyses, the core idea of the convergence study, gradually increasing the element size during spur gear meshing, is effectively demonstrated.

Analysis Process

This section describes the analysis methodology used for assessing spur gear performance with ANSYS. It includes detailed flowcharts for both static and dynamic analysis workflows, showing key stages like modelling, material selection, meshing, boundary conditions, and result comparison to identify the optimal material for varying load scenarios.

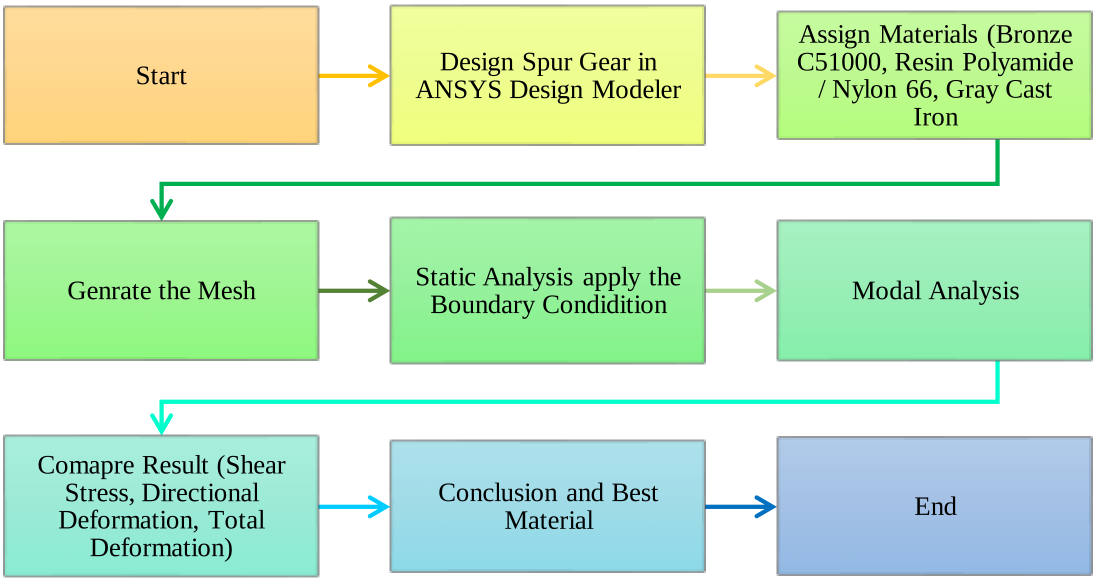

Figure 3. Flowchart of the Static Structural Analysis Process for Spur Gear in ANSYS.

The process of static analysis begins with the creation of the spur gear in ANSYS Design Modeller, followed by the assignment of materials like Bronze C51000, Nylon 66, and Grey Cast Iron, as shown in Fig. 3. Next, the gear model is meshed correctly. Static boundary conditions are then applied, followed by modal analysis to investigate vibrational characteristics. After the simulation is conducted, the outcomes—such as shear stress, directional deformation, and total deformation—are assessed for each material. Ultimately, conclusions are drawn from these performance indicators to identify the most appropriate material for gear applications.

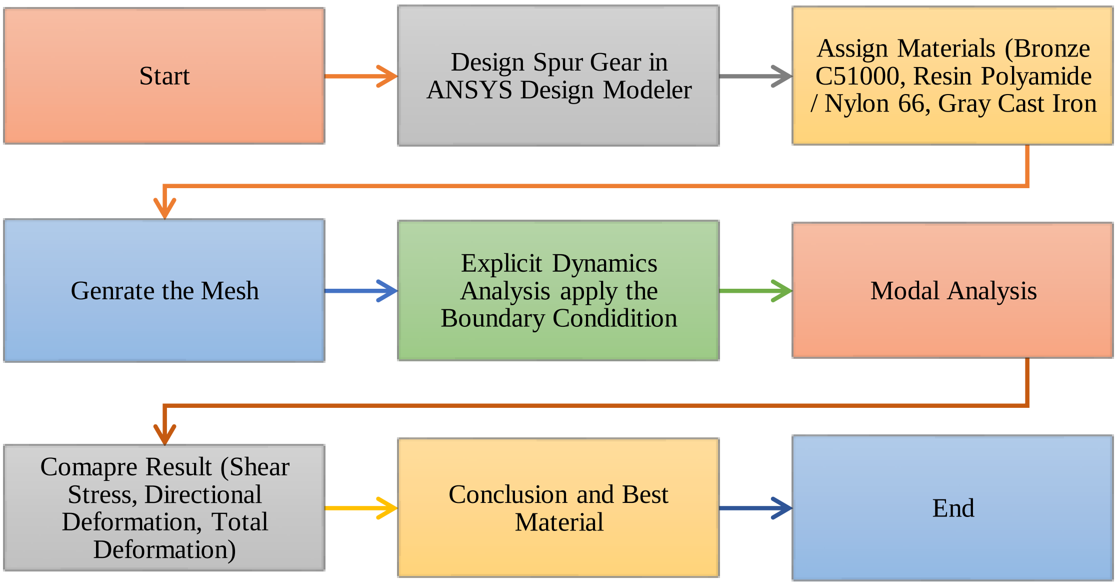

Figure 4. Flowchart of the Explicit Dynamic Analysis Process for Spur Gear in ANSYS.

In the dynamic analysis approach, the process begins with modelling gears and assigning materials as shown in Fig. 4. Following meshing, the model undergoes explicit dynamics analysis, which incorporates time-dependent boundary conditions to replicate operational forces in real-time accurately. A modal analysis is subsequently conducted to assess the vibrational characteristics of the model. The outcomes, including shear stress and deformation profiles, are then compared to evaluate how different materials respond to dynamic loads. Ultimately, the material that demonstrates the best performance under transient loading conditions is chosen as the optimal selection, signaling the conclusion of the analysis phase.

IV. Results and Discussion

This section presents the results and discussion derived from the static and dynamic analyses conducted on a spur gear using ANSYS. The mechanical performance of three distinct materials—Bronze, Nylon 66, and Gray Cast Iron—was evaluated under a range of loading conditions. Key findings, including shear stress, directional deformation, and total deformation, were compared across both static and dynamic simulations. The objective of this analysis is to identify the most suitable material by assessing the gear's behaviour under both steady and time-dependent loading scenarios.

Particular emphasis is placed on the simulation outcomes for Nylon 66 to avoid redundancy with findings associated with the other materials. This study also aims to explore alternative solutions, such as polymer composites, as replacements for traditional materials. By pursuing these alternatives, we strive to achieve substantial weight reductions in component design, thereby enhancing performance and efficiency. The exploration of innovative materials is pivotal for advancing engineering practices and promoting lightweight solutions across various applications.

Static Structural Analysis

The static structural analysis of the spur gear assembly is conducted utilising fixed support and displacement conditions on specific surfaces to replicate the support constraints experienced under static loading conditions accurately. In this analysis, certain components of the model are constrained to remain stationary, allowing for a zero-displacement scenario throughout the evaluation. The simulation results are comprehensive, illustrating key metrics such as shear stress distribution, directional deformation, and total deformation experienced by the assembly under the specified load. These findings are visually represented in Figs. 5-7, providing valuable insights into the performance and stability of the spur gear assembly under realistic operational conditions.

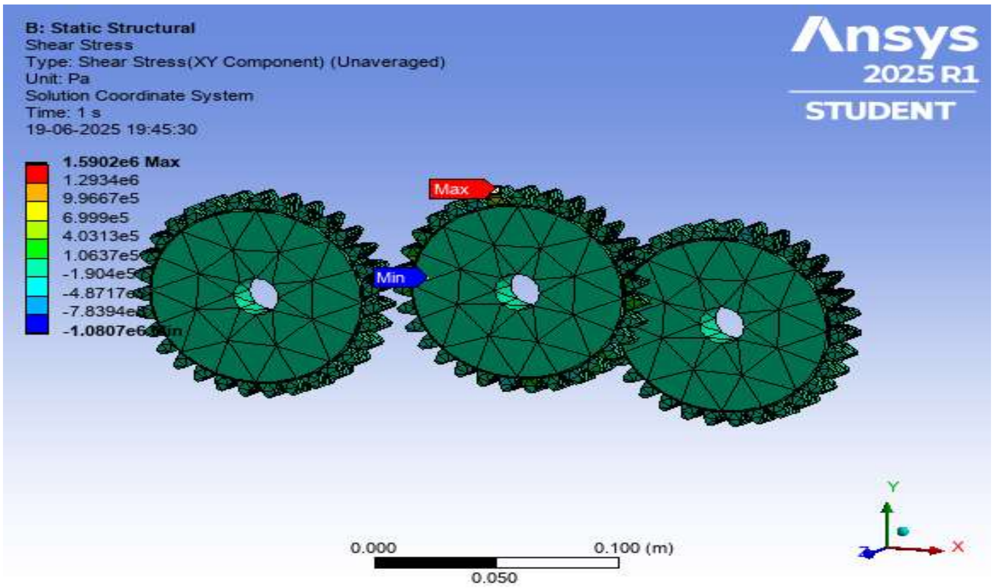

Figure 5. Shear Stress for Nylon 66

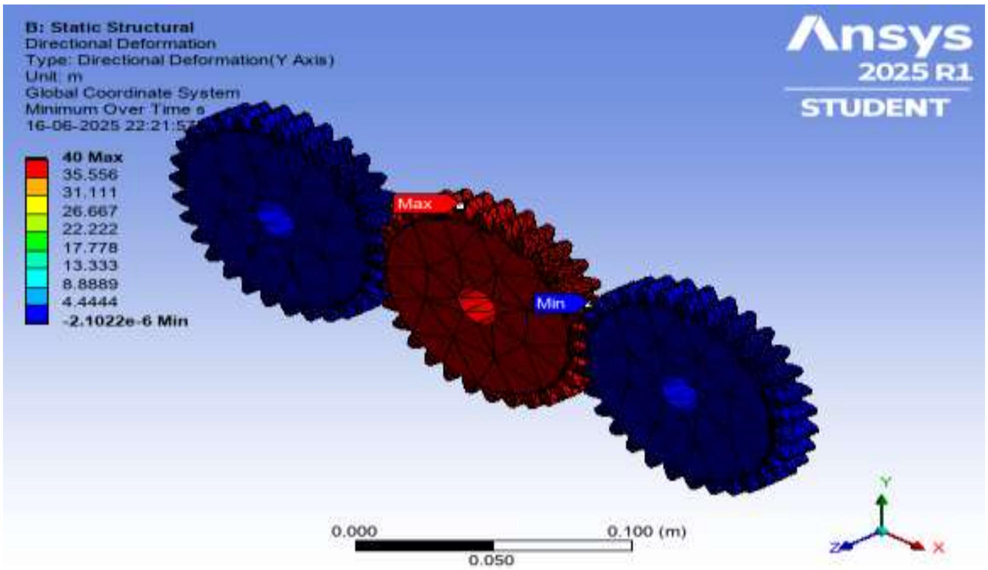

Figure 6. Directional Deformation for Nylon 66

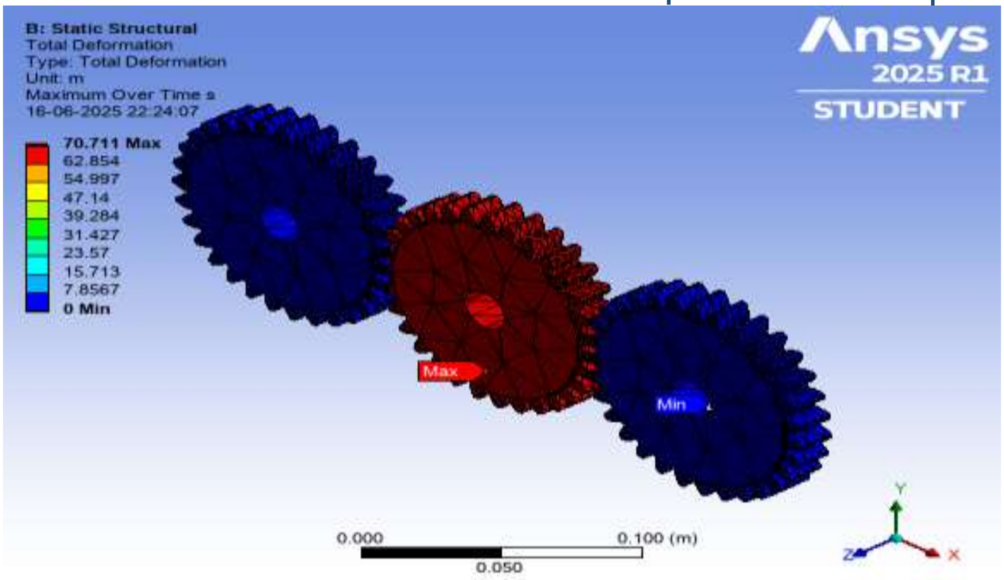

Figure 7. Total Deformation for Nylon 66

Explicit Dynamic Analysis

The explicit dynamic analysis of the spur gear assembly is performed by applying velocity and rotational velocity boundary conditions, enabling a realistic simulation of dynamic impacts and rotations. Instead of being fully constrained, the assembly's faces allow motion based on the velocity inputs. The simulation results are detailed, including key metrics such as shear stress distribution, directional deformation, and total deformation experienced by the assembly under the specified loads. These results are visually illustrated in Figs. 8-10, providing valuable insights into the performance and stability of the spur gear assembly under actual operational conditions.

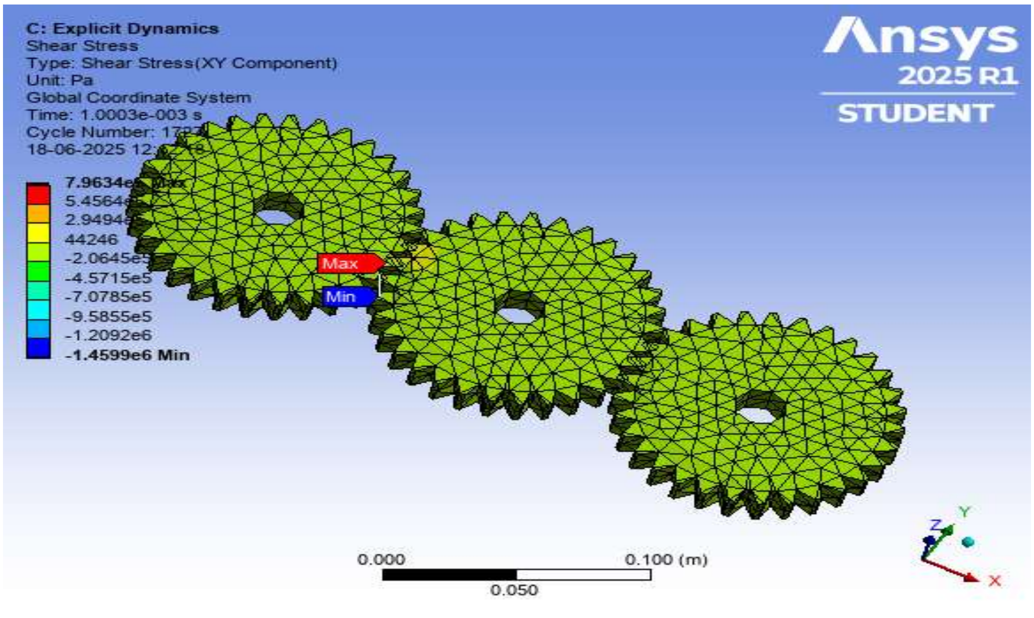

Figure 8. Shear Stress for Nylon 66

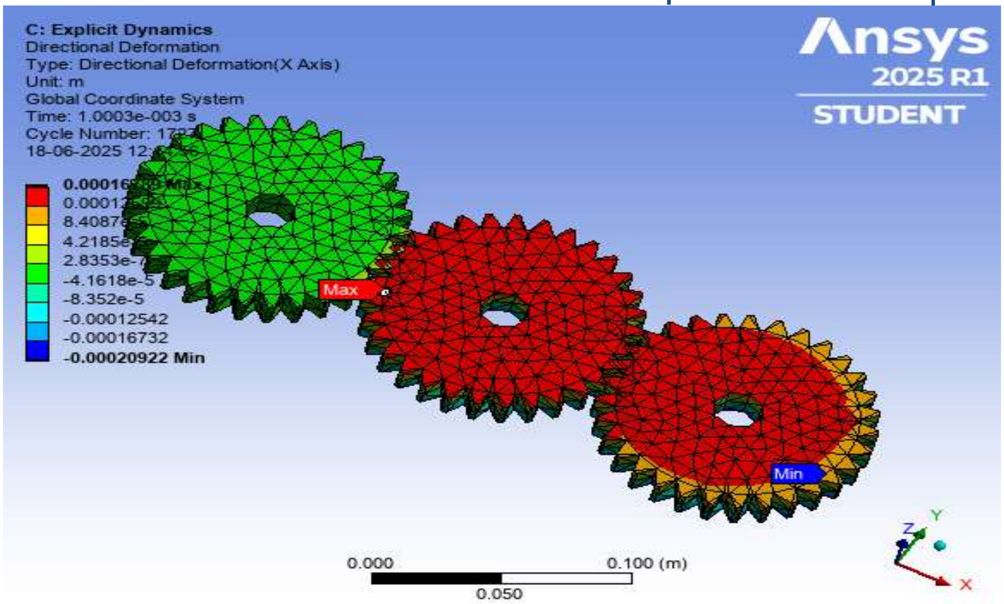

Figure 9. Directional Deformation for Nylon 66

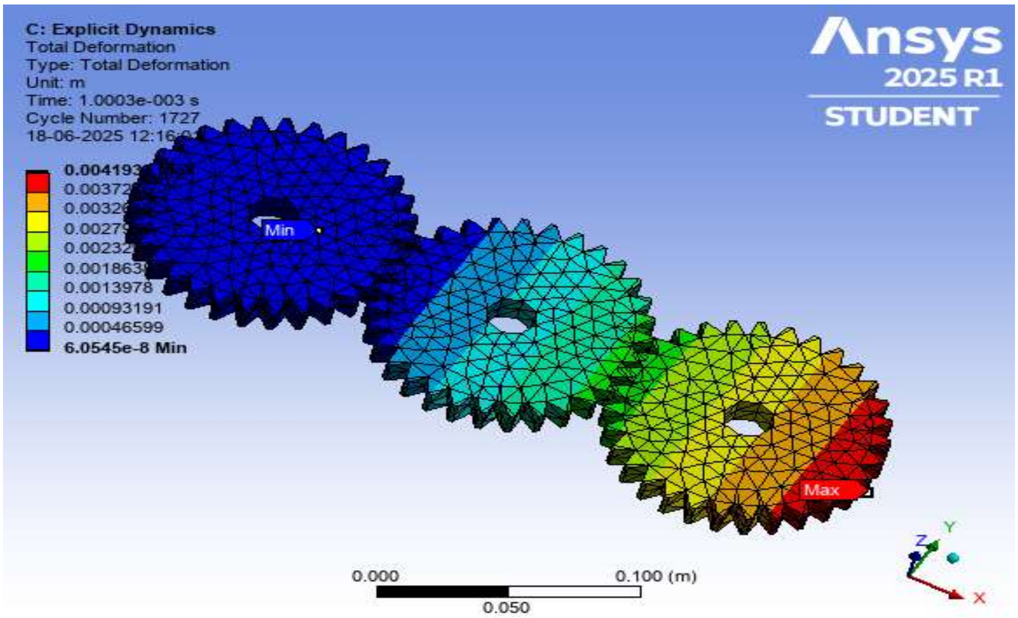

Figure 10. Total Deformation for Nylon 66

Table 2 Static and Dynamic Analysis Results for Spur Gear Using Different Materials.

Analysis Perform / Material		**Bronze C51000**	**Nylon 66**	**Gray Cast Iron**
Static Analysis	Shear Stress (Pa)	7.8849e8	1.5902e6	8.2945e7
	Directional Deformation (m)	4000	40	40
	Total Deformation (m)	7071.1	70.711	70.711
Explicit Dynamics Analysis	Shear Stress (Pa)	4.0706e7	7.9634e4	3.3063e7
	Directional Deformation (m)	0.16627	0.00016789	0.00016795
	Total Deformation (m)	0.0041923	0.0041934	0.0041927

The findings outlined in Table 2 encapsulate the performance of Bronze C51000, Nylon 66, and Grey Cast Iron in the static and dynamic evaluations of a spur gear utilising ANSYS software. In the static evaluation, Bronze exhibits the highest levels of shear stress and deformation, signifying a greater capacity to bear loads while also showing a notable degree of flexibility. On the other hand, Nylon 66 reveals the lowest levels of stress and deformation, making it particularly suitable for lightweight applications. In the dynamic evaluation, all materials demonstrate significantly lower values, with Bronze again leading in terms of stress response. The directional and overall deformation observed during dynamic analysis remains minimal across all materials. In summary, Bronze offers outstanding strength, whereas Nylon 66 excels in damping properties and exhibits minimal deformation when subjected to a load.

V. CONCLUSION

The study examined materials for gear manufacturing using static and explicit dynamic simulations with ANSYS. The materials compared included Bronze, Resin Polyamide (Nylon 66), and Gray Cast Iron, which were evaluated based on their mechanical properties under applied loads. In static modelling, Bronze demonstrated the highest capacity to withstand shear stress, measuring 7.8849 × 10^8 dyne/cm^2, and exhibited acceptable levels of deformation. This indicates that Bronze can support loads while maintaining structural integrity. In the explicit dynamic simulations, it displayed the highest dynamic shear stress at 4.0706 × 10^7 dyne/cm^2 and maintained controlled deformation in both directional and overall aspects. The results suggest that Bronze possesses high strength, ductility, and resilience under both static and dynamic conditions. In contrast, Gray Cast Iron, while reasonably strong, lacks yield strength and is susceptible to brittle failure. Nylon 66, although lightweight and resistant to corrosion, demonstrated poor mechanical performance and is unsuitable for high-stress applications.

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