International Journal of Materials and Mechanical Structures Engineering
Vol. 1, Issue 2 (July – December, 2025) pp: (37-56)

Analysis of Sprocket Strength and Deformation for Metallic and Composite Polymer Materials

Ravikant Nanwatkar[1*], Yash Gajanan Naikwadi[2], Abhishek Ganpat Shelke[2]
[1]Assistant Professor, [2]Undergraduate Student, Department of Mechanical Engineering, NBN Sinhgad School of Engineering, Pune, Maharashtra, India

[*]Corresponding Author: ravikant.nanwatkar@sinhgad.edu

Received Date: November 11, 2025; Published Date: November 25, 2025

Abstract

This paper is a comparative static structural analysis of a sprocket designed in Solid Edge 2025 (Student Edition) and a structural analysis performed by ANSYS R2 2025 (Student Version) using Finite Element Analysis (FEA). The aim is to measure and contrast the behavior of three different materials, which are C45 carbon steel, PA66-GF30 (glass-fiber reinforced nylon) and Kevlar-49 polymer composite, under the same loading conditions. The parameters under analysis are total deformation, von Mises stress, mass, and volume, to determine which material is most suitable for the application of sprockets. These findings show that C45 steel exhibits the least deformation and the greatest stiffness, confirming its current leadership in conventional sprocket production. Nevertheless, the factors of significant mass and volume reduction are observed in both PA66-GF30 and Kevlar-49 composites, which provide lightweight alternatives with acceptable and moderate deformation increase. Kevlar-49 is the best mechanical performance of the composite materials and it is the one with the best strength to weight ratio, and could therefore be promising in the applications where less weight is required without significant loss in strength or rigidity. Although they offer structural benefits, composite designs such as PA66-GF30 and Kevlar-49 have weaknesses in wear resistance and wear surface, and thus may limit their durability under heavy contact, sprocket system applications. The report addresses possible ways of curbing these disadvantages such as surface coating, optimization of lubrication, and hybrid material designs. In general, the present comparative analysis has indicated the possibility of substituting the traditional metallic sprockets with innovative composite materials in lightweight mechanical systems, as long as the issue of wear surface is adequately controlled.

Keywords- Composite materials, Finite Element Analysis (FEA), Sprocket design, Strength-to-weight ratio, Structural deformation

INTRODUCTION

A sprocket is a toothed wheel which transfers the rotational motion and power between two axes via the chains with belts, used many industrial and automobile gearing systems. Its purpose is to ensure a straight driving motion and a minimum of slip during chain engagement transferring rotation directly from driver (input) shaft to the driven (output) component, shown in Fig. 1. These devices are widely employed in bicycles, motorcycles, conveyors and industrial type machinery because of their simplicity, efficiency and capacity to accommodate variable loading conditions. The efficiency, vibrational effects and service life of the Sprocket is mainly affected by its geometry features, tooth profile & material. Due to the high cyclic tensile stresses, friction and wear situation under which sprockets generally run, their reliability is closely related with material properties and structure.

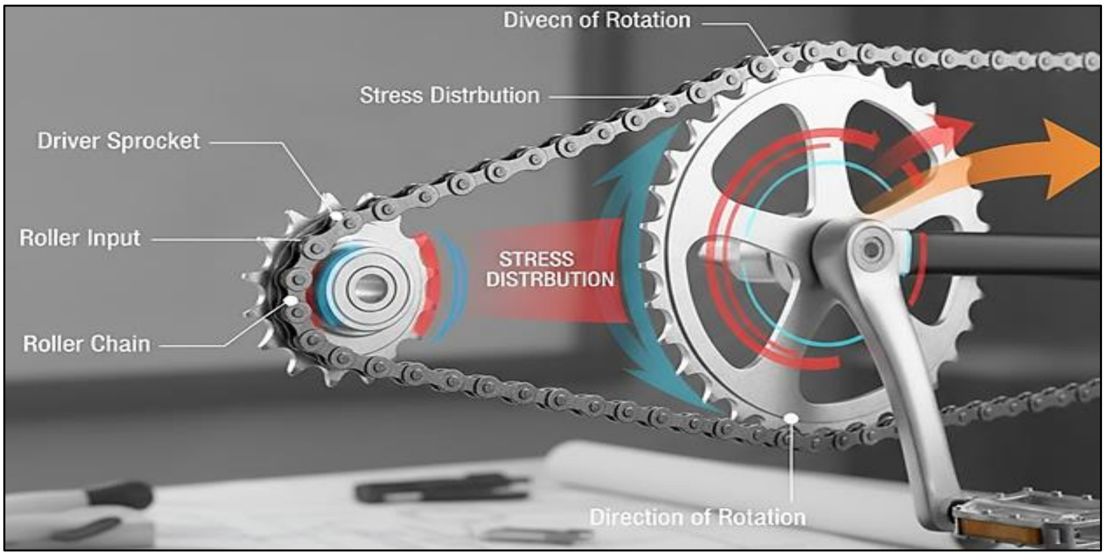


Figure 1: *Background on sprocket function and its role in power transmission systems.*

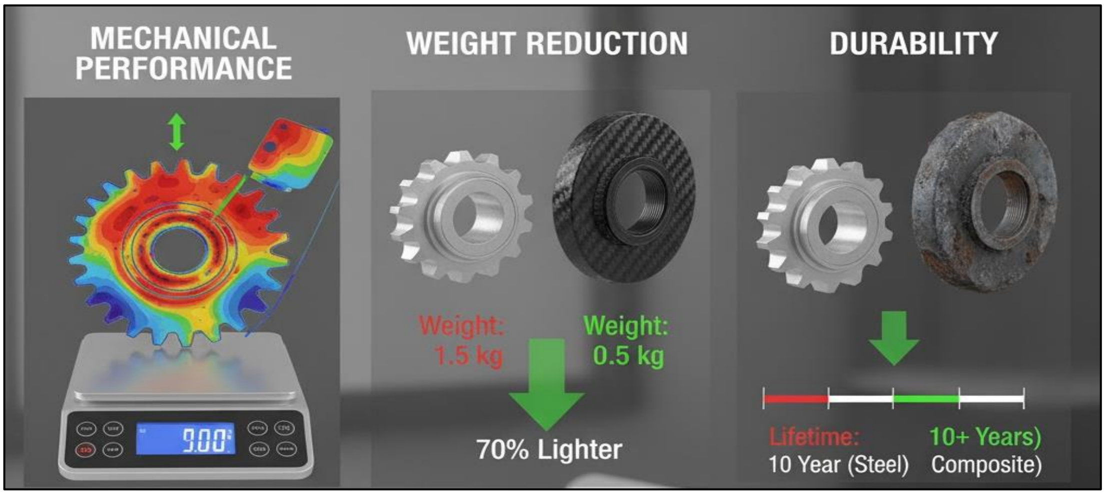


Figure 2: *Importance of material selection for mechanical performance, weight reduction, and durability.*

Fig. 2 shows that the material choice has an important influence on the mechanical quality, durability, and efficiency of the sprocket. Material selection influences key properties, including strength, stiffness, toughness, and resistance to wear and fatigue. Historically, metallic materials such as C45 carbon steel or steels with add-ons have been a favorite choice because of their good load carrying capacity and service life. Those materials, however, result in substantial weights and may corrode or deteriorate at surfaces under some conditions. However, more attractive properties can be gained by the use of polymer or composite materials due to low weight, resistance to corrosion and easy processing. However, typically, they suffer from lower stiffness and higher deformation for the same loading conditions. As such, identifying the appropriate damage resistant material is largely a compromise between mechanical strength, and wear resistance versus cost and weight. Rapidly increasing attention towards energy conservation, environmental concern and performance optimization has led to great interest in the development of lightweight high strength materials for modern mechanical systems. Weight reduction in the components of vehicle bodies, machine constructions and robotics systems results in lower energy consumption, higher acceleration levels and more efficient operation. Fiber-reinforced composite polymers (such as glass, carbon, or Kevlar) represent attractive materials in place of metals because they generally possess higher strength-to-weight ratio and also maintain structural soundness. Such materials make it possible for designers to lower inertia, improve dynamic response and cut production costs. In the case of sprocket systems, such light composites enhance mechanical efficiency and mitigate noise and chain life by damping impact forces and vibrations during engagement. Although there has made considerable progress in the development of composite materials and FE-based structural analysis, still a strong need exists in comparing directly metallic and polymer composites sprockets loaded under same conditions with the same boundary constraints. Existing studies were mainly conducted on conventional metal sprockets or pure polymer gears, leading to limited side-by-side comparisons such as deformation, stress distribution, and strength/weight ratios. Moreover, research on the tribological properties, wear mechanisms, and surface damage of polymer sprockets in practical service conditions is limited. This gap is limiting the wide spread industrial application of polymer and composite based sprockets for power transmission, thus further studies comparing their mechanical feasibility and their life cycle are required.

Research Objectives and Scope

The main aim of this study is to perform comparative structural analysis (material properties) sprockets for metallic and composite polymer material with FEA. The aim of the work is evaluating a mechanical response of C45 steel, PA66-GF30 and Kevlar-49 polymer composite subjected to (that same) static loading. Quantities like total deform, von Mises stress, mass and volume are investigated to assess how the selected materials could be appropriate for power transmission applications. The study involves a CAD model of a sprocket in Solid Edge 2025 and simulation with ANSYS R2 2025, which will allow for comparative analysis between these materials to determine the most favourable balance or tradeoff between strength, stiffness and weight. Moreover, the study highlights potential concerns including wear and surface deterioration of composites as well as offers possible countermeasures for their improved industrial application.

The objectives of the present study are as follows:

- To set the example for one of the sprockets on Solid edge software.
- The objective was to model the finite element analysis (FEA) in Ansys, therefore that same loading could be used for three materials – C 45 PA66-GF30 and Kevlar 49.
- To compare total deformations, von Mises stresses, masses and volumes of each material.
- To select the suitable material in mechanical performance and economy.

LITERATURE REVIEW

The literature described above covers three interconnected topics essential to this study: (i) the structural analysis of sprockets and gears using finite element analysis, (ii) the mechanical and tribological behavior of engineering polymers and fiber-reinforced composites (PA66-GF, Kevlar-49, carbon-fiber composites), and (iii) contact issues, primarily wear and durability related to chain–sprocket and gear contacts. The subsequent review of literature (and synthesis of cited works) summarizes investigation methods, key recommendations, and methodological reports, while also highlighting gaps in the literature to motivate the current comparative simulation of FEA C45 steel, PA66-GF30, and Kevlar-49. Some studies suggest that FEA is a well-developed tool for analyzing static and contact stresses, deformation, and process-induced changes in sprockets and gears. Hossan [1] used FEA to analyze the strength of polymer composite spur gears. These studies form the foundation for a set of best practice guidelines for modeling composite gear geometries, including the application of material orthotropy where appropriate, and the analysis of stress distributions and root deflection under static loads. Similarly, [2] performed FEA contact analysis on a sprocket of an armoured face conveyor focusing on realistic contact boundary conditions, mesh refinement at tooth contacts, and the importance of validating FEA results with experimental or simplified analytical models. They further developed these ideas by incorporating multi-body dynamics alongside FEA, demonstrating how dynamic load spectra influence contact stress patterns compared to static conditions [3]. Comparing metallic and non-metallic polymer composite gears through simulation, some phenomena aligned with expectations: metals show less deflection, whereas composites are lighter but tend to deform more [4]. These works support using Solid Edge for geometry creation in this study and ANSYS for static FEA, emphasizing modeling choices such as material definitions, contact, and mesh that affect result accuracy. Several practical applications of composite sprockets and gears in design, manufacturing, and tribological studies have been reported [5], [6]. They developed a design and conducted strength analysis of a bicycle's front sprocket made from CFRP, illustrating how those results inform manufacturability and the balance between stiffness, wear resistance, and weight reduction in real-world scenarios. Addressing a slightly different issue (induction hardening of steel sprockets), used a method combining process-FEA models with experimental measurements [7]. This approach is noteworthy because material processing and surface transformations significantly influence local stiffness, wear behaviour, and lifespan, aspects that are also relevant when comparing untreated polymer parts with hardened steel components.

Analyzed tooth deflection and thermal/durability aspects of polymer gears and reinforced polyamides [8], [9]. These show that increases in temperature, viscoelasticity, and moisture uptake in polymers can lead to variations in tooth structure stiffness and long-term deformation. Therefore, static cold-state FEA comparisons should be made with caution: under operating temperatures and load cycles, polymers may have a different effective modulus. To the best of our knowledge, published work on Kevlar-49 [10], [11] mainly focuses on its fiber mechanics, compressive response, and anisotropic stiffness. It is evident from studies by Yeung & Rao [12], [13] that Kevlar-49 fiber-reinforced thermoplastic composites are materials that exhibit high specific strength combined with favorable strength-to-weight ratios, although aspects like compressive behavior, bearing capacity, and exposure can be complex depending on reinforcement orientation, matrix compatibility (distortion), and environmental conditions. Weight relative to the tooth or a stiffness penalty from small diameters shows that carbon-fiber composites do provide mass savings with acceptable stiffness for sprocket application. These findings align with our observation that among the assessed materials, Kevlar-49 has the highest strength-to-weight response. While weight reduction using polymers/composites is widely acknowledged, the high contact area of chain–sprocket interaction and the dynamic sliding over many cycles pose tribological challenges. On radial basis functions and smooth, compactly supported solutions, experimental studies at the device level detail surface topography changes, transfer films, and wear mechanisms abrasive and adhesive as well as the effects of lubricants [14-16]. Mbarek [2] review friction and wear results of fiber-reinforced composites versus polymeric materials, noting that wear in polymer gear and sprocket applications can be worsened by fiber pullout, matrix degradation, and third-party abrasives [17], [18]. These tribological investigations explain why polymer sprockets with reasonable static strength may underperform in service unless lubrication, coatings, or hybrid metal–polymer designs are employed [this inference is supported by the present study. Simulations of metal and polymer gears, providing quantitative benchmarks: metal teeth experience small deflections and higher contact fatigue safety factors, while properly designed fiber-reinforced polymers can have larger deflections at adequate stresses. Experimental validation shows composite sprockets can be manufactured and effectively used for low to moderate loads, such as bicycle drivetrains. Choi et al. [4] and He et al. [11] highlight the importance of process impact and contact modeling for accurate performance prediction. Hriberšek et al. [19] stress the importance of durability testing and thermal characterization for reinforced polyamides areas often overlooked in purely static FEA. The reviewed literature confirms a key conclusion of this study: metals (C45) provide higher stiffness and minimal deflection, whereas fiber-reinforced composites (PA66-GF, Kevlar-49, carbon fibers) offer lower mass and favorable strength-to-specific-stiffness ratios. Long-term wear resistance in communicative environments remains a challenge for polymer sprockets. Future research should combine static FEA with dynamic multi-body simulations, fatigue life prediction, and temperature-dependent material modeling within the same framework to thoroughly evaluate tribological mitigation strategies such as coatings, lubrication, and hybrid designs for industrial applications.

Gaps, Synthesis and Implications for Current Work

Dynamic/fatigue behaviour(a) Many of the FEA studies considered (as well as the present one) refer to static loading conditions; less attention is concentrated towards combining multi-body dynamics and fatigue life assessment under realistic service being a noteworthy exception). In sprocket, fatigue and repeated contact play significantly.

Environmentally Sensitive Material Properties: Polymer modulus and tribological behavior are affected by the temperature and humidity. Static comparisons made at a single reference state might not indicate stiffness or wear rates in service.

Surface Treatment and Coatings: Tribological papers indicate wear as a primary limitation, but less work is done to combine FEA structural benefits of composites with surface treatments or hybrid designs that reduce wear while retaining weight savings.

Experimental Validation for High Loads: Previous case studies have shown feasibility for low loads, but there is less literature that has experimentally validated the treated metal vs. reinforced polymer under the same load cycles for an industrial torqued sprocket application.

METHODOLOGY AND MATERIAL ANALYSIS

Fig. 3 and 4 shows the sprocket geometry was made in Solid Edge according to the standard ISO chain sprocket dimensions. The model includes:

- A major point of shaft mounting
- Profile Tooth that fits roller chains
- Keyway

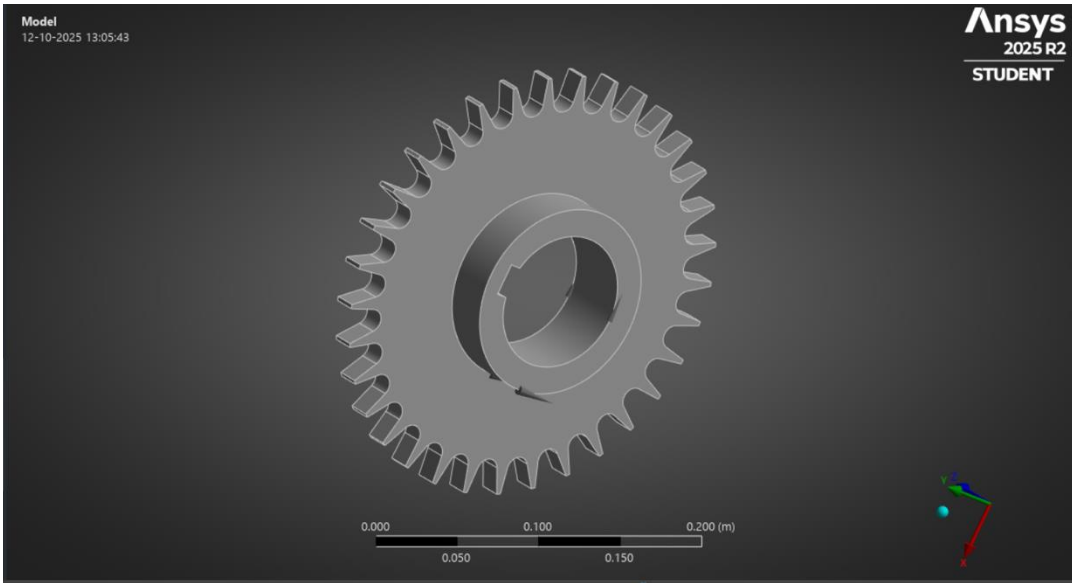


Figure 3: *Sprocket design (Drafted in Solid edge 2025 student edition & imported to Ansys 2025 R2 Student edition).*

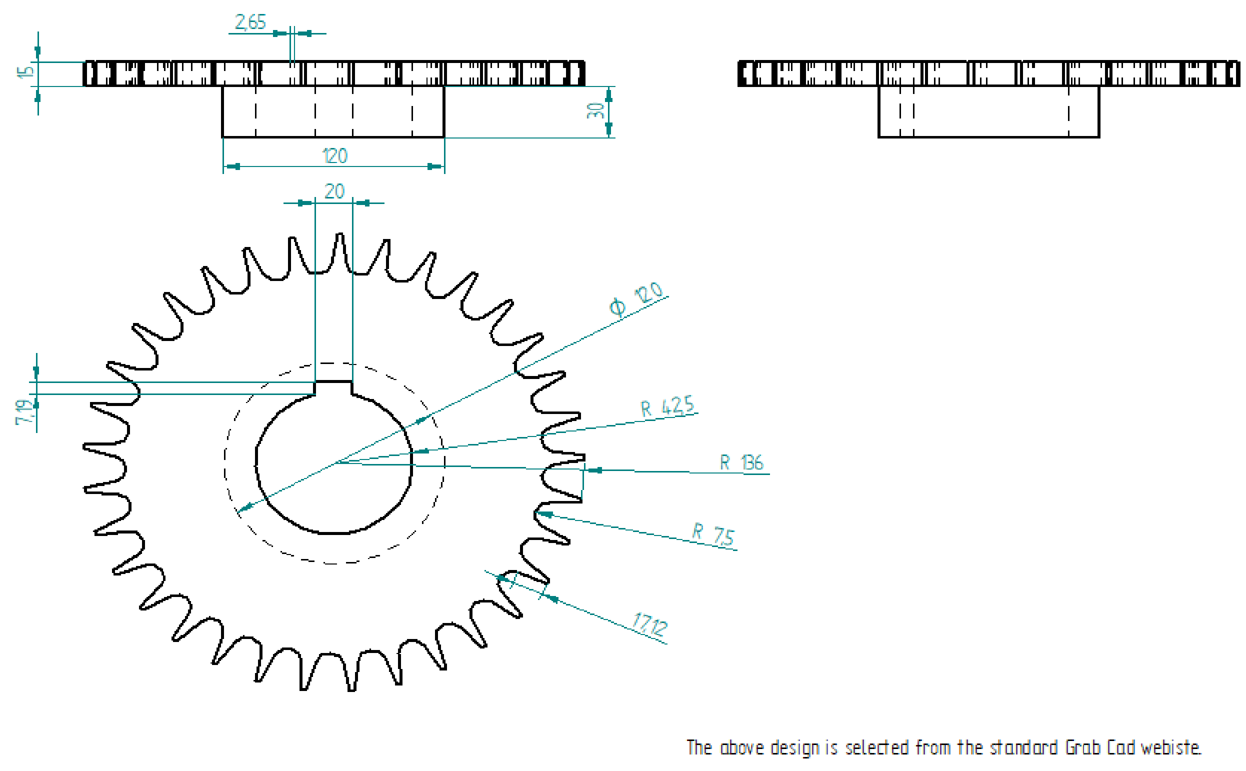


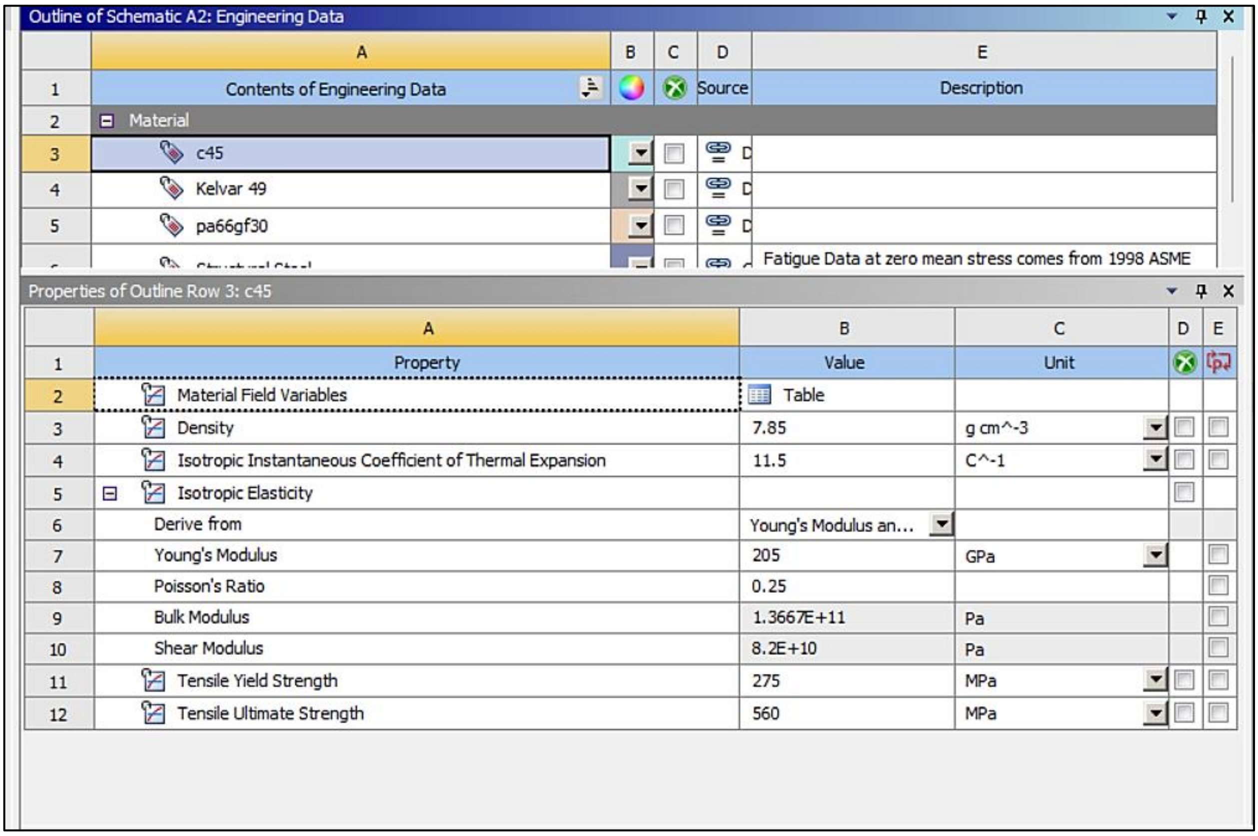
Figure 4: *Sprocket front, top, side view.*

Material Selection and Properties

Fig. 5-7 shows three materials were selected for simulation. Each represents a distinct class of engineering materials shown in Table 1.

Table 1: *Material properties of C45, PA66 and Kevlar.*

S. No.	Property	C45 Carbon Steel	PA66-GF30 (Glass-Fiber Reinforced Nylon)	Kevlar-49 Polymer Composite
1	Density (g/cm^3)	7.85	1.34	1.44
2	Isotropic coefficient of thermal expansion. (c^{-1})	11.5	-	-
3	Orthotropic coefficient of thermal expansion in X Direction (K^{-1})	-	0.00003	-0.000002
4	Orthotropic coefficient of thermal expansion in Y Direction (K^{-1})	-	0.00007	0.00006
5	Orthotropic coefficient of thermal expansion in Z direction (K^{-1})	-	0.00009	0.00006
6	Isotropic Young's Modulus (GPA)	205	-	-
7	Orthotopic Youngs modulus in X direction (GPA)	-	10	112
8	Orthotopic Youngs modulus in Y direction (GPA)	-	7	5
9	Orthotopic Youngs modulus in Z direction (GPA)	-	3.5	5
10	Isotropic Poisons Ratio	0.25	-	-
11	Orthotopic Poisons Ratio in X direction	-	0.3	0.34
12	Orthotopic Poisons Ratio in Y direction	-	0.3	0.4
13	Orthotopic Poisons Ratio in Z direction	-	0.3	0.34
14	Isotropic Shear Modulus (GPA)	82	-	-
15	Orthotropic Shear Modulus in X direction (GPA)	-	3.6	2.4
16	Orthotropic Shear Modulus in Y direction (GPA)	-	2.5	1.5
17	Orthotropic Shear Modulus in Z direction (GPA)	-	1.2	2.4
18	Tensile Yield Strength (MPa)	275	91	3600
19	Tensile Ultimate Strength (MPa)	560	104	-
20	Type of Material	Metallic	Polymer Composites	Aramid Composite



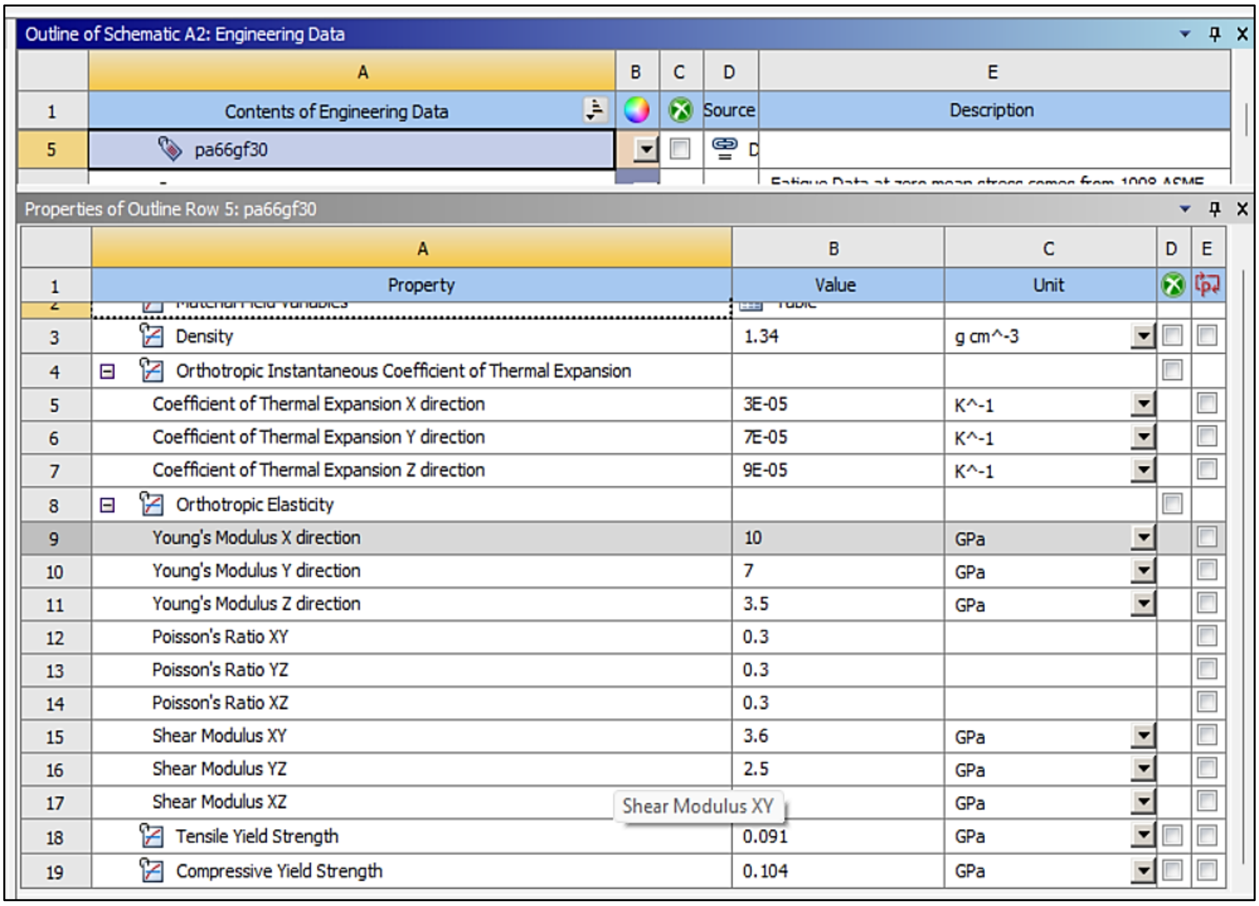
Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	c45			D	
4	Kelvar 49			D	
5	pa66gf30			D	
6	Structural Steel				Fatigue Data at zero mean stress comes from 1998 ASME

Properties of Outline Row 3: c45

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7.85	g cm^-3		
4	Isotropic Instantaneous Coefficient of Thermal Expansion	11.5	C^-1		
5	Isotropic Elasticity				
6	Derive from	Young's Modulus an...			
7	Young's Modulus	205	GPa		
8	Poisson's Ratio	0.25			
9	Bulk Modulus	1.3667E+11	Pa		
10	Shear Modulus	8.2E+10	Pa		
11	Tensile Yield Strength	275	MPa		
12	Tensile Ultimate Strength	560	MPa		

Figure 5: *Properties of C45 carbon steel.*



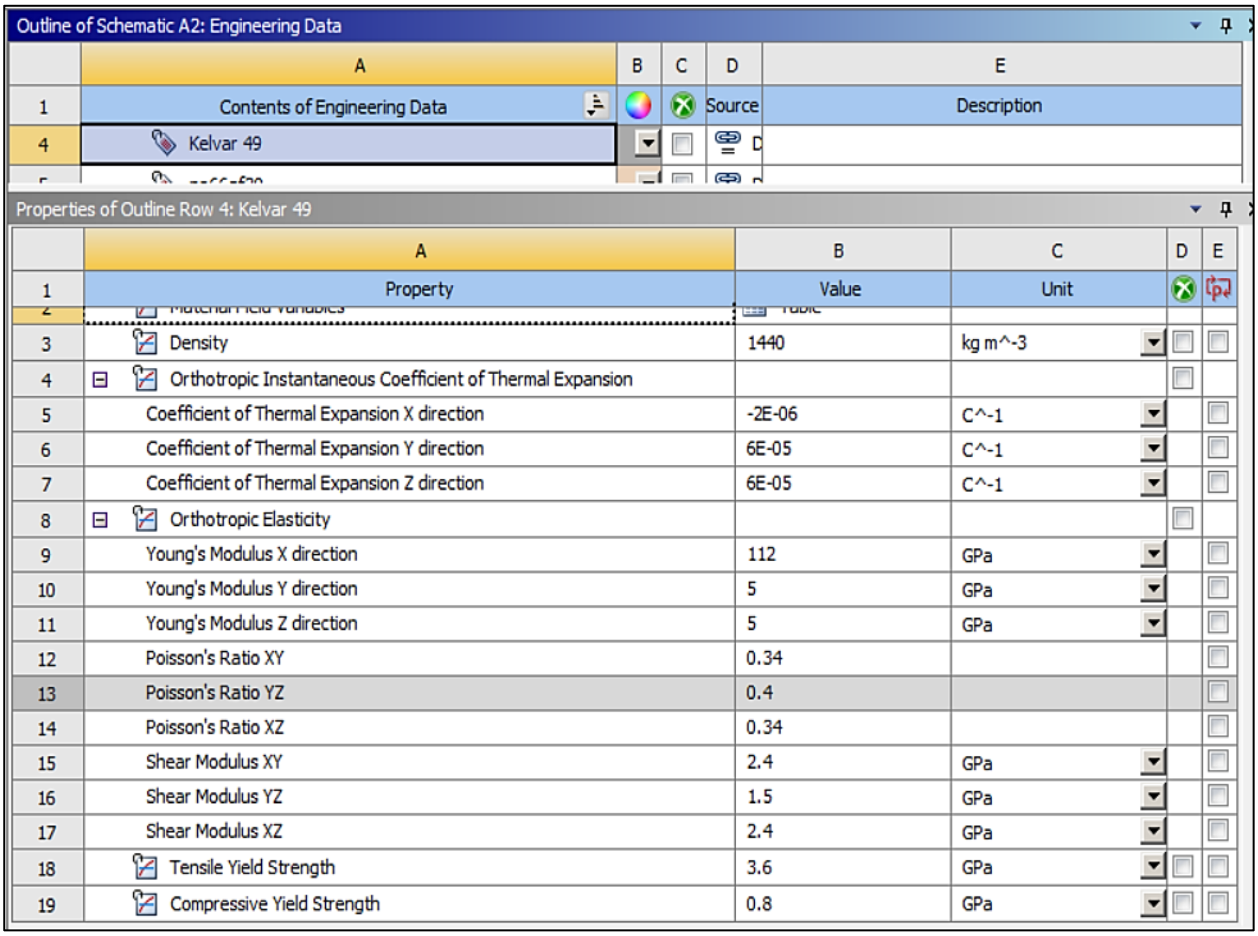
Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
5	pa66gf30			D	

Properties of Outline Row 5: pa66gf30

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	1.34	g cm^-3		
4	Orthotropic Instantaneous Coefficient of Thermal Expansion				
5	Coefficient of Thermal Expansion X direction	3E-05	K^-1		
6	Coefficient of Thermal Expansion Y direction	7E-05	K^-1		
7	Coefficient of Thermal Expansion Z direction	9E-05	K^-1		
8	Orthotropic Elasticity				
9	Young's Modulus X direction	10	GPa		
10	Young's Modulus Y direction	7	GPa		
11	Young's Modulus Z direction	3.5	GPa		
12	Poisson's Ratio XY	0.3			
13	Poisson's Ratio YZ	0.3			
14	Poisson's Ratio XZ	0.3			
15	Shear Modulus XY	3.6	GPa		
16	Shear Modulus YZ	2.5	GPa		
17	Shear Modulus XZ	Shear Modulus XY	GPa		
18	Tensile Yield Strength	0.091	GPa		
19	Compressive Yield Strength	0.104	GPa		

Figure 6: *Properties of PA66GF30 (glass-fibre reinforced nylon).*


Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
4	Kelvar 49				

Properties of Outline Row 4: Kelvar 49

	A	B	C	D	E
1	Property	Value	Unit		
3	Density	1440	kg m^-3		
4	Orthotropic Instantaneous Coefficient of Thermal Expansion				
5	Coefficient of Thermal Expansion X direction	-2E-06	C^-1		
6	Coefficient of Thermal Expansion Y direction	6E-05	C^-1		
7	Coefficient of Thermal Expansion Z direction	6E-05	C^-1		
8	Orthotropic Elasticity				
9	Young's Modulus X direction	112	GPa		
10	Young's Modulus Y direction	5	GPa		
11	Young's Modulus Z direction	5	GPa		
12	Poisson's Ratio XY	0.34			
13	Poisson's Ratio YZ	0.4			
14	Poisson's Ratio XZ	0.34			
15	Shear Modulus XY	2.4	GPa		
16	Shear Modulus YZ	1.5	GPa		
17	Shear Modulus XZ	2.4	GPa		
18	Tensile Yield Strength	3.6	GPa		
19	Compressive Yield Strength	0.8	GPa		

Figure 7: *Properties of kelvar 49.*

Finite Element Analysis Setup

Meshing

Fig. 8-10 shows a fine tetrahedral mesh of element size 0.02, which was generated to ensure accurate stress and deformation predictions. Mesh convergence was checked to confirm accuracy.

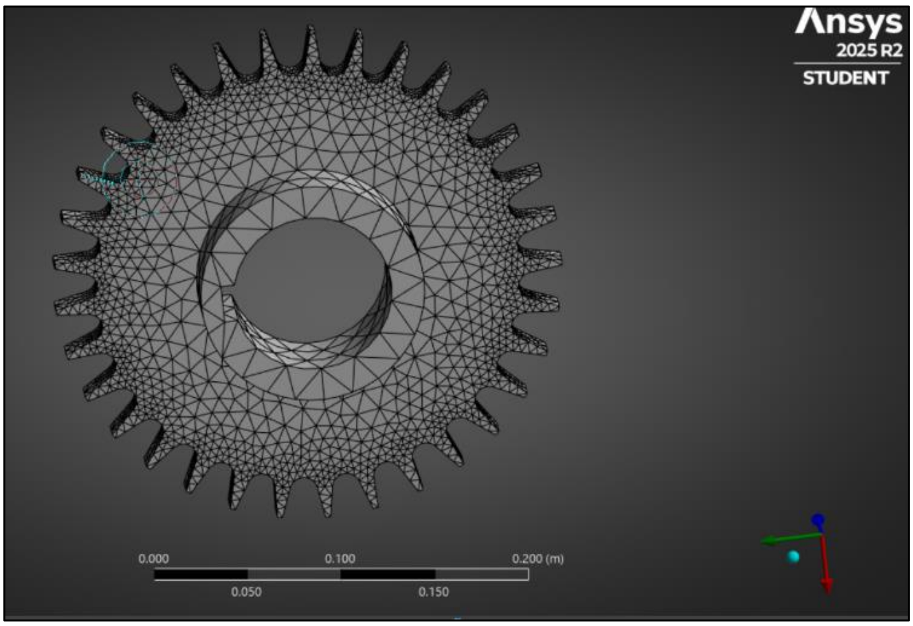


Figure 8: *Meshing with material 1.*

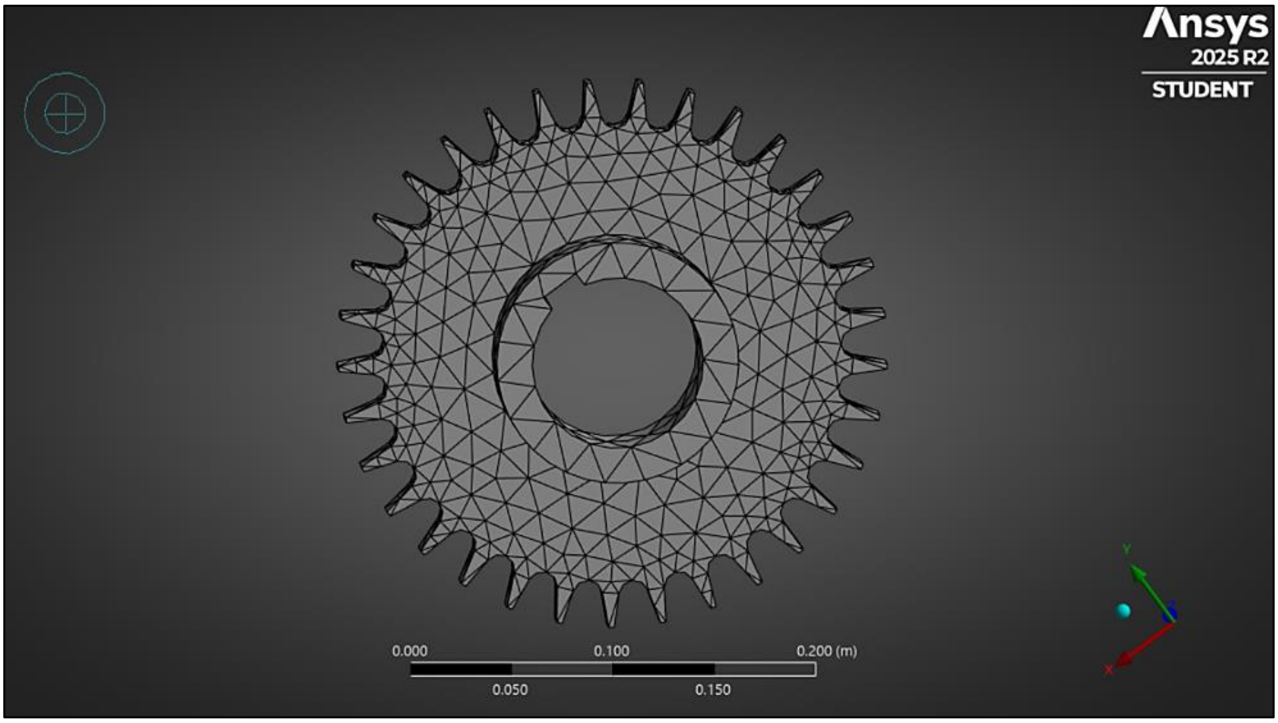


Figure 9: *Meshing with material 2.*

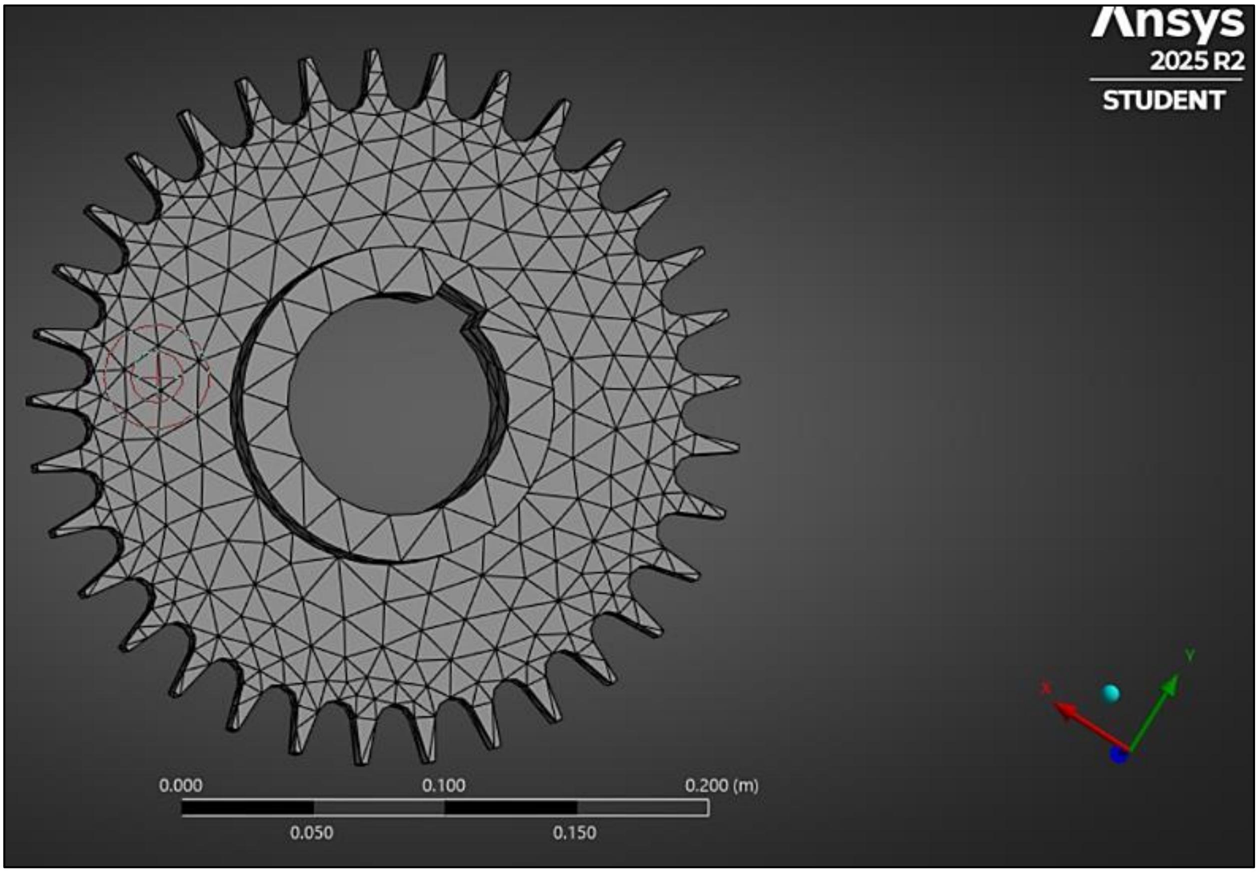


Figure 10: *Meshing of sprockets for material-3 for 0.02 element size.*

Boundary Conditions

Fixed Constraint: Central hub region fixed to simulate shaft contact.

Applied Load: A tangential force of 400 N distributed along the 16 tooth contact surfaces to represent chain tension & Moment of 400 N is acts at central part as a rotational motion of sprocket shown in Fig. 11-14.

Analysis Type: Static structural.

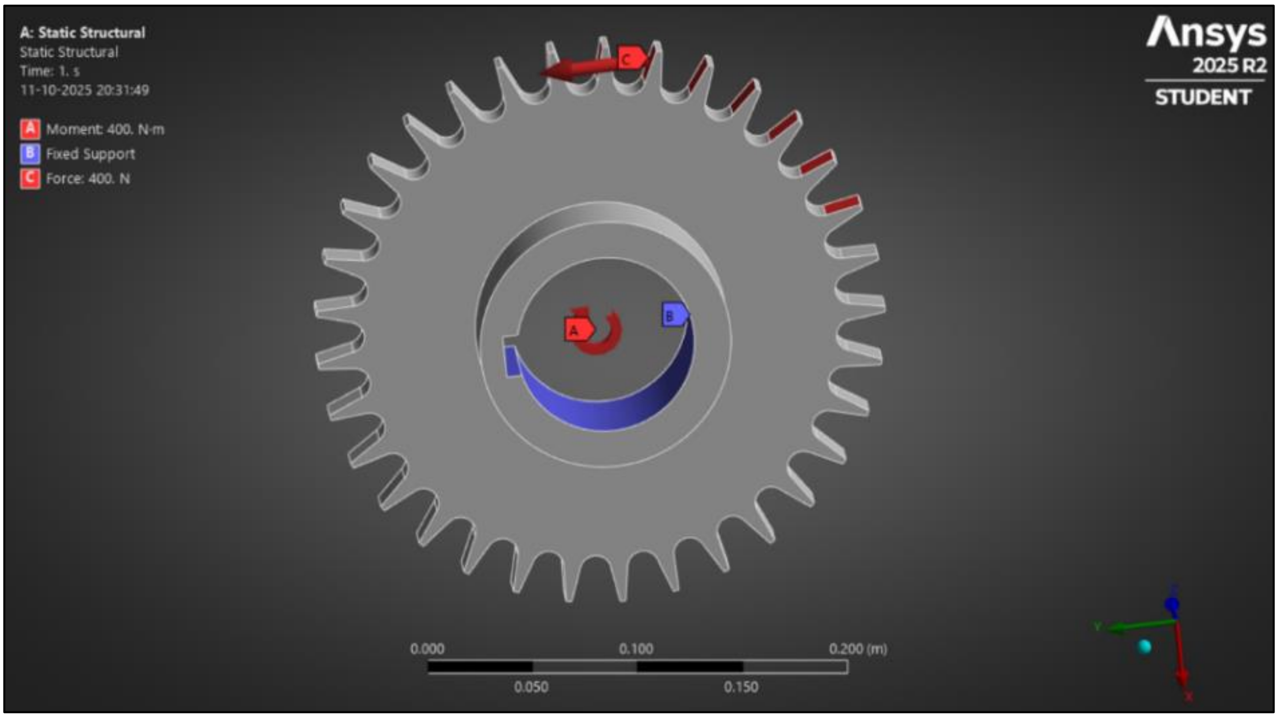


Figure 11: *Boundary conditions with material 1.*

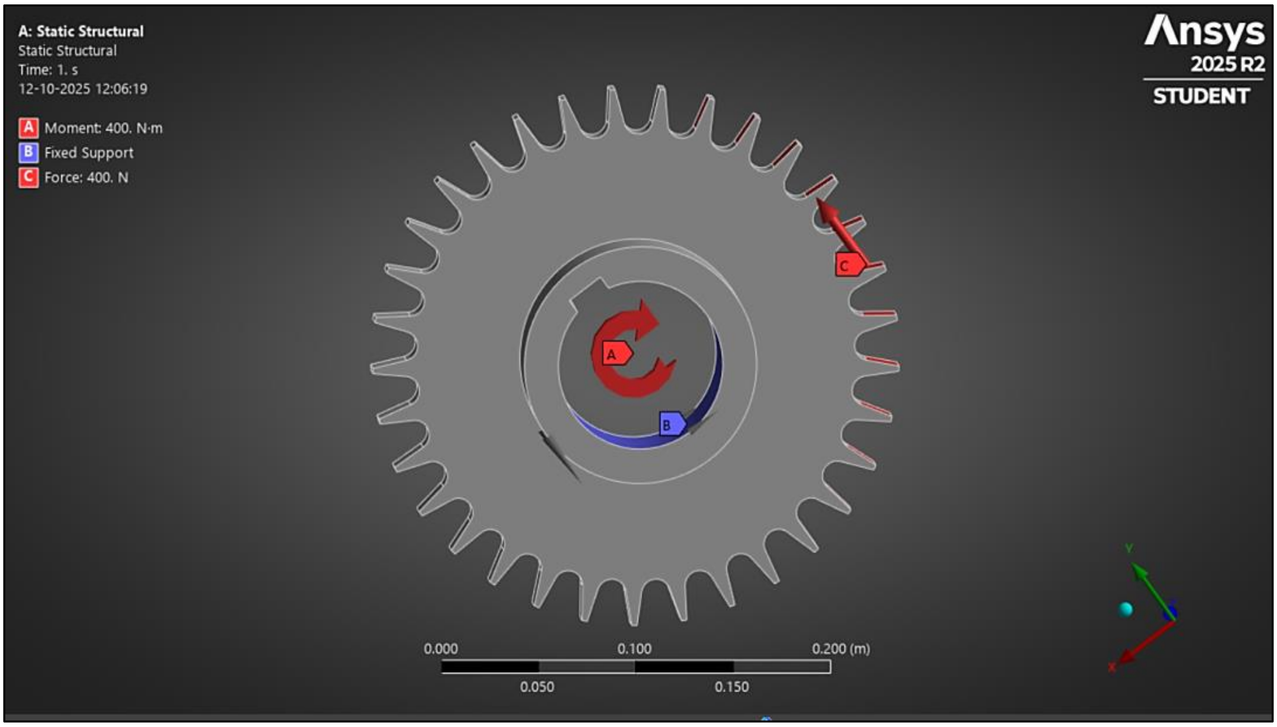


Figure 12: *boundary conditions with material 2.*

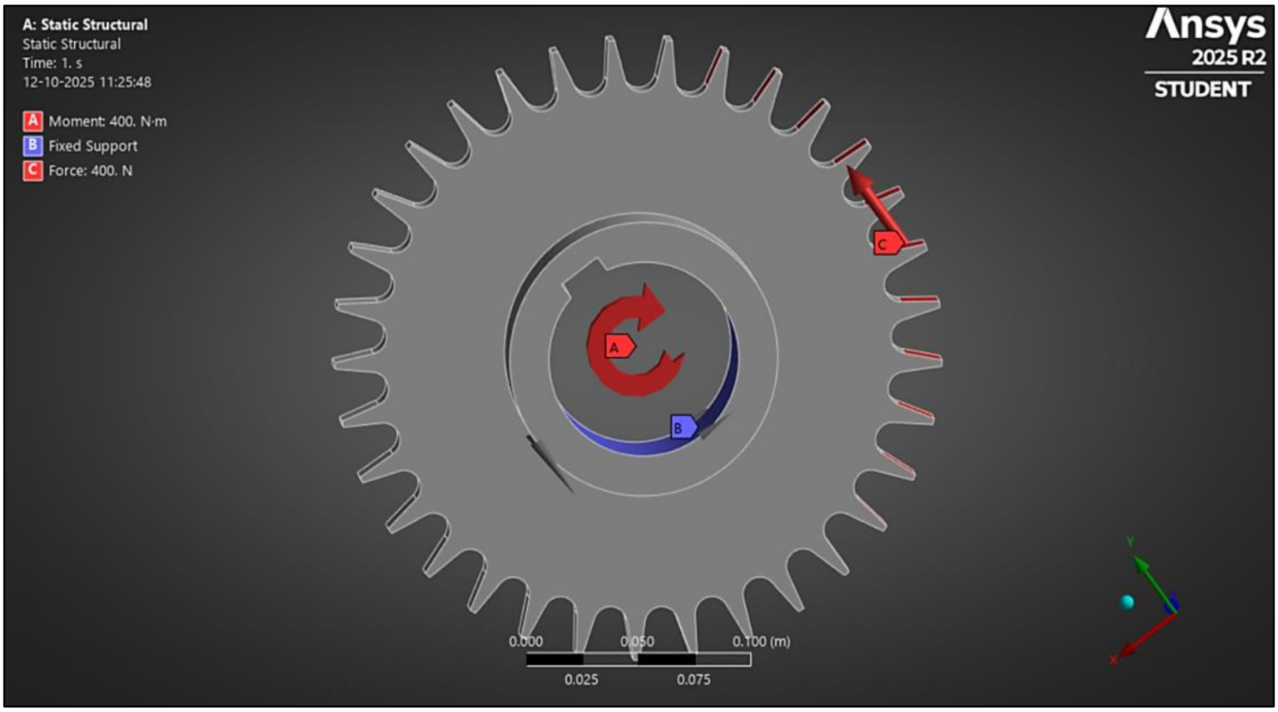


***Figure 13:** Boundary condition –moment, fixed support & forces on teeth with material 3.*

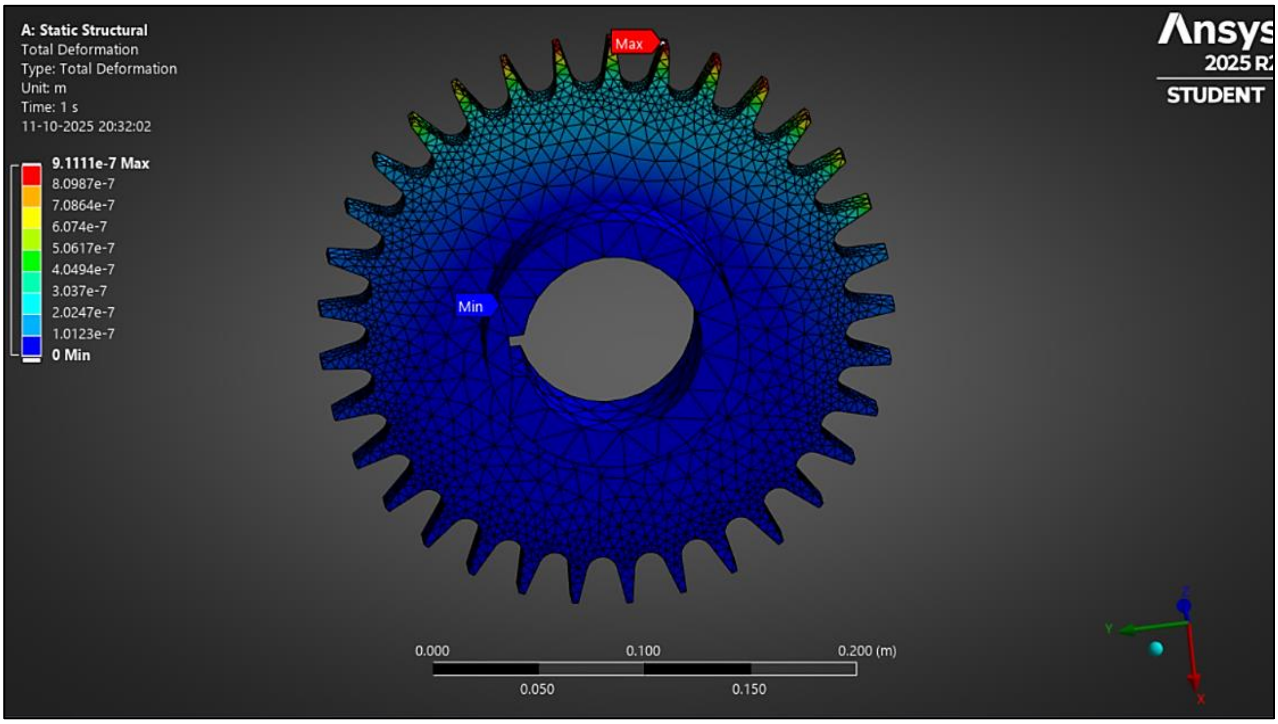


***Figure 14:** Total deformation of sprocket using C45 carbon steel.*

RESULTS AND ANALYSIS

Interpretation

Fig. 15-17 shows C45 has least deformation as the modulus of elasticity is high. Both PA66-GF30 and Kevlar 49 exhibit greater compliance and this might be beneficial where impact loading reduction is required but could compromise the dimensional accuracy at elevated stress levels shown in Table 2 and 3.

Table 2: *Total Deformation of material.*

Material	Total Deformation (m)
C45	9.1111×10^{-7}
PA66-GF30	1.9767×10^{-5}
Kevlar 49	1.9743×10^{-5}

Table 3: *Von mises stress.*

Material	Von Mises Stress (Pa)
C45	2.4516×10^{6}
PA66-GF30	2.2324×10^{6}
Kevlar 49	3.2737×10^{6}

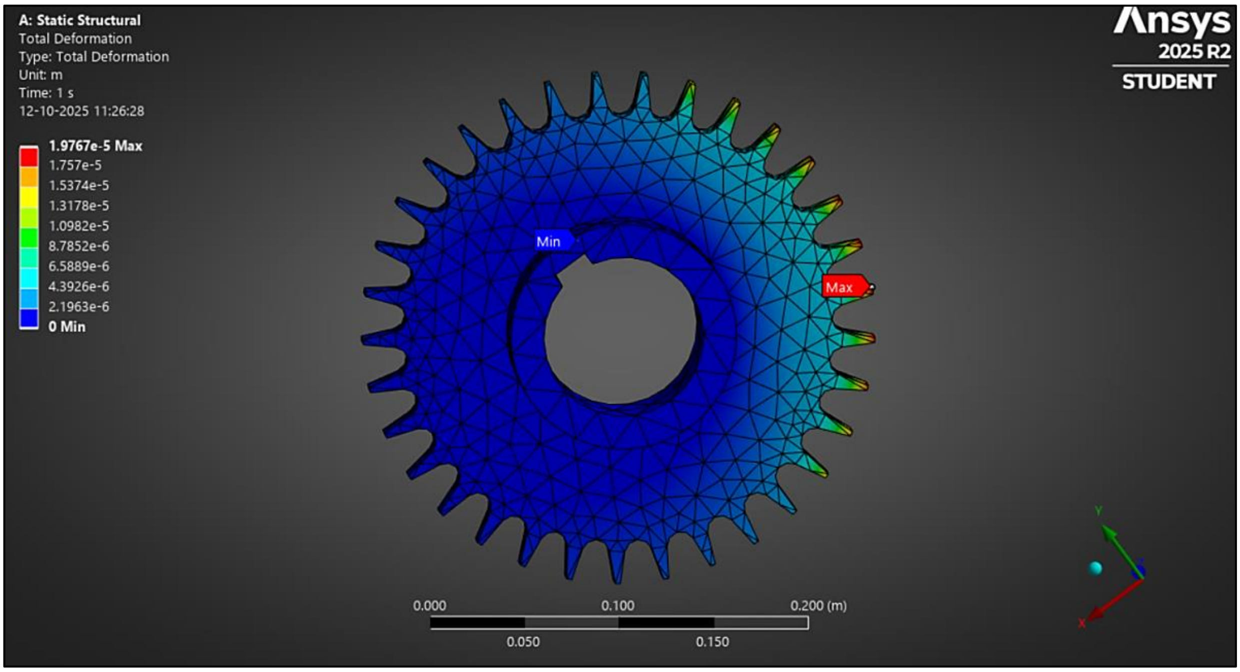


Figure 15: *Total deformation of sprocket using PA66GF30 – glass fiber reinforced material.*

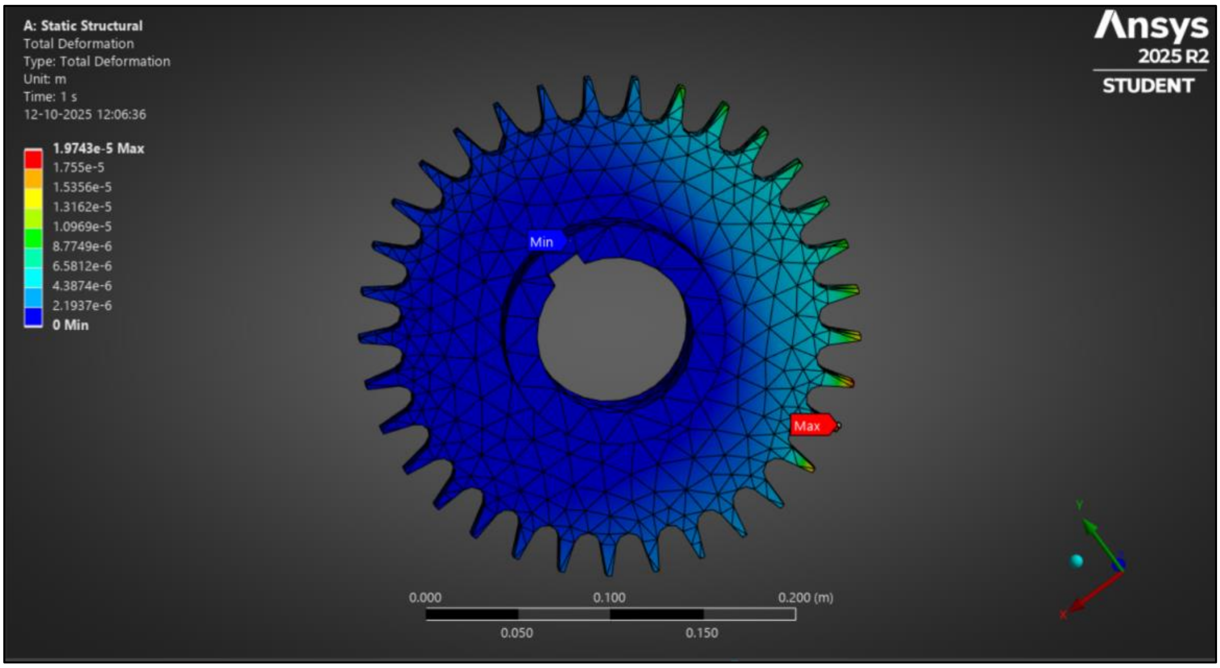


Figure 16: *Total deformation of sprocket using Kevlar 49 polymer composite.*

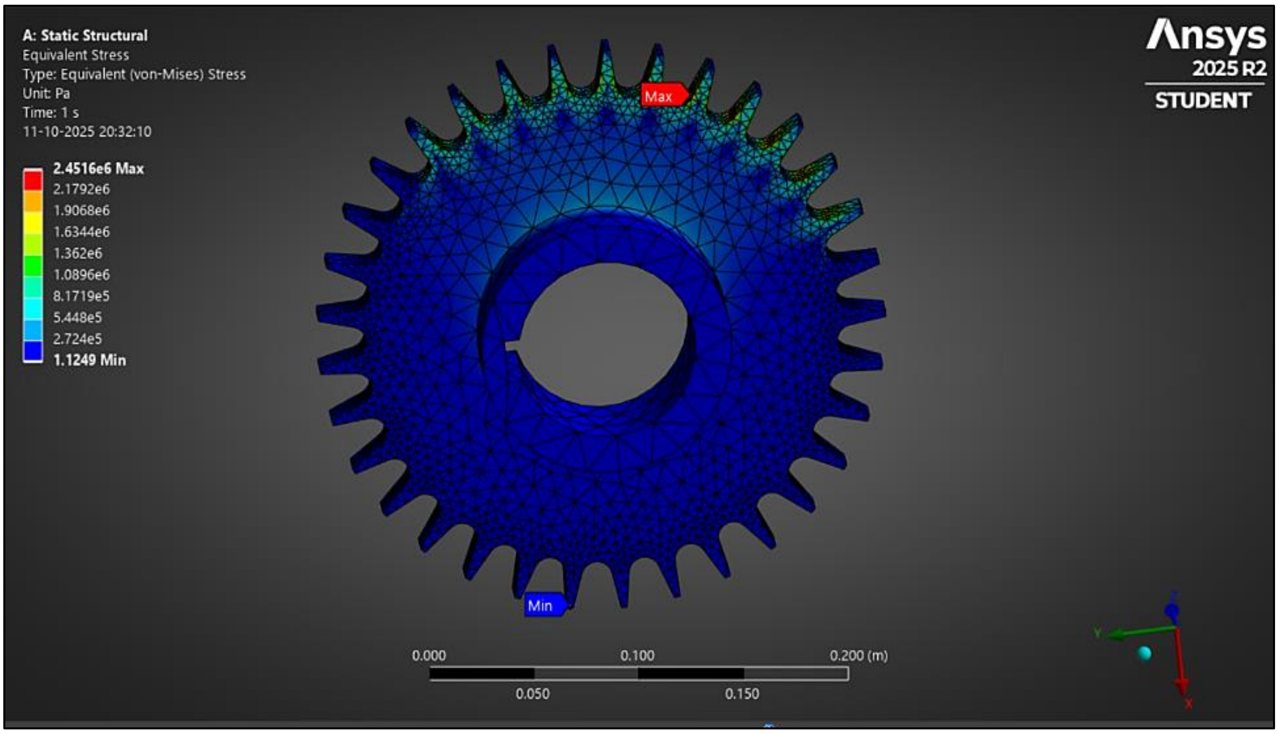


Figure 17: *Von mises, stress of sprocket using material 1.*

Interpretation

Fig. 18 and 19 shows the stresses are quite safe in all materials. Kevlar 49 has a somewhat greater concentration of the stress, but its higher strength-weight ratio guarantees the structural safety. PA66GF30 - Glass Fiber Reinforced material demonstrates the highest von mises stress.

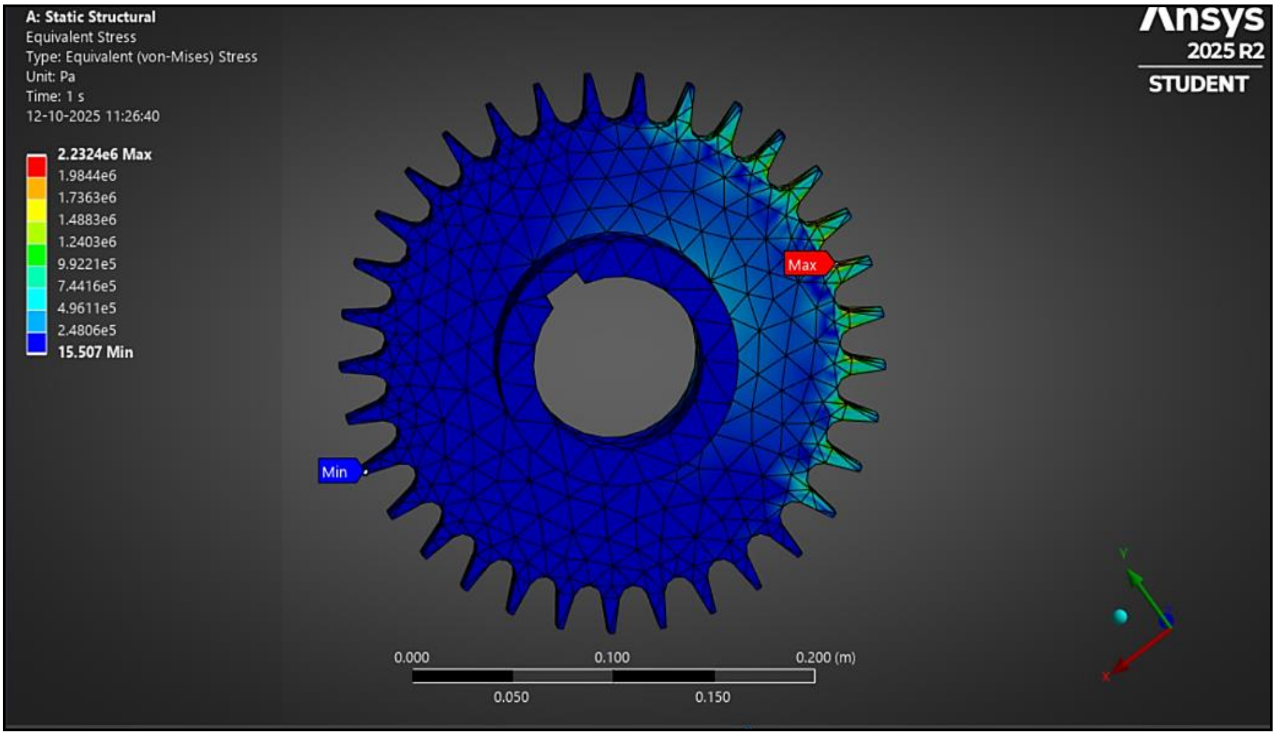


Figure 18: *Von mises, stress of sprocket using PA66GF30 – glass fiber reinforced material.*

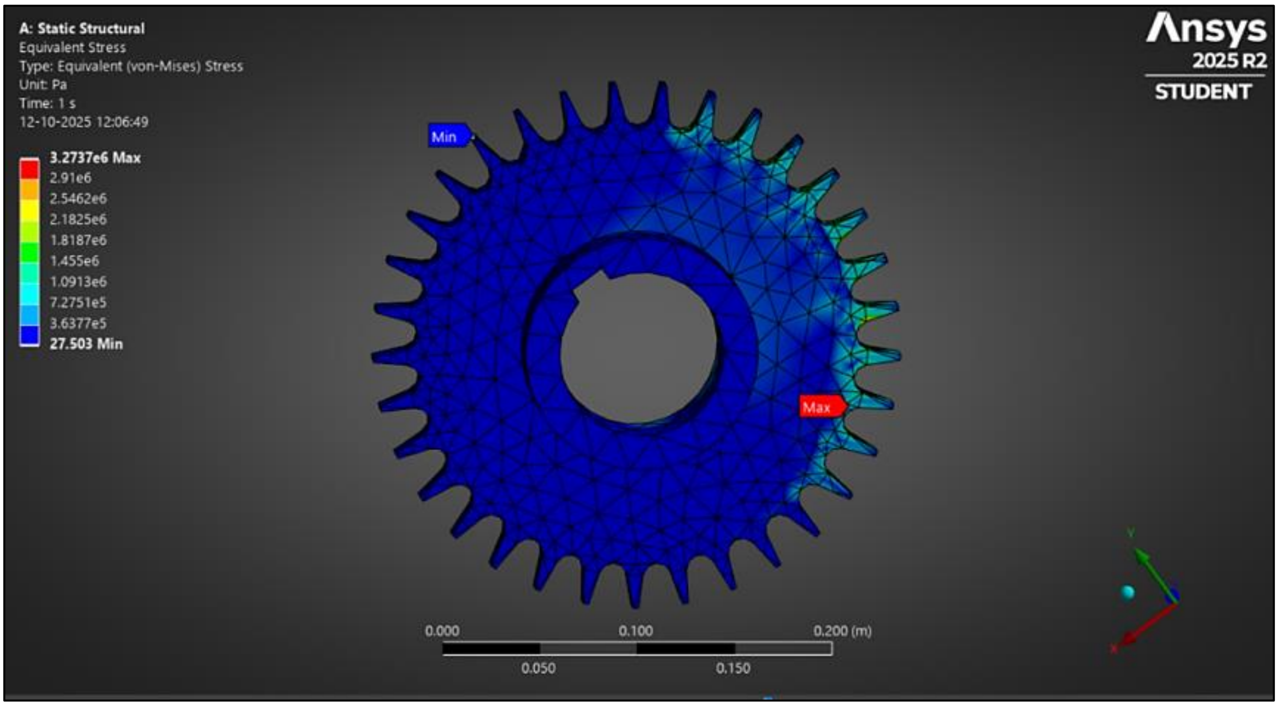


__Figure 19:__ Von mises, stress of sprocket using kevlar 49 polymers composite.

__Table 4:__ Mass comparison.

Material	Mass (kg)	Volume (m^3)
C45	5.95	0.00075866
PA66-GF30	1.016	0.00075866
Kevlar 49	1.0925	0.00075866

Observation

Table 4 shows the composite materials provide a dramatic reduction in sprockets weight (up to 83%) which is an important advantage for rotating systems where a reduced inertia is an efficiency factor shown in Fig. 20-25.

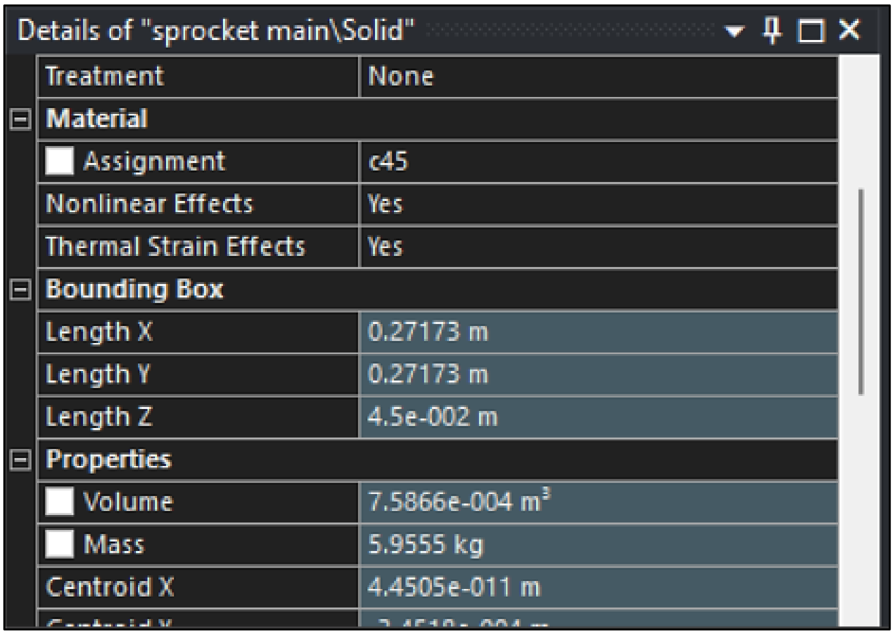
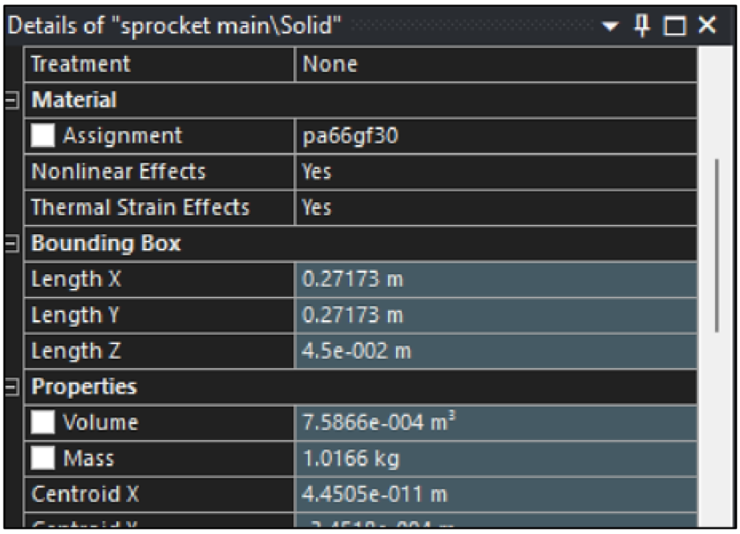


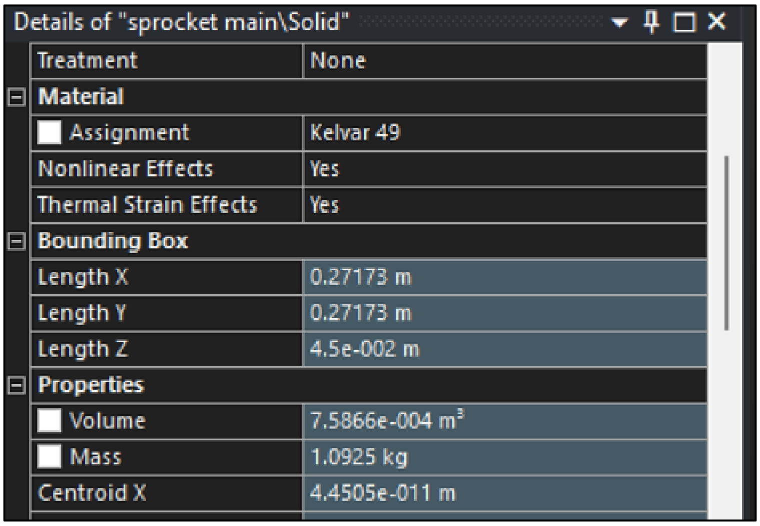
__Figure 20:__ Mass & volume of sprocket using C45 carbon steel.



Details of "sprocket main\Solid"

Treatment	None
Material	
Assignment	pa66gf30
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	0.27173 m
Length Y	0.27173 m
Length Z	4.5e-002 m
Properties	
Volume	7.5866e-004 m^3
Mass	1.0166 kg
Centroid X	4.4505e-011 m

Figure 21: *Mass & volume of sprocket using PA66GF30 – glass fiber reinforced material.*



Details of "sprocket main\Solid"

Treatment	None
Material	
Assignment	Kelvar 49
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	0.27173 m
Length Y	0.27173 m
Length Z	4.5e-002 m
Properties	
Volume	7.5866e-004 m^3
Mass	1.0925 kg
Centroid X	4.4505e-011 m

Figure 22: *Mass & volume of sprocket using kevlar 49 polymers composite.*

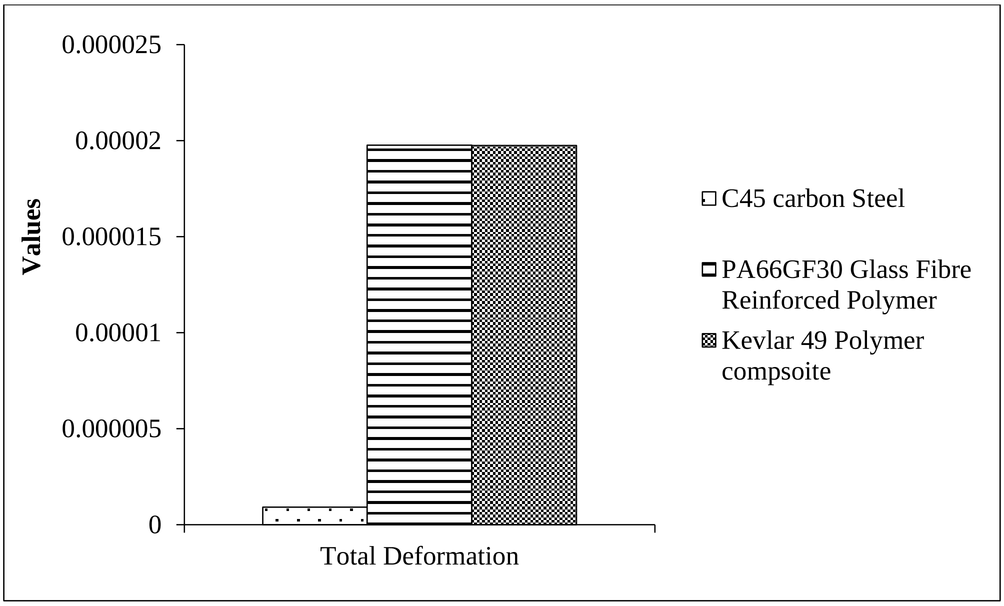


Figure 23: *Comparative visualization of total deformation.*

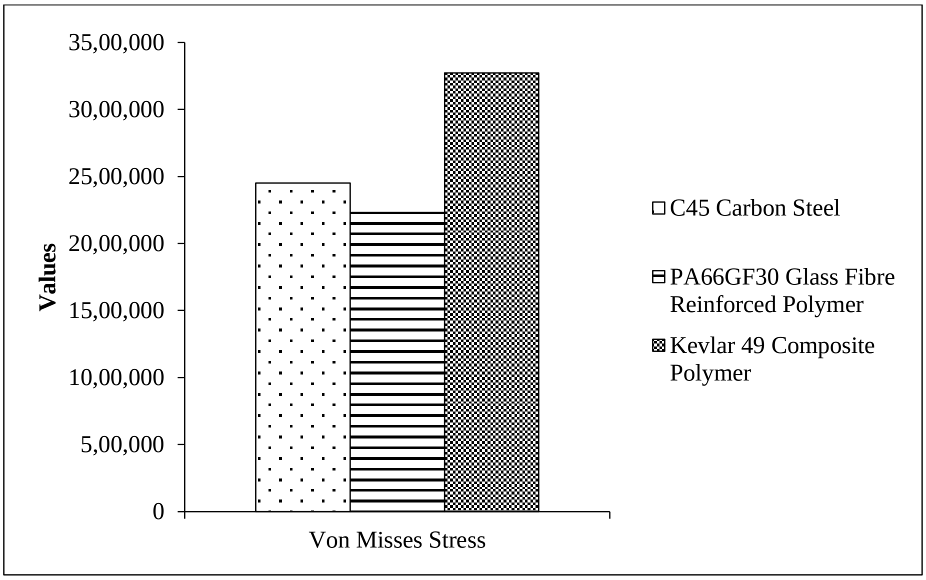


Figure 24: *Comparative visualization of von misses stress.*

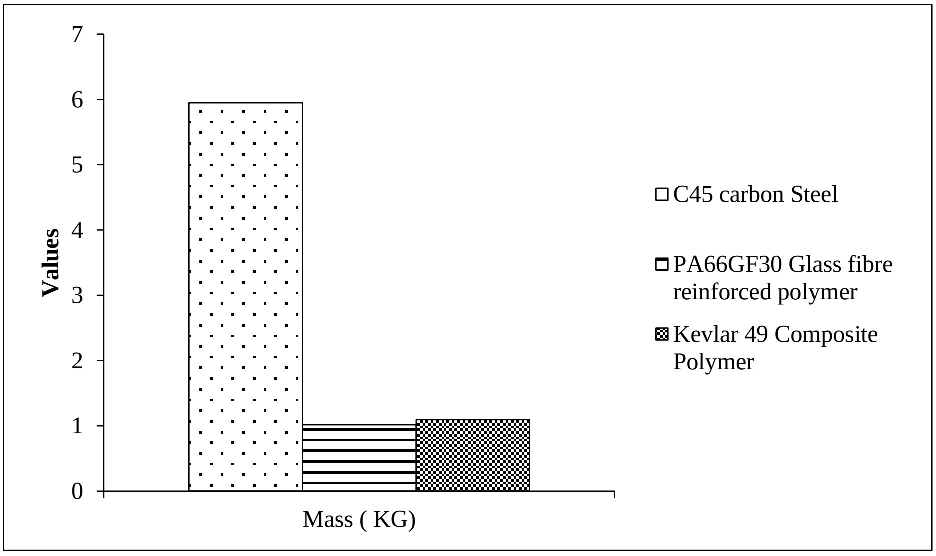


Figure 25: *Comparative visualization of mass of materials.*

DISCUSSION

Finite Element Analysis (FEA) was performed to assess the structural response of a sprocket at rest, modelled with three materials: C45 carbon steel, PA66-GF30 (glass fibre-reinforced material), and Kevlar 49 composite polymer, each under the same loading and boundary conditions. The results point out trade-offs between stiffness, strength, and mass that govern material selection in power transmission systems.

Static Structural Response

The resulting values of the total deformation and Von Mises stress of the FEA are shown below:

In decimal form:
C45 Steel: Deformation = 0.00000091111m, Stress = 2.45 MPa
PA66-GF30: Deformation = 0.000019767m, Stress = 2.23 MPa
Kevlar 49: Deformation = 0.000019743m, Stress = 3.27 MPa

The results of the FEA reveal that the C45 steel exhibits minimum deformation thus middle stress levels, which depict the high level of stiffness and rigidity shown in Table 5.

Table 5: *The resulting values of the total deformation and Von Mises stress.*

Material	Total Deformation (m)	Von Mises Stress (Pa)
C45 Steel	9.1111×10^{-7}	2.4516×10^{6}
PA66-GF30	1.9767×10^{-5}	2.2324×10^{6}
Kevlar 49	1.9743×10^{-5}	3.2737×10^{6}

The deformation of PA66-GF30 and Kevlar 49 composites is higher, which is typical of polymer-based materials because they possess a lower elastic modulus. Nevertheless, their stress traces are far below their actual yield or tensile threshold, which proves safety in its operation under static loading.

Mass and Weight Reduction

The summary of the mass and volume data of the sprockets are given below in Table 6:

Table 6: *The summary of the mass and volume data of the sprockets.*

Material	Density (calculated kg/m³)	Mass (kg)	Volume (m³)
C45 Steel	5.95 / 0.00075866 = 7844 kg/m³	5.95	0.00075866
PA66-GF30	1.016 / 0.00075866 = 1339 kg/m³	1.016	0.00075866
Kevlar 49	1.0925 / 0.00075866 = 1440 kg/m³	1.0925	0.00075866

These densities are consistent with typical literature values which confirm the model accuracy.

Weight saving in comparison to C45:

- PA66-GF30 - 82.9% lighter
- Kevlar 49 - 81.6% lighter

This dramatic mass saving causes a corresponding decreasing rotational inertia, which translates to increased energy efficiency, reduced torque requirement and reduced acceleration in chain-drive systems.

In the case of high-speed applications, this optimisation in terms of weight translates directly into improvements in power transmission efficiency and mechanical losses.

Comparison of Stress and Stiffness

Though reduced drastically, the weight of both polymer composites shows higher similarity in von Mises stresses of both materials (2.23-3.27 MPa) to that of steel (2.45 MPa). This means that the carrying capacity will not be compromised by the material replacement shown in Table 7.

To determine stiffness qualitatively, we can take deformation (δ) to stress (σ), since $E \propto \frac{\sigma}{\delta}$.

Relative comparison of C45 with relative stiffness:

Table 7: *The summary of the comparison of stress and stiffness.*

Material	σ (Pa)	δ (m)	Relative Stiffness ($E/E_{(C45)} = (\sigma/\delta) / (\sigma/\delta)_{(C45)}$)
C45	2.4516×10^{6}	9.1111×10^{-7}	1.00
PA66-GF30	2.2324×10^{6}	1.9767×10^{-5}	(2.2324e6/1.9767e-5)/(2.4516e6/9.1111e-7) ≈ **0.042**
Kevlar 49	3.2737×10^{6}	1.9743×10^{-5}	(3.2737e6/1.9743e-5)/(2.4516e6/9.1111e-7) ≈ **0.077**

Thus:

- PA66-GF30 is ~4% as stiff as C45
- Kevlar 49 is ~7.7% as stiff as C45

The two materials have lower stiffness, but both retain structural integrity at safe levels of deformation and are feasible for moderate-load or lightweight systems.

Cost and Material Efficiency

Approximate Material cost (Market 2025) and cost per sprocket:

Although Kevlar 49 is much more costly, its weight reduction and much better strength-to-weight ratio make it superior for use in high-performance and aerospace-grade systems, as shown in Table 8.

Table 8: *Comparison of cost and material efficiency.*

Material	Cost (₹/kg)	Mass (kg)	Cost per Sprocket (₹)
C45 Steel	100	5.95	595
PA66-GF30	300	1.016	305
Kevlar 49	4500	1.0925	4916

However, the best cost-performance ratio would be found in PA66-GF30, which can likely be used in the industrial and automotive field where moderately stressed and high corrosion resistance needs are required.

Wear Resistance and Hybrid Optimization

An important factor with polymeric sprockets and composite sprockets is that teeth wear because of lower hardness at the surface, unlike steel. In the long-term operation, abrasion and surface fatigue can be caused by a direct contact between the chains.

This can be alleviated by ensuring that a hybrid sprocket is designed having:

- Core (light weight and vibration damping) Composite or polymer core,
- Steel reinforced teeth (to resist wear and to enhance load transfer).
- This hybrid design can accomplish:
- Mass reduction to up to 70 percent less than in all-steel designs,
- Major decrease in vibration and noise, and
- Longer service life with long-lasting contact surfaces.

This has become the best option in the current lightweight engineering systems since it combines the mechanical merits of metals and the practical merits of composites.

Overall Insights

The study confirms that:

- C45 steel has great rigidity and low deformation, although it has the disadvantage of high mass and corrosiveness.
- PA66-GF30 offers the best tradeoff - lightweight design, reasonably good stiffness, corrosion resistance, and low cost.
- Kevlar 49 has a better strength-to-weight ratio hence it is suitable in precision and high-speed system, but it is more expensive.

In using steel-capped teeth, polymer and composite sprockets are able to be used to achieve greater durability and wear resistance, prolonged service life at a substantial weight and energy savings shown in Table 9.

Table 9: *Summary of findings.*

Property	C45 Steel	PA66-GF30	Kevlar 49
Von Mises Stress (Pa)	2.45×10^{6}	2.23×10^{6}	3.27×10^{6}
Total Deformation (m)	9.11×10^{-7}	1.98×10^{-5}	1.97×10^{-5}
Mass (kg)	5.95	1.016	1.0925
Density (kg/m³)	7844	1339	1440
Weight Reduction vs C45	—	82.9%	81.6%
Relative Stiffness	1.00	0.042	0.077
Cost per Part (₹)	595	305	4916
Wear Resistance	Excellent	Moderate	High (with steel teeth)
Suitability	Heavy-duty	Medium-duty	High-performance

Therefore, hybrid composite spur gears are the future trend of innovating materials that can be used in lightweight and effective power transmissions.

CONCLUSION AND RECOMMENDATIONS

Comparison analysis of the sprocket produced using C45 Carbon Steel, PA66-GF30 (glass-fiber-reinforced nylon), and Kevlar 49 indicates that there are major differences in mechanical and physical performance of the same when these are loaded and subjected to the same conditions.

C45 Steel has the lowest overall deformation (9.1111 x 10-7 m) and the least equivalent strain (1.2441 x 10-4), which means that it has an outstanding stiffness and dimensional stability. It is however very heavy with the greatest mass (5.95 kg).

PA66-GF30 and Kevlar 49 have significantly greater deformation values (~1.97 x 10-5 m) which demonstrates low stiffness in these materials as compared to steel. Nonetheless, the two materials are light; hence, the overall weight of the sprocket is approximately 80 dwt less than that of C45 steel.

Kevlar 49 has a higher von Mises stress (3.27 x 106 Pa) compared to PA66-GF30 (2.23 x 106 Pa), which means it has a greater load-bearing capability and a moderate performance in terms of structure.

In summary:

- C45 Steel - Best Mechanical Strength and stiffness, but heavy.
- PA66-GF30 - Lightest, economical & Higher deformation.
- Kevlar 49 - middle-ground between weight, stiffness, and strength.
- In high-load or industrial applications, where strength, rigidity and durability are essential (i.e. heavy machinery, chain drives when under constant load), C45 steel is the most stable material despite its heaviness.
- In lightweight or medium-duty applications, e.g. automotive or robotic systems, where decreased weight is sought after, noise reduction is sought after, etc., Kevlar 49 provides an ideal trade-off between strength and mass.
- PA66-GF30 can be considered when cost is a concern as well as light and stress-free applications where moderate strength is required including prototype models or lightweight machinery.
- Future research would involve fatigue testing, wear tests and thermal experimentation on long term integrity and appropriateness at cyclic loading and modulating temperatures.

REFERENCES

1. M. R. Hossan and Z. Hu, “Strength Evaluation of Polymer Composite Spur Gear by Finite Element Analysis,” *Design and Manufacturing*, pp. 65–72, Jan. 2008, doi: https://doi.org/10.1115/imece2008-66617
2. M. Mbarek, S. Rhaiem, M. Kharrat, and M. Dammak, “Experimental Study Of The Rolling–Sliding Contact Conditions In A PA66/Steel Gear Using Twin-Disc Test Rig: Friction and Wear Analysis,” *Surface Review and Letters*, vol. 22, no. 06, p. 1550074, Oct. 2015, doi: https://doi.org/10.1142/s0218625x15500742
3. A. Behera, R. K. Behera, P. Sahu, R. R. Swain, and T. R. Mahapatra, “Tensile and Failure Behavior of Kevlar Fiber Reinforced Epoxy Matrix Composite Exposed to Different Environmental Conditions,” *Materials Today: Proceedings*, vol. 5, no. 9, pp. 20250–20256, 2018, doi: https://doi.org/10.1016/j.matpr.2018.06.396
4. J.-K. Choi, K.-S. Park, and S.-S. Lee, “Predicting the hardening depth of a sprocket by finite element analysis and its experimental validation for an induction hardening process,” *Journal of Mechanical Science and Technology*, vol. 32, no. 3, pp. 1235–1241, Mar. 2018, doi: https://doi.org/10.1007/s12206-018-0227-4
5. J. Singh, M. R. Tyagi, G. Singh, and R. D. Sharma, “Design, Analysis and Manufacturing of Front Sprocket of a Bicycle using Carbon Fiber Reinforced Plastics,” *Journal of Physics: Conference Series*, vol. 1240, no. 1, p. 012071, Jul. 2019, doi: https://doi.org/10.1088/1742-6596/1240/1/012071
6. V. N. Sai, V. Siva, J. Sai, and P. S. R. Sreekanth, “Comparative analysis and simulation of metal and non-metal polymer composite gears,” *Materials Today Proceedings*, vol. 56, pp. 1109–1114, Nov. 2021, doi: https://doi.org/10.1016/j.matpr.2021.10.174
7. Y. K. Chen, S. N. Kukureka, C. J. Hooke, and M. Rao, “Surface topography and wear mechanisms in polyamide 66 and its composites,” *Journal of Materials Science*, vol. 35, no. 5, pp. 1269–1281, Jan. 2000, doi: https://doi.org/10.1023/a:1004709125092

8. X. Huang, S. Su, Z. Xu, Q. Miao, W. Li, and L. Wang, “Advanced Composite Materials for Structure Strengthening and Resilience Improvement,” *Buildings*, vol. 13, no. 10, p. 2406, Oct. 2023, doi: https://doi.org/10.3390/buildings13102406
9. W. Suwannahong and C. Suvanjumrat, “An Integrating Finite Element Method and Multi-body Simulation for Drive Systems Analysis,” *Engineering Journal*, vol. 21, no. 1, pp. 221–234, Jan. 2017, doi: https://doi.org/10.4186/ej.2017.21.1.221
10. J. H. Greenwood and P. G. Rose, “Compressive behaviour of Kevlar 49 fibres and composites,” *Journal of Materials Science*, vol. 9, no. 11, pp. 1809–1814, Nov. 1974, doi: https://doi.org/10.1007/bf00541750
11. B. Y. He, Y. H. Sun, G. P. Li, and S. Z. Chen, “Finite Element Contact Analysis for Sprocket of an Armoured Face Conveyor,” *Materials Science Forum*, vol. 697–698, pp. 740–744, Sep. 2011, doi: https://doi.org/10.4028/www.scientific.net/msf.697-698.740
12. K. K. H. Yeung and K. P. Rao, “Mechanical Properties of Kevlar-49 Fibre Reinforced Thermoplastic Composites,” *Polymers and Polymer Composites*, vol. 20, no. 5, pp. 411–424, Jun. 2012, doi: https://doi.org/10.1177/096739111202000501
13. C. Birleanu, M. Cioaza, F. Serdean, M. Pustan, P. Bere, and G. Contiu, “Tribological Investigation of Glass Fibre Reinforced Polymer Composites against 52100 Chrome Alloy Steel Based on ELECTRE Decision-Making Method,” *Polymers*, vol. 16, no. 1, p. 62, Dec. 2023, doi: https://doi.org/10.3390/polym16010062
14. T. Kunishima, Y. Nagai, T. Kurokawa, “Tribological behavior of glass fiber reinforced-PA66 in contact with carbon steel under high contact pressure, sliding and grease lubricated conditions,” *Wear*, vol. 456–457, pp. 203383–203383, Jun. 2020, doi: https://doi.org/10.1016/j.wear.2020.203383
15. T. Kunishima, Y. Nagai, S. Nagai, “Effects of glass fibre properties and polymer molecular mass on the mechanical and tribological properties of a polyamide-66-based composite in contact with carbon steel under grease lubrication,” *Wear*, vol. 462–463, p. 203500, Dec. 2020, doi: https://doi.org/10.1016/j.wear.2020.20350
16. L. Penn and F. N. Larsen, “Physicochemical properties of Kevlar 49 fibre,” *Journal of Applied Polymer Science*, vol. 23, no. 1, pp. 59–73, Jan. 1979, doi: https://doi.org/10.1002/app.1979.070230106
17. B. Majeed and S. Basturk, “Analysis of polymeric composite materials for frictional wear resistance purposes,” *Polymers and Polymer Composites*, vol. 29, no. 2, pp. 127–137, Feb. 2020, doi: https://doi.org/10.1177/0967391120903957
18. A. Ignatijev, S. Glodež, and J. Kramberger, “Computational Model for Analysing the Tooth Deflection of Polymer Gears,” *Polymers*, vol. 16, no. 5, p. 677, Mar. 2024, doi: https://doi.org/10.3390/polym16050677
19. M. Hriberšek and S. Kulovec, “Thermal and durability characterization of polyacetal and polyamide gear pairs,” *Journal of Mechanical Science and Technology*, vol. 35, no. 8, pp. 3389–3394, Jul. 2021, doi: https://doi.org/10.1007/s12206-021-0712-z

CITE THIS ARTICLE

R. Nanwatkar, Y. G. Naikwadi, and A. G. Shelke, “Analysis of Sprocket Strength and Deformation for Metallic and Composite Polymer Materials,” *International Journal of Materials and Mechanical Structures Engineering*, vol. 1, no. 2, pp. 37–56, Nov. 2025.