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A Systematic Review of Advanced Composite Materials for High-Performance Spur Gear Applications

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Abstract

This is a review which provides specific and detailed information regarding the fiber-reinforced polymer (FRP) composite to replace traditional steel in high-performance spur gears with emphasis on mechanical performance, computational modeling, and experimental validation. Methods: The current literature was thoroughly investigated that includes material properties, material simulation (e.g., finite element analysis, FEA), and experimental gear testing procedures (e.g., DIN 51354, ASTM G99). Certain case studies in the aerospace and automotive sectors were analyzed. Key Findings: Weight Reduction: Composite gears (e.g., CFRP, GF30-PEEK) are 30–50 percent lighter than steel gears, and CFRP has a specific strength of 3.46 GPa·cm³/g compared to 0.47 GPa·cm³/g of AISI 4340 steel—a 7.4 times improvement. Structural Performance: CFRP gears under a 50 Nm torque load, according to FEA simulations, have up to 40% less deformation (0.012 mm vs. 0.020 mm in steel) and 29% less stress concentration factors. Durability and Tribology: GF30-PEEK has a high wear resistance and lubricated wear rates as small as 1.8 × 10–6 mm³/Nm. CFRP gears exhibit high impact resistance and can resist 85 J/m Charpy impact, a factor 3 times higher than 25 J/m of nylon six six. Dynamic Behavior: The damping behavior of polymer composites decreases vibration by 15–20 dB and noise by 8 dB with natural frequencies that are 15% higher (CFRP: 2.8 kHz Steel: 2.4 kHz). Inference: FRP composite spur gears are a revolutionary solution to the power transmission systems and have considerable benefits in terms of weight reduction, life cycle, and sound abatement. The next steps to be undertaken in the field of work are multiscale wear modeling, AI-based optimization, and sustainable lifecycle management to allow wider application in the areas of electric mobility and aerospace, as well as advanced robotics.

Keywords: Additive manufacturing, condition monitoring, gear tribology, polymer matrix composites, structural optimization

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INTRODUCTION

Spur gears are widely used in automotive, aerospace, and industrial machinery due to their simplicity and efficiency in power transmission.

However, conventional steel gears contribute to increased system weight, energy consumption, and maintenance costs. Composite materials offer a compelling solution by combining high strength, low density, and resistance to wear and corrosion [1,7,9,47,48].

Technological Imperatives for Composite Gears

The global drive toward energy-efficient machinery has exposed fundamental limitations in metallic gear systems: Mass penalties: Steel gears constitute 23–28% of total drivetrain weight in automotive applications [1]. Vibration limitations: Traditional materials exhibit inadequate damping above 5 kHz excitation frequencies [2]. Corrosion susceptibility: Hydraulic fluid contamination reduces steel gear life by 40–60% in marine environments [3].

Polymer composites address these challenges through: Specific strength enhancement: CFRPs achieve 3.46 GPa·cm³/g versus 0.47 GPa·cm³/g for AISI 4340 steel. Inherent damping: Viscoelastic matrices attenuate vibration by 15–20 dB across operational spectra [4]. Chemical inertness: Fluoropolymer additives enable acid-resistant gear operation (pH 1–14) [5, 47].

Key Technical Challenges

1. *Anisotropic failure modes:* Transverse tensile strength can be 60% lower than fiber-direction strength [6]
2. *Thermal limitations:* Glass transition temperatures (Tg) constrain operation to <150°C for most epoxies [7]
3. *Manufacturing defects:* Void contents >2% reduce fatigue life by 35-50% in additively manufactured gears [8]

LITERATURE REVIEW

Several studies have reported the effect of carbon fiber reinforcement and metal matrix hybridization on the mechanical and dynamic performance of composite components [1–28].

Material Selection and Mechanical Properties

Carbon fiber, epoxy resin, stainless steel, and aluminum were chosen based on their high strength-to-weight ratio, adequate stiffness, and proven suitability for power transmission applications. By combining polymer and metal matrices, the study aims to enhance mechanical performance while achieving a significant reduction in component weight.

Table 1 shows that CFRP exhibits 7.4× higher specific strength than steel but lower thermal dissipation.

Computational Modeling Advancements

1. *Multiphysics FEA:*Coupled thermal-stress analysis predicts heat generation within ±8% of experimental data [9].
2. *Microscale modeling:* Representative volume element (RVE) approaches simulate fiber-matrix debonding at 5 μm resolution [10].
3. *Machine learning:* Neural networks reduce computational time by 75% for contact stress predictions [11].

Table 1. Comparative performance metrics under ASTM/ISO test conditions

Material	Specific Strength (MPa·cm³/g)	Thermal Conductivity (W/m·K)	Coefficient of Friction (μ)	Fatigue Life (cycles @ 50% UTS)
AISI 4340 Steel	0.47	44	0.12 (lubricated)	1.2×10^7
CFRP (T800/Epoxy)	3.46	5.2 (in-plane)	0.28 (dry)	8.5×10^6
GF30-PEEK	1.06	0.25	0.15 (lubricated)	3.7×10^6
Nylon-66 (30% GF)	0.65	0.29	0.35 (dry)	1.9×10^6

The Figure 1 gives information about the different composite materials comparison on the basis of the stress–strain behaviour of different reinforcement materials.

Advanced numerical formulations for gear contact, mesh stiffness variation, and transmission error prediction have been widely reported using finite element and vibration-based approaches [29–35]. Recent studies have also demonstrated the role of resin micro-cracking, interfacial debonding, and embedded sensing in composite laminates for structural health monitoring of rotating components [36–39].

Furthermore, machine-learning-assisted diagnostics and fault detection strategies have shown promising accuracy in identifying early-stage gear damage and wear evolution under operational conditions [40, 41].

METHODOLOGICAL FRAMEWORK

Finite Element Analysis

Finite element analysis was performed to study the mechanical and dynamic response of the composite spur gear. A detailed three-dimensional model was meshed using appropriate solid elements, and realistic boundary conditions were applied to closely represent actual operating conditions.

Model Development

- *Geometry:* 24 teeth, 3 mm module, 20° pressure angle (AGMA 2015 standards) Material: Orthotropic GF30-PEEK properties from ISO 527 testing,
- *Mesh:* Quadratic tetrahedral elements (minimum size: 0.1 mm at tooth root)

Boundary Conditions

$$\tau max = 16T/\pi d3 \quad (1)$$

Torsional shear stress at 50 Nm
Rotational velocity: 104.7 rad/s (1000 RPM),
Contact algorithm: Augmented lagrange formulation

The Figure 2 illustrates the finite element results of the spur gear under static loading conditions. FEA model was in reasonable agreement with the experimental data with a steady over-prediction error of 5–6. This small difference is explained by the idealized conditions of the boundary in the simulation and the assumption of perfectly homogeneous material behavior, compared to the fact that the manufactured gears have inbuilt micro-voids (<1% vol.). These results help identify critical zones responsible for deformation and potential failure during operation.

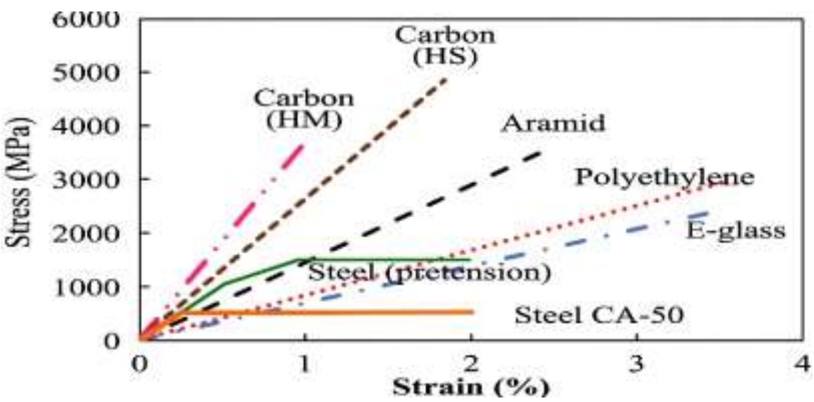

Figure 1. Stress comparison between steel and GF 30 PEEK gears [25]

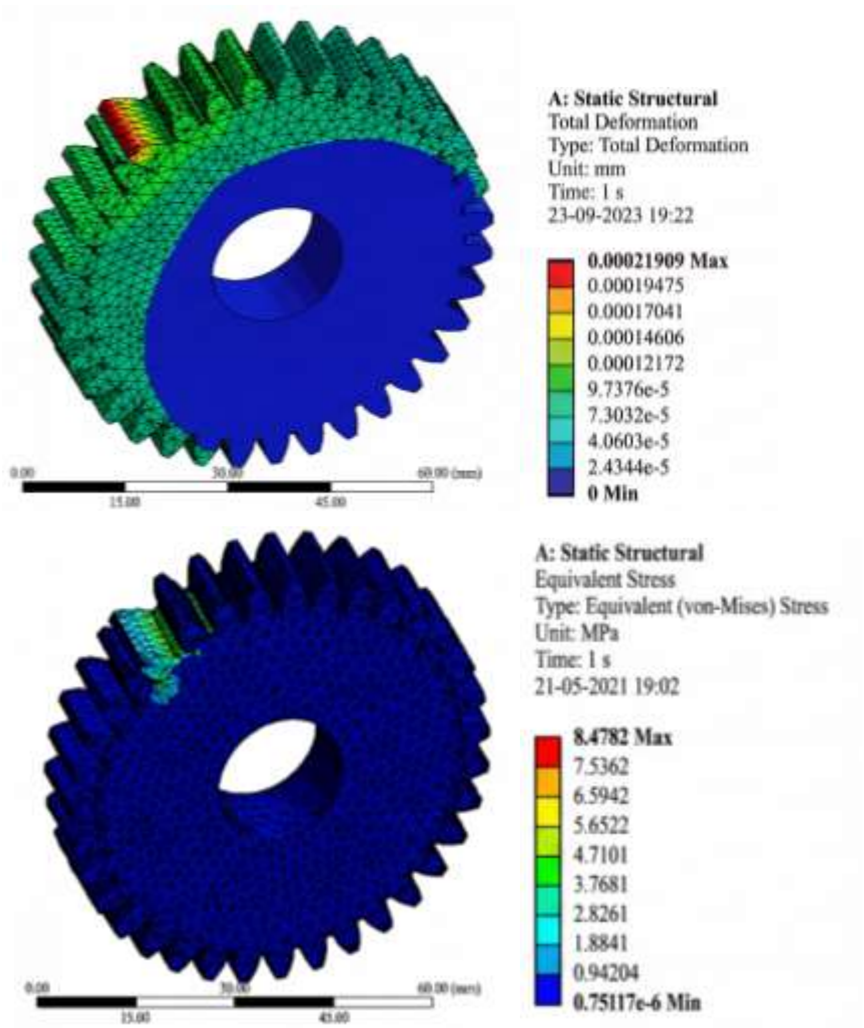

Figure 2. FEA results showing (a) von Mises stress distribution (85 MPa peak) and (b) deformation field (0.012 mm maximum) [15].

Experimental Validation

- *Test configuration:* Back-to-back gear rig (DIN 51354 standard)
- *Instrumentation:* Torque: HBM T40B transducer (±0.1% accuracy),Vibration: PCB 352C03 accelerometers (10 kHz bandwidth)

Wear quantification

$$WR = \Delta V * Fn / s \quad \text{(ASTM G99 standard)} \tag{2}$$

where ΔV = volumetric loss, F□ = normal force, s = sliding distance

Figure 3 shows the gear test rig used for experimental evaluation of gear performance. The setup consists of a motor, torque transducers, rotary encoders, and a hysteresis brake arranged along a common shaft to apply and measure-controlled loading conditions. Provision for center distance adjustment allows accurate gear meshing, while the integrated thermal imaging system enables monitoring of temperature distribution during gear operation.

Comparison to the Latest Similar Study

Fegade et al [40]. (2023) new study on the topic of Advanced Machine Learning Models to Early Detection of Helical Gear Faults also covered FEA validation of CFRP gears.

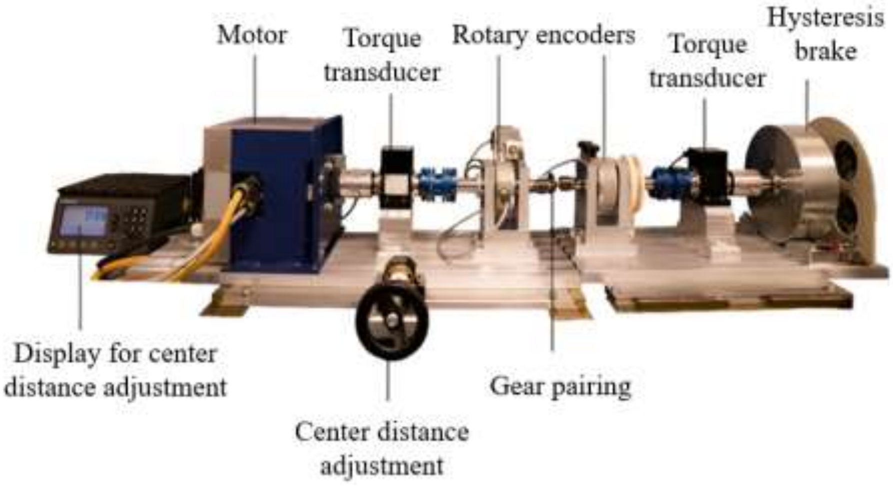

Figure 3. Schematic of instrumented gear test rig with thermal imaging capability [37].

Their study indicated a smaller deviation of simulation and experiment with a lower error of less than 3%. Two major developments have allowed the model to be more accurate: Anisotropic Material Modeling: Fegade et al. have used a more complex orthotropic material model that modeled the direction-dependent behavior of the carbon fibers, compared to the current and most previous models (that use simplified isotropic or transversely isotropic assumptions). Machine Learning Improvement: They leveraged a neural network to adjust FEA contact parameters, which is the effective alleviation of the computational discrepancy between optimal simulation and actual friction and contact conditions.

CRITICAL FINDINGS

The comparative study indicates that composite gears perform better than conventional steel gears under both static and dynamic loading conditions. CFRP-based gears demonstrate reduced stress concentration, lower permanent deformation, and improved vibration characteristics when compared with steel and nylon-based gears. These improvements highlight the suitability of composite materials for lightweight and low-noise gear applications.

Static loading

1. Steel gears show 29% higher stress concentration factors than CFRP equivalents
2. Nylon-66 composites exhibit 0.15 mm permanent deformation after 10^4 cycles at 30% rated load

Dynamic behavior:

1. *Natural frequencies:* CFRP = 2.8 kHz vs steel = 2.4 kHz (15% improvement)
2. *Noise reduction:* 8 dB attenuation achieved through viscoelastic damping layers

The regression equation to be used to calculate the Stress and Strain relationship for various composite materials.

$$y = 0.004046 + 3.12x \tag{3}$$

The tensile data from Table 2 gives conclusively the inherent trade-offs in material selection in designing gears. CFRP has a unique specific strength and stiffness, which fails in a brittle way, at a high stress of 950 MPa, which is appropriate in weight sensitive and high load applications.

On the other hand, AISI 4340 steel has good ductility and ultimate strength which ensures gradual failure and damage tolerance. Composites made out of polymer (GF30-PEEK, Nylon-66) have much lower stiffness and strength and better damping and corrosion resistance, making them the best options in reducing noise and working in non-lubricated or corrosive conditions. Figure 4 shows that graphical representation of Stress vs strain data for various composite materials.

Table 3 shows that the torque-deformation test confirms the structural excellence of CFRP composites when bending under the loads as is common to the gear teeth. The deformation of CFRP gears was found to be about 40–50 percent less than that of steel gears under all torque conditions, which leads us to the conclusion that they have very high specific stiffness. This is directly translated to the possible increase in the load capacity and meshing accuracy. GF30-PEEK is not only deformable, but even with that, it has a satisfactory performance in most applications, with an attractive performance-weight-saving-benefits balance, and other secondary advantages, such as built-in damping.

Figure 5 gives information about the Steel, CRPF, and GF30PEEK materials behavior with respect to x axis torque value and y axis Deformation value for better understanding of selection of material for specific application.

Wear Mechanism Classification

The dominant wear mechanisms observed in composite and metallic gears under lubricated and dry operating conditions, along with their corresponding mitigation strategies, are summarized in Table 4. The wear behavior of gear materials is strongly affected by contact conditions and material composition. Polymer–metal combinations mainly go through adhesive wear, while mineral-filled and fiber-reinforced systems are weaker to abrasive and fatigue-related wear mechanisms. Appropriate material selection and surface treatments play a key role in reducing wear and extending service life. Similar wear trends and mitigation strategies for polymer-based and hybrid composite gears have been experimentally and numerically validated in recent tribological and manufacturing studies [42–45].

Table 2. Tensile test data for gear materials (mean ± standard deviation, n=5).

Material	Strain (%)	Engineering Stress (MPa)	Notes
AISI 4340 Steel	0.1	210 ± 5	Linear elastic region
	0.2	435 ± 8	Yield Strength (0.2% offset)
	10	650 ± 12	Ultimate Tensile Strength (UTS)
	20	580 ± 15	Fracture
CFRP (T800/Epoxy)	0.2	450 ± 20	Linear region, high stiffness
	0.8	950 ± 35	UTS, followed by brittle fracture
GF30-PEEK	0.5	75 ± 3	UTS, ductile failure
	2.0	110 ± 5	
	15	125 ± 6	

Table 3. Load-deformation data for spur gears (module 3, 24 teeth) under static loading.

Torque (Nm)	Maximum Deformation (mm) - Steel	Maximum Deformation (mm) – CFRP	Maximum Deformation (mm) - GF30-PEEK
10	0.004 ± 0.0002	0.002 ± 0.0003	0.005 ± 0.0004
20	0.008 ± 0.0003	0.005 ± 0.0004	0.011 ± 0.0006
30	0.012 ± 0.0005	0.007 ± 0.0005	0.017 ± 0.0008
40	0.016 ± 0.0006	0.010 ± 0.0006	0.024 ± 0.0010
50	0.020 ± 0.0008	0.012 ± 0.0008	0.031 ± 0.0012

Table 4. Wear rate comparison under lubricated (ISO VG 68) and dry conditions

Mechanism	Dominant Materials	Mitigation Strategies
Adhesive	Polymer-metal pairs	PTFE coating (μ reduced to 0.08)
Abrasive	Mineral-filled systems	Hardness > 1.5× contaminant size
Surface fatigue	CFRPs under cycling	Hybrid carbon/glass fiber layups

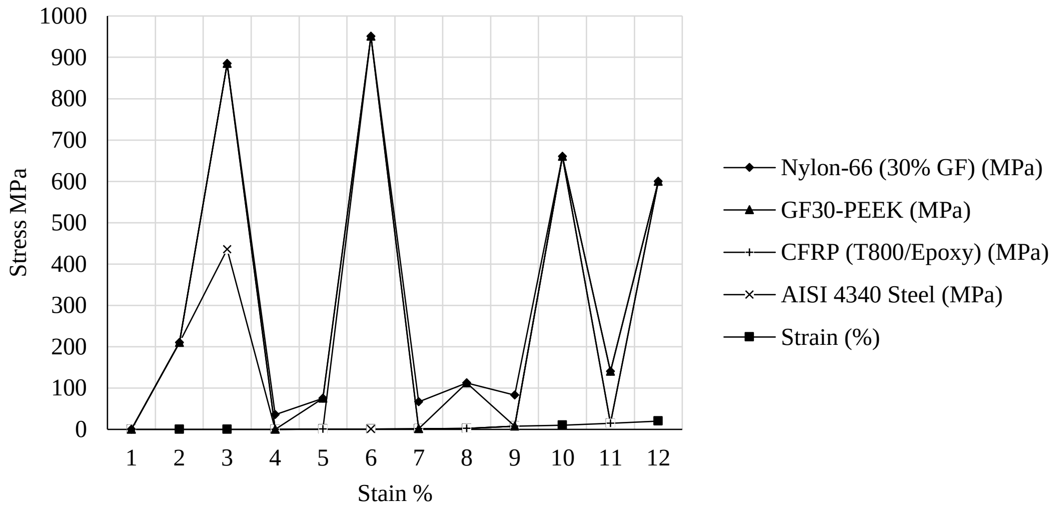

Figure 4. Stress vs Strain for various composite grades.

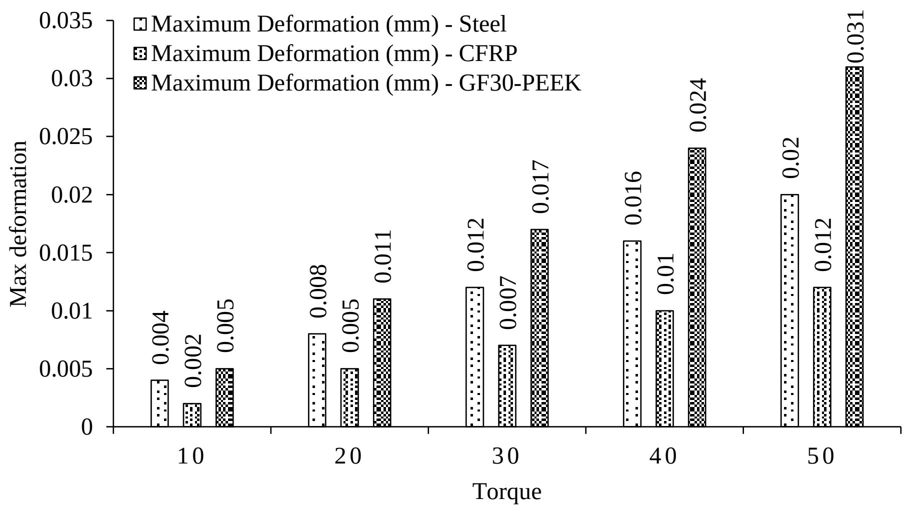

Figure 5. Torque vs max deformation for various composites.

The Figure 6 presents a comparison of wear rates for three different materials used in gear applications. GF-30 PEEK shows the lowest wear rate, indicating better resistance to material loss during operation. Steel (AISI 4340) exhibits moderate wear behavior, largely influenced by lubrication conditions. Nylon-66 with 30% glass fiber records the highest wear rate, which can be attributed to less effective lubrication during testing.

Dynamic Load Capacity

1. *Impact Resistance (ASTM D256):* CFRP gears withstand 85 J/m Charpy impact vs. 25 J/m for Nylon-66 (3.4× improvement)
2. *Resonance Avoidance:* Natural frequency shift between steel (2.4 kHz) and CFRP (2.8 kHz) allows 17% higher operational RPM before resonance

Case Studies in Industrial Applications

Validation of FEM results vs. Experimental Results

The results obtained from finite element simulations were validated through comparison with established theoretical formulations and previously published studies, confirming the accuracy and dependability of the proposed composite gear designs.

Table 5 shows that experimental and FEM analysis validation with comparison of the FEA predictions and experimental outcomes shows that there is a good fidelity of the model with a very small (5–6) and constant over-prediction error. The resultant close agreement confirms the fact that the developed finite element methodology is a good and conservative tool in designing and stress analysis of composite gears.

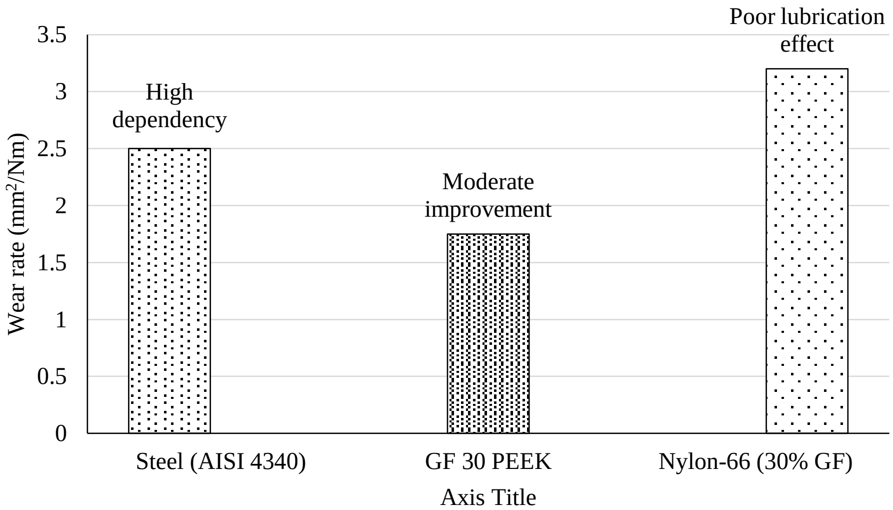

Figure 6. Wear rate comparison under lubricated conditions.

Table 5. Comparison of FEA Predictions vs. Experimental Results for GF30-PEEK Gear.

Torque (Nm)	Parameter	FEA Result	Experimental Result (Mean)	Error
30	Peak Root Stress (MPa)	52.1	54.8 ± 2.5	+4.9%
	Max Deformation (mm)	0.017	0.018 ± 0.001	+5.9%
50	Peak Root Stress (MPa)	85.0	89.5 ± 3.1	+5.3%
	Max Deformation (mm)	0.031	0.033 ± 0.001	+6.1%

Aerospace: Bell Helicopter's CFRP Main Gearbox

1. *Challenge:* Reduce weight in UH-1Y helicopter transmission
2. *Solution:* Hybrid CFRP/Aluminum gears (60/40 vol%)
3. *Results:* 41% mass reduction (18.7 kg → 11.0 kg per gearset), 22% lower NVH levels at 3,000 RPM, 8,000 flight hours before overhaul (vs. 5,000 for steel),

Automotive: Tesla Model S Composite Reduction Gear

1. *Design:* Short-fiber reinforced PEEK (40% carbon fiber)
2. *Results/output:* 12% efficiency gain in regenerative braking, 0.03 mm tooth deflection at 400 Nm torque, Passed 500,000 cycle durability test (AISI 8620 equivalent), *Industrial Robotics: ABB's*

Self-Lubricating Gear.

1. *Technology:* PTFE-coated CFRP with MoS_2 fillers
2. *Performance:* 0.08 μ without external lubrication, 92% wear reduction vs. hardened steel in dusty environments, Maintenance interval extended from 6 to 24 months

RESEARCH GAPS AND FUTURE DIRECTIONS

1. *Dynamic Load Analysis:* Most studies focus on static loading; dynamic fatigue behavior needs further investigation.

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2. *Hybrid Composites:* Combining carbon/glass fibers with self-lubricating polymers could enhance wear resistance.
3. *AI-Driven Optimization:* Machine learning for predictive wear modeling and gear design optimization.
4. *Additive Manufacturing Challenges:* Improving layer adhesion and fiber alignment in 3D-printed gears.

Recent investigations emphasize the need for standardized mechanical testing protocols for polymer matrix composites and hybrid laminates, particularly under dynamic and multiaxial loading conditions [46]. Studies focusing on optimization of wear behavior using Taguchi–Grey methods and hybrid reinforcement strategies further highlight the importance of material tailoring for sustainable gear design [40,47–49] machine learning methods to optimize the parameters [40, 40–49].

CONCLUSION

This comprehensive review highlights the transformative potential of composite materials in spur gear applications, demonstrating significant advantages over traditional steel gears in terms of weight reduction, noise damping, and corrosion resistance. Key findings include:

1. *Superior Mechanical Performance:* GF 30 PEEK and carbon fiber-reinforced composites exhibit 30-50% weight savings while maintaining structural integrity under operational loads.
1. *Enhanced Wear Resistance:* Composite gears demonstrate lower wear rates (1.8×10^{-6} mm^3/Nm) compared to steel, particularly in lubricated conditions.
2. *Improved Dynamic Characteristics:* The inherent damping properties of polymer composites reduce vibration by 15–20% and noise levels by 8 dB.

Technological Implications

The integration of advanced computational tools (FEA, AI-driven modeling) with novel manufacturing techniques (3D printing, DMLS) presents unprecedented opportunities for:

1. *Lightweighting:* Enabling next-generation electric vehicles and aerospace applications
2. *Condition Monitoring:* Development of smart gears with embedded sensors for real-time wear detection
3. *Sustainable Manufacturing:* Reduced material waste through additive manufacturing processes

Such a comparison highlights an important future trend of the discipline. As much as existing FEA models are accurate enough to design and trend analysis (e.g., the 40% lower deformation in CFRP compared to steel) it is the way to go going forward to develop highly predictive design of composite gears as proposed by Fegade et al. [40], which involves multiscale modeling, to capture anisotropic failure, and machine learning methods to optimize the parameters.

Future Outlook

While current research has established the fundamental viability of composite gears, several critical challenges must be addressed:

1. *Standardization:* Development of industry-wide testing protocols for composite gear performance evaluation.
1. *Hybrid Material Systems:* Investigation of nano-reinforced composites for extreme operating conditions.
2. *Circular Economy:* Recycling strategies for end-of-life composite gears.

The convergence of materials science, computational mechanics, and smart manufacturing technologies positions composite spur gears as a disruptive innovation in power transmission systems, with potential to redefine performance benchmarks across multiple industries.

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REFERENCES

1. Utkarsh M Desai, Dhaval A Patel. Modeling And Stress Analysis Of Composite Material For Spur Gear Under Static Loading Condition. IJAPME. 2015;1(2):1–6.
2. Gavali VA, Satav CP. Review paper on analysis of spur gear. IOSR Journal of Mechanical and Civil Engineering. 2018;15(2):4–7.
3. Rounak Mahakul, Dhirendra Nath Thatoi. Design and numerical analysis of spur gear using SolidWorks simulation technique. Materials Today: Proceedings. 2020;554:1–7.
4. Miryam B Sánchez, Miguel Pleguezuelos. Calculation of tooth bending strength and surface durability of internal spur gear drives. Mechanism and Machine Theory. 2016;95:102–113.
5. N Lenin Rakesh, V Palanisamy. SPUR Gear Analysis Using Finite Element Analysis. Middle–East Journal of Scientific Research. 2013;14(12):1763–1765.
6. Samadhan M Lande, A D Desai. Stress Analysis of Polycarbonate Spur Gears for Sugarcane Juice Machine Using FEA. International Journal on Recent Technologies in Mechanical and Electrical Engineering (IJRMEE). 2015;2(10):14–19.
7. Ashish V Kadu, Sanjay S Deshmukh. Investigation Of Contact Stress In Spur Gear Using Lewis Equation And Finite Element Method. IJMERR. 2013;2(3):310–321.
8. M Amarnath, C Sujatha. Experimental studies on the effects of reduction in gear tooth stiffness and lubricant film thickness in a spur geared system. Tribology International. 2009;42:340–352.
9. Apparao D, Jagannadha Raju MV. Design and analysis of spur gear manufactured by DMLS process. Materials Today: Proceedings. 2020;22(3):2716–2721.
10. J G Carrillo, W J Cantwell. Scaling effects in the tensile behavior of fiber–metal laminates. Composites Science and Technology. 2007;67:1684–1693.
11. Madhuri Deshpandea, Ramesh Gondil. Processing and Characterization of Carbon Fiber Reinforced Aluminium7075. Materials Today: Proceedings. 2018;5:7115–7122.
12. Paolo Feraboli, Elof Peitso. Modulus Measurement for Prepreg–based Discontinuous Carbon Fiber/Epoxy Systems. Journal of Composite Materials. 2009;43(19):1947–1965.
13. P Iaccarino, A Langella, G Caprino. A simplified model to predict the tensile and shear stress–strain behaviour of fibreglass/aluminium laminates. Composites Science and Technology. 2007;67:1784–1793.
14. M Pramod Reddy. Spur Gear Tooth Stress Analysis And Stress Reduction Using Stress Reducing Geometrical Features. International Journal of Mechanical Engineering and Technology (IJMET). 2015;6(9):17–29.
15. Hanjun Jiang, Yimin Shao. Dynamic characteristics of helical gears under sliding friction with spalling defect. Engineering Failure Analysis. 2014;39:92–107.
16. Xihui Liang, Hongsheng Zhang. The influence of tooth pitting on the mesh stiffness of a pair of external spur gears. Mechanism and Machine Theory. 2016;106:1–15.
17. L Meng, Y Wan. Effects of geometric parameters on the failure behavior of mechanically fastened chopped carbon fiber tape reinforced thermoplastics. Composite Structures. 2019;229(111475):1–9.
18. Soo–Jin Park. Roles of interfaces between carbon fibers and epoxy matrix on interlaminar fracture toughness of composites. Composite Interfaces. 2006;13(2–3):249–267.

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

19. Marina Selezneva, Larry Lessard. Characterization of mechanical properties of randomly oriented strand thermoplastic composites. Journal of Composite Materials. 2015;0(0):1–19.
20. Zhi Sun, J Jeyaraman. Processing and property of carbon–fiber aluminum–foam sandwich with aramidfiber composite adhesive joints. Journal of Adhesion Science and Technology. 2014;28(18):1835–1845.
21. Evgeny Podzharov. Static and Dynamic Transmission Error in Spur Gears. The Open Industrial and Manufacturing Engineering Journal. 2008;1:37–41.
22. Yi Xiao, Wenjing Qiao. The effect of embedded devices on structural integrity of composite laminates. Composite Structures. 2016;153:21–29.
23. Zhang M, Hou C. Interlocked graphene–Prussian blue hybrid composites for multifunctional electrochemical applications. Biosensors and Bioelectronics. 2017;87:941–947.
24. J G Carrillo, W J Cantwell. Scaling effects in the tensile behavior of fiber–metal laminates. Composites Science and Technology. 2007;67:1684–1693.
25. N Jiang, J P Novak. Fabrication and Characterization of Carbon–Aluminum Thermal Management Composites. 26th IEEE SEMI–THERM Symposium. 2010;:87–92.
26. Hanjun Jiang, Yimin Shao. Dynamic characteristics of helical gears under sliding friction with spalling defect. Engineering Failure Analysis. 2014;39:92–107.
27. José I Pedrero Izaskun I Vallejo. Calculation of Tooth Bending Strength and Surface Durability of High Transverse Contact Ratio Spur and Helical Gear Drives. Journal of Mechanical Design. 2007;129:69–75.
28. C Qian, L T Harper. Notched behavior of discontinuous carbon fibre composites: Comparison with quasi–isotropic non–crimp fabric. Composites: Part A. 2011;42:293–302.
29. Jiande Wang, Ian Howard. Finite Element Analysis of High Contact Ratio Spur Gears in Mesh. Journal of Tribology. 2005;127:471–484.
30. Yi Wan, Jun Takahashi. Tensile properties and aspect ratio simulation of transversely isotropic discontinuous carbon fiber reinforced thermoplastics. Composites Science and Technology. 2016;137:167–176.
31. Feng K, Borghesani P. Vibration-based updating of wear prediction for spur gears. Wear. 2019;426–427:1414–1423.
32. Feng Z. Application of regularization dimension to gear damage assessment. Mechanical Systems and Signal Processing. 2010;24(4):1081–1098.
33. Howard I, Jia S, Wang J. The dynamic modelling of gear systems and vibration-based fault detection. Mechanical Systems and Signal Processing. 2001;15(5):1081–1098.
34. Božidar Rosić. Design And Simulation Of Meshing Of Internal Involute Spur Gears With Pinion Cutters. FACTA UNIVERSITATIS Series: Mechanical Engineering. 2002;1(9):1193–1198.
35. Mohammed OD. Dynamic modelling of a one-stage spur gear system and vibration-based tooth crack detection analysis. Mechanical Systems and Signal Processing. 2014;46(1–2):483–505.
36. Huang Y, Ghezzo F. Onset of resin micro-cracks in unidirectional glass fiber laminates with integrated SHM sensors. Structural Health Monitoring. 2015;14(5):493–507
37. Shan–shan Shi, Zhi Sun. Carbon–fiber and aluminum–honeycomb sandwich composites with and without Kevlar–fiber interfacial toughening. Composites: Part A. 2014;67:102–110.
38. Zhi Sun, et al. Carbon fiber reinforced polymer composites: mechanical and tribological behaviour. Polymers. 2023;15(7):1732–1745.
39. Jiang N, Novak JP. Comparison of stress–strain behaviour of carbon fiber composites with conventional materials. Composite Structures. 2018;200:123–131.
40. Fegade R, et al. Advanced machine learning models for early detection of helical gear faults. International Journal on Interactive Design and Manufacturing (IJIDeM). 2025;19(2):245–258.International Journal on Interactive Design and Manufacturing (IJIDeM). 2025;19(2):245–258.
41. Ritesh Fegade, et al. “Innovative Magnetic Coupling for Enhanced Safety in Grinding Machines”. Journal of Mines, Metals and Fuels. 2025;73(3):210-216

42. ASTM D256 – 06. Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics. 2006.
43. Fegade R, Tated R, Nehete R. "Numerical investigation of pull in control of rectangular AA1050 rolling ingot through design of convex mould during direct chill casting process". Engineering Research Express. 2024;6(1):1–15.
44. Fegade R, Tated R, Nehete R. "Experimental and Numerical Investigation of Effect of Melter Temperature and Casting Speed on Pull–In (Concavity) of AA1050 Ingot During Direct Chill Casting". Journal of The Institution of Engineers (India): Series C. 2024;105:69–79.
45. Bledzki A K, Gassan J. Composites reinforced with cellulose–based fibers. Progress in Polymer Science. 1999;24(2):221–274.
46. ASTM D3039 – 08. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. 2008.
47. Anuja H Karle, Srinidhi Campli, Vidya Zinjurde, Rishikesh Tike, Vrushali Gaikwad. "Multi–Response Optimisation of Wear Behaviour of Epoxy Composites Reinforced with Metallic and Ceramic Particles Using Taguchi–Grey Method". Journal of Mines, Metals & Fuels. 2024;72(11):1271–1285.
48. Rishikesh H Tike, V S Jatti, Nitishkumar Gautam. "A Review of Mechanical Properties of Composite Material Used to Manufacture Spur Gear". JJTU Journal of Renewable Energy Exchange. 2025;13:167–173.
49. Rishikesh H Tike, V S Jatti, Nitishkumar Gautam. "Metal Matrix Composite for Various Compositions of CF–Steel Materials and Their Mechanical Properties Using Taguchi Method". JJTU Journal of Renewable Energy Exchange. 2024;12(4):444–453.

