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EFFECT OF NANO TIO_2–SIO_2 REINFORCEMENT ON THE PERFORMANCE OF HDPE SPUR GEARS

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Abstract: Gear design and analysis are fundamental aspects of mechanical engineering, particularly due to their extensive applications in industries such as automotive, aerospace, and marine. In power transmission systems, gears must meet strict performance requirements to ensure efficiency and durability. Recent advancements in materials science have led to increased research on composite materials in gear design, offering improved performance over conventional materials. This study examines the comparative effectiveness of contact and bending stress in pure HDPE spur gears versus HDPE reinforced with TiO_2 and SiO_2 composites. Using ANSYS Workbench, the contact and bending stresses between polymer gear pairs are analyzed through simulation, modeling their behavior under applied torque loads. The study provides a detailed three-dimensional analysis of gear tooth interactions, treating the contact between teeth as a dynamic engagement. Torque is applied to the driving gear under controlled loads, while the driven gear is constrained to facilitate an in-depth stress evaluation around the gear teeth. The results indicate that HDPE-TiO_2-SiO_2 composite spur gears exhibit significantly improved performance in managing contact and bending stresses compared to pure HDPE gears, demonstrating their potential for enhanced durability and reliability in demanding applications

KEYWORDS: Polymer Gears, ANSYS Workbench, Simulation-based optimization, Stress Analysis, TiO_2-SiO_2 Reinforced HDPE.

1 Introduction

The design and analysis of gears play a vital role in mechanical engineering, particularly in power transmission applications where efficiency is essential [1]. Spur gears are crucial for accurate control of speed and torque, making them widely used in the automotive, aerospace, and marine industries [2, 3, 4]. While traditional gear design has favored metallic materials, there is a notable shift toward polymer composites due to increasing demands for lighter, more efficient, and cost-effective alternatives [5, 6, 7].

High-Density Polyethylene (HDPE) has become a popular choice for spur gears, due to its favorable mechanical properties such as strength, stiffness, and toughness which enable it to withstand continuous mechanical loads [8, 9]. Its recyclability further positions HDPE as an environmentally friendly option. However, pure HDPE can struggle under high-stress conditions, necessitating the addition of reinforcement materials to improve performance. To address these limitations, nanoparticles such as Titanium Dioxide (TiO_2) and Silicon Dioxide (SiO_2) are integrated into HDPE. TiO_2 contributes to greater wear resistance and strengthens the material, enhancing its durability under operational stresses [10, 11]. Meanwhile, SiO_2 improves thermal resistance and dimensional stability, allowing the composite gears to handle higher loads and withstand elevated temperatures with minimal deformation [12]. These enhancements make HDPE composites more suitable for demanding applications.

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Evaluating how these composites handle contact and bending stresses is crucial for assessing their overall performance and durability. Inadequate management of these stresses can lead to premature gear failure, highlighting the importance of thorough analysis under realistic conditions. This study combines theoretical contact stress calculations based on the Hertzian equation with ANSYS simulations to offer a comprehensive perspective. While theoretical models provide fundamental insights into stress distribution, ANSYS simulations yield an accurate three-dimensional representation of these stresses during actual loading scenarios, resulting in reliable data for optimizing spur gear designs.

Previous studies have examined stress distribution in spur gears, often comparing Finite Element Analysis (FEA) results with theoretical values from the Hertzian contact stress equation, which is widely used to calculate bending and contact stresses. Several key contributions have advanced knowledge in this area. For instance, S. Senthilvelan et al [13] studied nylon 6 with and without 20% short glass fiber reinforcement, observing improved performance in the reinforced variant. B. N. Bakshe and S. R. Patil [14] employed the Finite Element Method (FEM) and Hertz's equations to analyze contact stress in spur gears, concluding that increasing the module size leads to reduced contact stresses. P. B. Pawar and A. A. Utpat [15] developed an aluminum-silicon carbide composite and conducted FEA using ANSYS 14.0, demonstrating that composite gears exhibit superior properties compared to traditional steel alloys. S. Kumar Tiwari and U. Kumar Joshi [16] compared stress analysis results from Lewis, Hertzian, and AGMA equations, contributing valuable insights into gear performance under various conditions. S. Ramanjaneyulu et al [17] examined graphene-reinforced acetal copolymer gears using Finite Element Method (FEM) to illustrate enhanced mechanical properties, including improved strength and wear resistance, indicating their potential in high-performance applications.

Further studies have explored additional influences on gear stress. For example, P. Kumar et al [18] investigated contact stress variations in spur gears with different module sizes, comparing FEA results with predictions from the Hertzian equation. P. K. Simhadri et al [19] analyzed the strength of spur gears, noting variations in contact stress based on material properties. V. V Ambade et al [20] employed FEA to investigate both contact and bending stresses in involute spur gears. R. K. Rathore et al [21] found that adjusting the fillet radius minimized deformation and stress, while D. Zorko et al [22] demonstrated that one-side involute asymmetric teeth with optimized fillet radii reduced stress levels.

Phani Kumar S et al [23] studied the effect of addendum on gear contact and bending strength, while A. Saxena et al [24] developed a dynamic model-based method for optimizing tooth profiles to improve spur gear system dynamics. Bae et al [25] assessed bending stress using FEA by replacing trochoidal fillets with circular fillets, and A. Joshi [26] showed that optimizing tooth fillet radius increased load capacity and decreased bending stress.

T.G.Yılmaz et al [27] found that bimetallic gears effectively reduce weight without compromising stress distribution, while identified maximum bending stress at the root of helical gears.

Based on earlier research that optimized TiO_2 and SiO_2 nanoparticle compositions for HDPE reinforcement, this study investigates the design of spur gears made from nano-reinforced HDPE under various torques and loading conditions [28]. It specifically evaluates the performance of contact and bending stresses in both pure HDPE and HDPE-TiO_2-SiO_2 composites. The research further explores the three-dimensional interactions between gear teeth, treating their contact as a tactile event. It includes the design and simulation of spur gear models under torque loads using ANSYS Workbench software, providing a comprehensive perspective on stress distribution within these composite materials through both analytical and simulation-based approaches.

2 Materials and methodology

2.1 Materials for spur gears

Drawing from prior research, the materials chosen for spur gear pairs in the design and analysis are pure HDPE (S-0) and HDPE reinforcement with 1.5 wt.% TiO_2 and 1.5 wt.% SiO_2 composites (S-3). This selection was informed by studies that demonstrated their suitability for spur gear manufacturing. These materials are applied throughout the design, modeling, and analysis processes within ANSYS Workbench. Table 1 provides the details of mechanical and tribological properties for both pure HDPE and the TiO_2-SiO_2 reinforced nanocomposite.

Table 1. Mechanical and tribological properties of gear materials [8]

Properties	Material	
	(S-0)	(S-3)
Density (g/cm^3)	0.956	1.037
Tensile strength (MPa)	23.5	38.9
Young's modulus (MPa)	1152	1380
Flexural strength (MPa)	26.4	49.1
Friction coefficient	0.25	0.21
Poisson's ratio	0.42	0.41

2.2 Modeling and simulation of gears

Modeling a spur gear centers on precisely constructing the tooth profile, requiring the formation of involute curves, illustrated in Fig. 1(a). The dimensions essential for creating this gear model are listed in Table 2. Upon completing the gear model, finite element analysis is conducted in ANSYS Workbench, with material properties applied according to the specifications as shown in Table 1.

Table 2. Spur Gear Specifications: Gear/Pinion Parameters

Part Dimensions	Symbol	Value
No. of teeth	Z	20
Pressure angle (degree)	∅	20
Module	M	5
Pitch circle diameter (mm)	d_p	100
Face width (mm)	L	20
Dedendum circle diameter (mm)	d_d	111.76
Addendum circle diameter (mm)	d_a	139.7
Tooth thickness (mm)	t	10
Tooth depth (mm)	h	14.287
Face width (mm)	b	25.4
Diametral pitch	P_d	0.157

The gear geometry is imported from a specified directory, after which the pre-set material properties from the engineering data are applied. Fig. 1(b) displays the imported gear geometry, highlighting eight contact surfaces four on each gear designed to accurately simulate real-world rotation. These contact areas, marked in the figure, utilize frictionless, no-separation surfaces, created with the automatic contact tool. For meshing, a 4-node 3D tetrahedron element was used, ideal for plane geometries, with stress convergence achieved by refining the mesh. The final mesh consisted of 62,634 elements and 287,663 nodes, with an element length of 2.0 mm, as shown in Fig. 1(c). To simulate rotational behavior, force was applied to the inner rim, with frictionless support provided on each gear rim, and constraints were established per FEA guidelines. Loads from 100 N to 500 N were applied, and the corresponding turning moments were calculated based on the shaft radius, illustrated in Fig. 1(d).

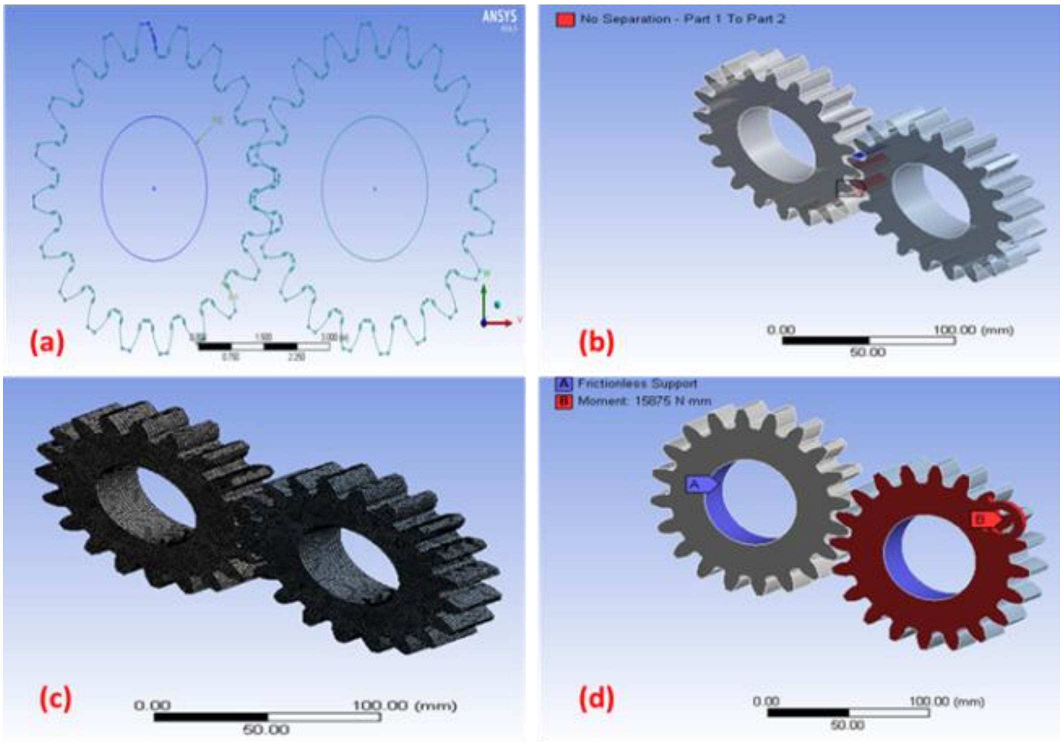

Fig. 1 (a) Replication of gears (b) 3D solid gears and connections
(c) Meshed model (d) boundary conditions

3 Theoretical analysis of stresses in gears

3.1 Contact stresses

The Hertzian equation calculates contact stresses between curved surfaces, such as gear teeth, by considering factors like radii of curvature, material properties, and applied loads, which helps understand elastic deformation and localized stresses. The Hertzian equations calculating contact stresses in gears are given in Eq. (1).

For the materials under study, including pure HDPE (S-0) and HDPE reinforced with TiO_2 and SiO_2 (S-3) nanocomposites as listed in Table 1. and gears specifications sated in Table 2. The resulting contact stresses calculated using Eq. (1), are tabulated in Table 3. The applied torque values range from 100 to 500 N-m. in increments of 100 N-m.

$$\sigma_c = \frac{E}{\pi(1-\vartheta^2)}\left[\frac{F_t}{L r_p \sin\emptyset \cos\emptyset}\right] \tag{1}$$

The contact stress (σ_c) in gears is influenced by several key factors. Young's Modulus (E) and Poisson's Ratio (ϑ) are critical material properties that affect stress calculations. The gear's face width (L) and the pitch circle radius ($r_p = \frac{d_p}{2}$), which is half the pitch circle diameter (d_p), also play significant roles. The tangential force ($F_t = \frac{2T}{d_p}$) acting on the gear. Where T represents the turning moment applied to the gear. These factors collectively impact the distribution and magnitude of contact stress in gear teeth.

3.2 Bending stresses

AGMA (American Gear Manufacturers Association) equations are widely used for calculating bending stresses in spur gears because they provide a standardized and reliable method for analyzing gear performance. These equations take into account various factors such as tangential load, geometry, material properties, and dynamic effects, allowing for a comprehensive assessment of the stresses experienced by gear teeth during operation. The AGMA method ensures that the bending stress calculations reflect real-world operating conditions, making it suitable for designing durable and efficient gears while minimizing the risk of failure due to excessive stresses.

The bending stress in spur gears can be calculated using the AGMA stress analysis formula, as given in Eq. (2).

$$\sigma_b = \frac{\mathrm{F_t \times P_d \times K_s \times K_m \times K_a}}{\mathrm{b \times Y \times K_v}} \tag{2}$$

where the bending stress (σ_b), $F_t$is the tangential tooth load, P_d is the diametral pitch, and K_s is the size factor, which is taken as 1 for an accurate model. The load distribution factor K_m is considered as 1.2, and the application factor K_a is also set at 2. The face width is denoted by b, and the geometry factor Y is set at 0.4. The dynamic factorK_v which is influenced by the gear quality number Q_v and the pitch line velocityV_t, adjusts for dynamic loads. The pitch line velocity can be calculated using Eq. (3).

$$\mathrm{V_t}=\frac{\pi(\mathrm{d_p})(\mathrm{n_p})}{60} \tag{3}$$

Where d_p, the pitch circle diameter, and n_p is the rotational speed in RPM. The dynamic factor K_v can be determined from the Eq. (4).

$$\mathrm{K_v}=\left[\frac{\mathrm{A}+\sqrt{\mathrm{B}}}{\mathrm{A}}\right]^{\mathrm{B}} \tag{4}$$

Where A = 50+56(1-B), and B = $0.25(12-Q_v)^{2/3}$. These factors collectively allow for a comprehensive evaluation of the bending stress in the gear teeth. A sample calculation for contact and bending stress in pure HDPE spur gears at 100 RPM, as shown in section 3.2.

4 Sample calculations of stresses for S-0 gears at 100 N-m

$$F_t = \frac{2T}{d_p} = \frac{2(100)(1000)}{127} = 1574.803 \text{ N}$$

$$\sigma_c^2 = \frac{1380.01}{\pi(1-0.41^2)}\left[\frac{1574.803}{(25.4)(63.5)\sin 20 \cos 20}\right]$$

$$\sigma_c = 36.98\ {}^{N}/_{mm^2}$$

$$\sigma_b = \frac{F_t \times P_d \times K_s \times K_m \times K_a}{b \times Y \times K_v}$$

$$\sigma_b = \frac{1574.803 \times 0.157 \times 1 \times 1.2 \times 2}{25.4 \times 0.4 \times 2.2741}$$

$$\sigma_b = 24.88 \text{ N/mm}^2$$

5 Validation of theoretical and simulated stresses

To validate the simulation outcomes, pure HDPE (S-0) gears operating under standard conditions serve as the baseline. Maximum contact and bending stresses on the meshing gear teeth, under ideal alignment, are calculated using Hertzian contact theory Eq. (1) for contact stress and AGMA bending theory Eq. (2) for bending stress. These theoretical calculations are then compared with the results from Finite Element Analysis (FEA) performed in ANSYS Workbench.

Table 3. shows a strong alignment between theoretical and FEA values. Fig. 2 (a-b) visually represents the FEA results, displaying contact and bending stresses, Y-directional strain, equivalent strain, and the contact zone under loading conditions for the gear pair. The data affirms that the FEA model closely corresponds with the predictions from Hertzian contact and AGMA bending theories, validating the simulation approach.

Table 3. Comparison of Theoretical and Simulation Stresses (MPa) in S-0 Spur Gears

	Simulation		Theoretical	
Moment 100 N-m	Contact Stress	Bending Stress	Contact Stress	Bending Stress
	36.94	23.04	36.98	24.88

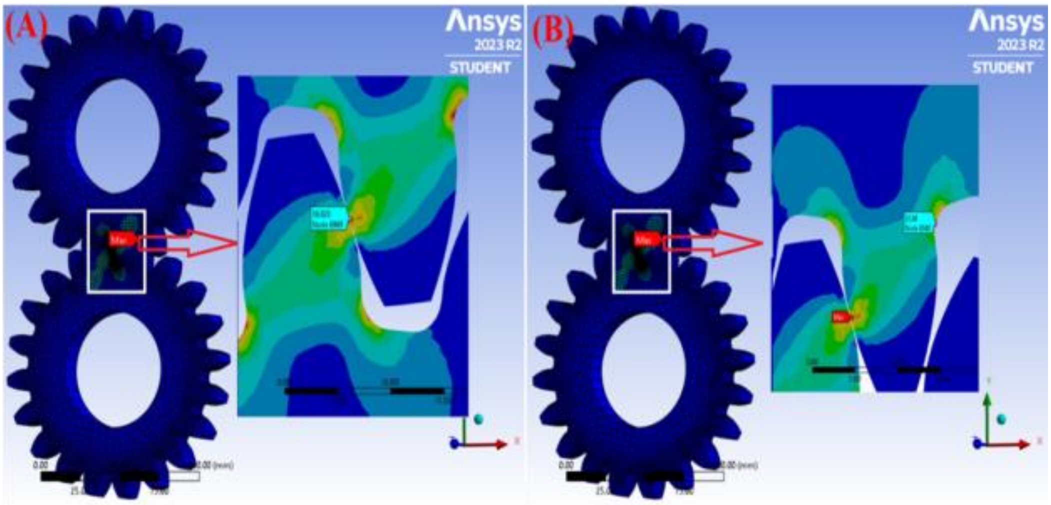

Fig. 2 Simulation results of maximum contact and bending stress at a load of 100 N-m for S-0 gears.

6 Results and Discussions

The assessment of spur gears performance which are designed with pure HDPE (S-0) and reinforced with TiO_2-SiO_2 composites (S-3) was conducted to analyze their performance under varying torque conditions. Using ANSYS Workbench for simulations, the results were compared against theoretical calculations based on Hertzian and AGMA equations. This comprehensive analysis aimed to highlight the TiO_2-SiO_2 reinforcement influence on the mechanical performance of HDPE gears, particularly in terms of stress distribution.

Table 4. presents a detailed comparison of bending and contact stresses for both S-0 and S-3 gears at different torque levels. The results indicate a significant reduction in stress levels for S-3 gears across all torque conditions, affirming the advantages of incorporating nanoparticle reinforcement.

6.1 Contact Stress Analysis

Contact stress is a critical parameter that affects the durability and performance of gear teeth during meshing. In the context of this study, the simulation results clearly illustrate the advantages of using TiO_2-SiO_2 composites. The data presented in Table 4. and Fig. 13(a) show that the contact stresses show that the contact stresses in S-3 gears was significantly lower than in S-0 gears across all torque levels, confirming the hypothesis that the incorporation of nanoparticles enhances load-bearing capabilities.

Table 4. Comparison of stresses for S-0 and S-3 Gears at different loads

Moment (N-m)	Contact Stress (MPa)		Bending Stress (MPa)	
	S-0	S-3	S-0	S-3
100	36.82	29.31	23.04	16.34
200	50.54	40.56	41.35	32.98
300	61.24	52.81	70.48	66.64
400	80.22	70.28	105.53	94.32
500	107.9	93.59	140.91	136.20

Figs. 3-7 depict the simulated maximum contact stresses for both S-0 and S-3 gears under various torque conditions. At a torque of 100 N-m, the S-0 gears experienced higher contact stress levels compared to the S-3 gears. This trend continued as torque levels increased, with the gap in contact stress widening at higher torques, particularly noticeable at 500 N-m, where S-3 gears demonstrated a substantially reduced contact stress.

The improvement in contact stress performance can be attributed to several factors inherent to the TiO_2-SiO_2 reinforcement. First, the nanoparticles enhance the stiffness of the HDPE matrix, resulting in better load distribution across the gear teeth. This property reduces the peak contact pressures experienced during gear meshing, thereby minimizing wear and increasing the gears' operational life. Additionally, the hardness imparted by the nanoparticles improves wear resistance, further contributing to the observed reductions in contact stress.

Moreover, the simulation results validate the effectiveness of the TiO_2-SiO_2 composite in enhancing contact stress performance under varying loading conditions. The consistent reduction in contact stress not only signifies better load-bearing capacity but also indicates a lower risk of gear failure, making these composite gears suitable for applications requiring high performance under heavy loads.

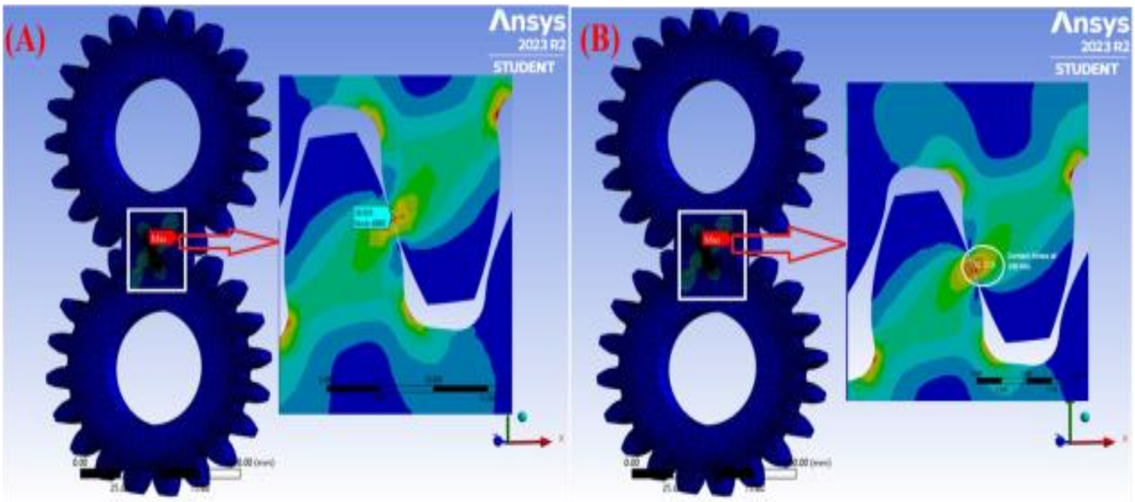

Fig. 3 Simulated Maximum Contact Stress at 100 N-m for S-0 and S-3 Gears

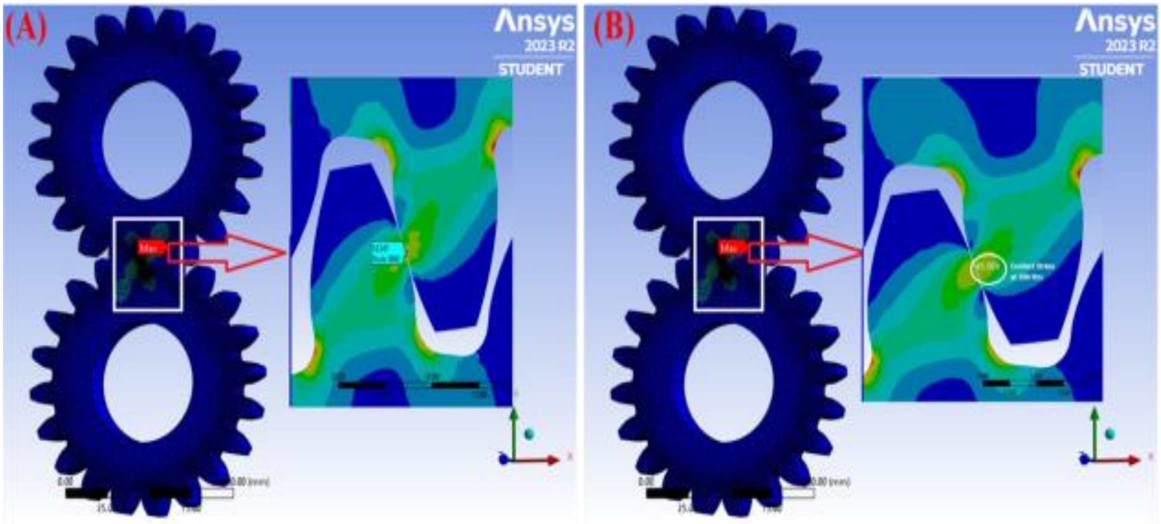

Fig. 4 Simulated Maximum Contact Stress at 200 N-m for S-0 and S-3 Gears

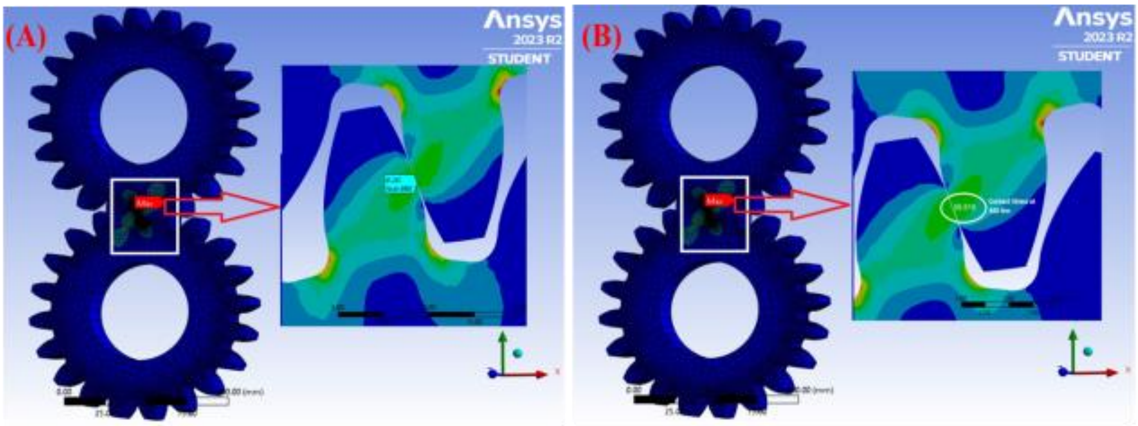

Fig. 5 Simulated Maximum Contact Stress at 300 N-m for S-0 and S-3 Gears

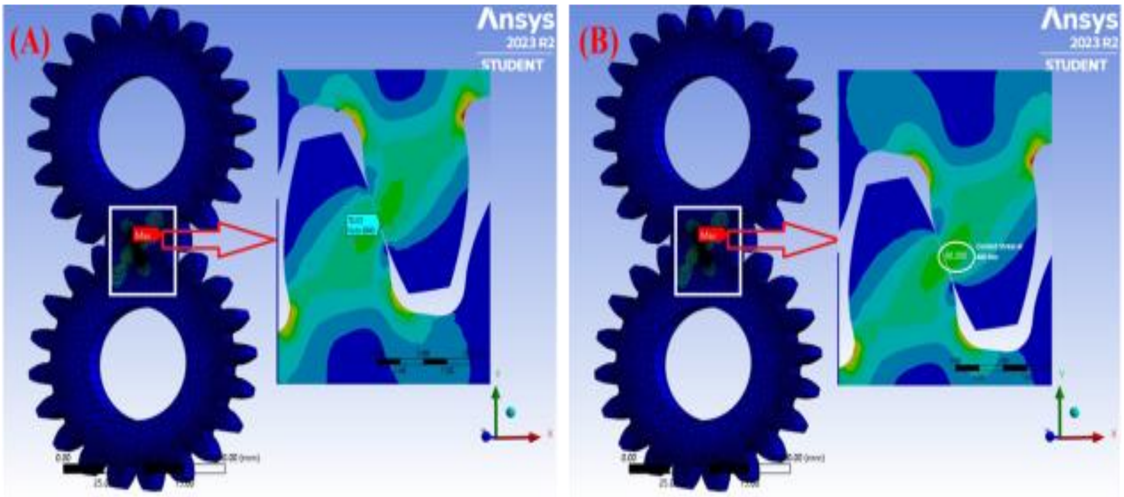

Fig. 6 Simulated Maximum Contact Stress at 400 N-m for S-0 and S-3 Gears

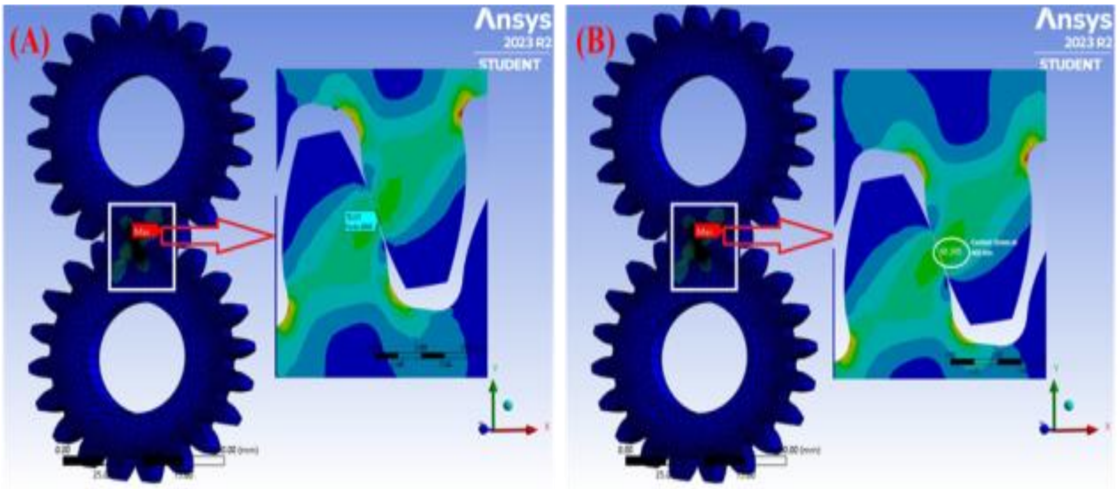

Fig. 7 Simulated Maximum Contact Stress at 500 N-m for S-0 and S-3 Gears

6.2 Bending stress analysis

Bending stress is another critical parameter influencing the potential for gear tooth failure, particularly under dynamic loading conditions. The findings from both simulation and theoretical calculations reveal that the S-3 composite gears exhibited significantly reduced bending stresses compared to the S-0 gears. This reduction in bending stress is crucial for preventing fatigue failure, especially in applications involving repetitive loading.

Figs. 8-12 illustrate the simulated maximum bending stresses for both S-0 and S-3 gears under different torque levels. As with contact stress, the S-3 gears consistently demonstrated lower bending stress levels across the torque range, with the most notable differences appearing at higher torques. At 500 N-m, the S-3 gears maintained a lower bending stress, indicating their superior ability to withstand mechanical loads without succumbing to fatigue.

The enhanced performance in bending stress can be primarily attributed to the improved flexural strength provided by the TiO_2 and SiO_2 nanoparticles. These reinforcements help distribute applied loads more evenly across the gear tooth, reducing stress concentrations that could lead to premature failure. As a result, the S-3 gears can better resist bending loads, making them more reliable for demanding applications. Additionally, the simulation results closely correlate with the theoretical predictions, as outlined in Table 4. and graphically represented in Figs. 13(b). The agreement between simulation and theoretical calculations validates the accuracy of the finite element analysis (FEA) models employed in this study. The results for both contact and bending stresses affirm the effectiveness of the TiO_2-SiO_2 composite in improving the overall mechanical performance of HDPE gears.

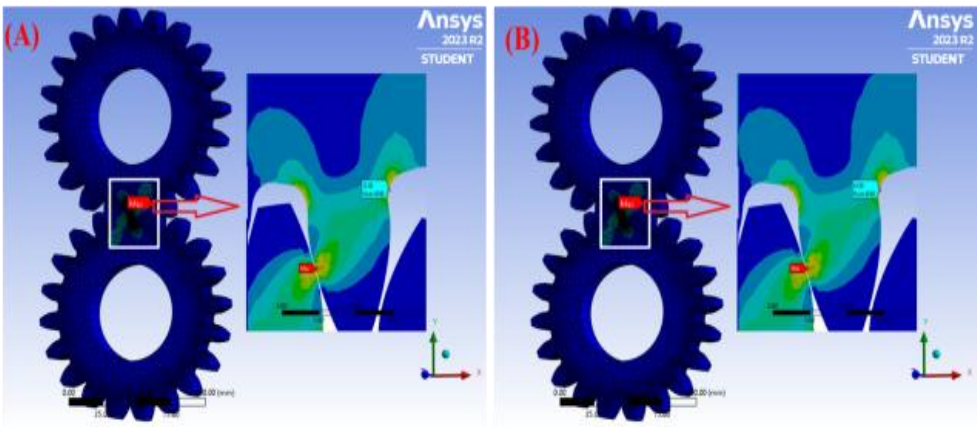

Fig. 8 Simulated Maximum Bending Stress at 100 N-m for S-0 and S-3 Gears

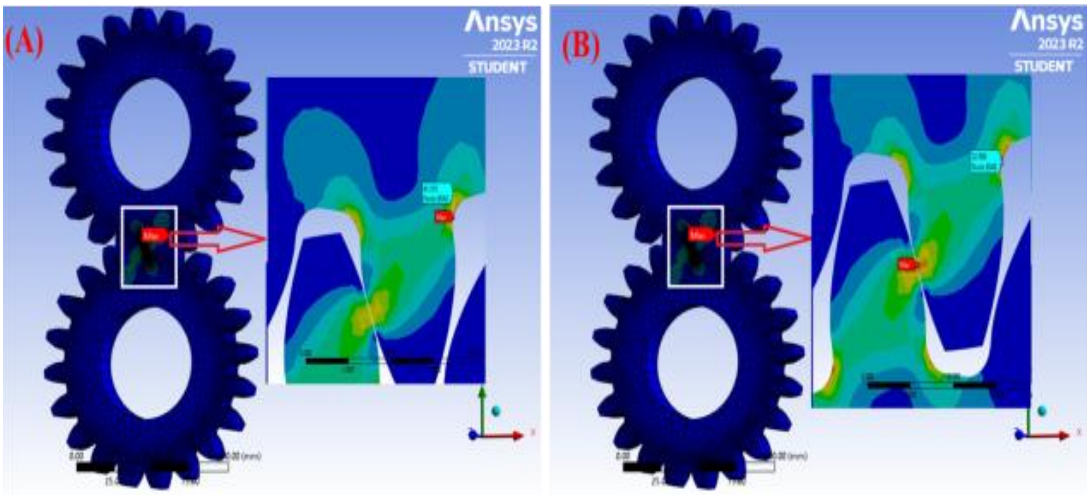

Fig. 9 Simulated Maximum Bending Stress at 200 N-m for S-0 and S-3 Gears

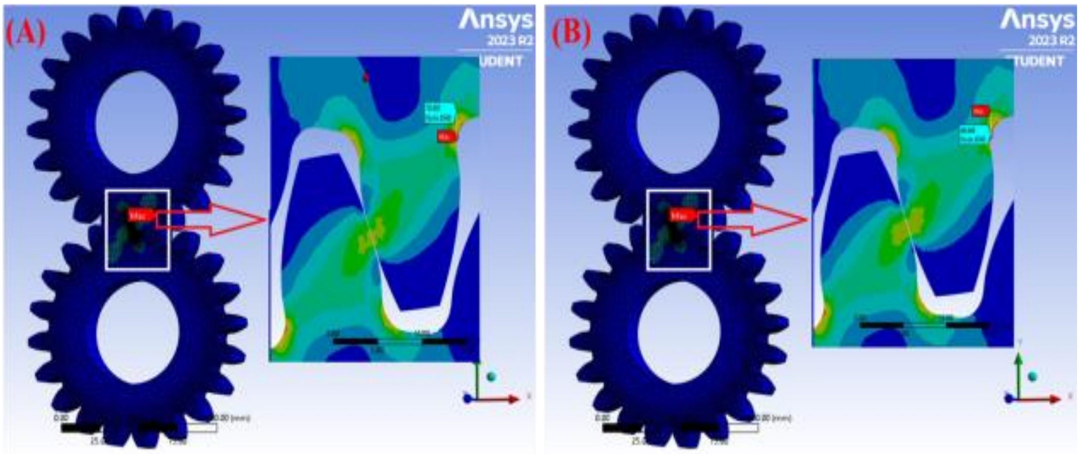

Fig. 10 Simulated Maximum Bending Stress at 300 N-m for S-0 and S-3 Gears

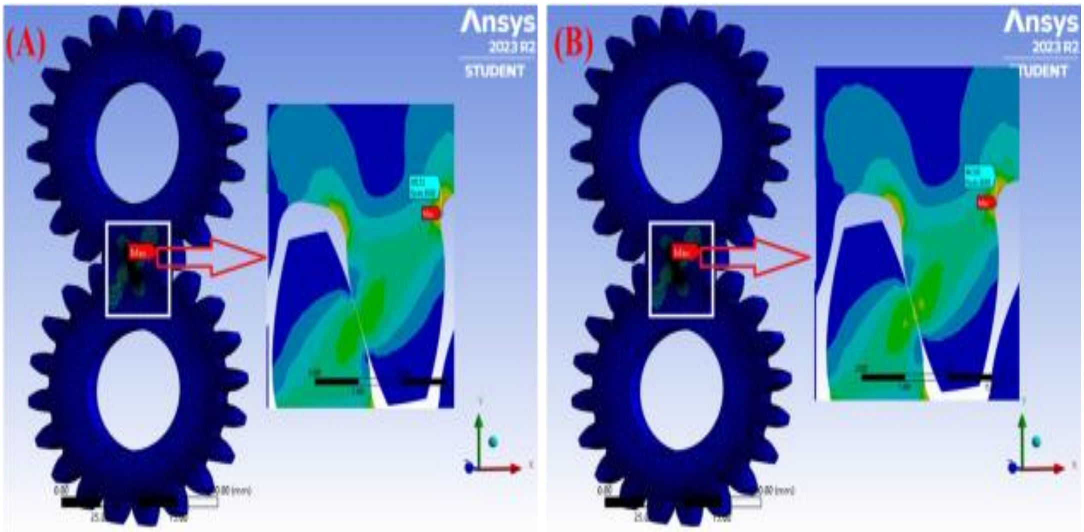

Fig. 11 Simulated Maximum Bending Stress at 400 N-m for S-0 and S-3 Gears

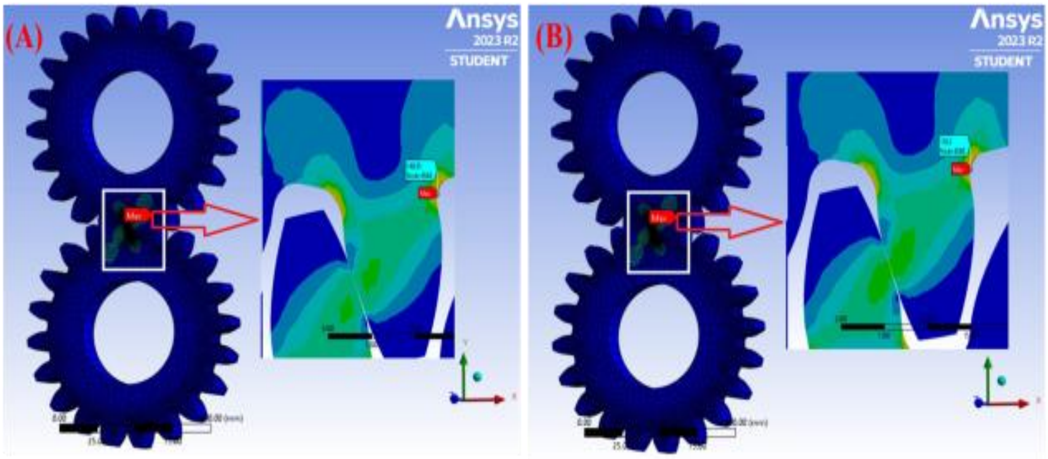

Fig. 12 Simulated Maximum Bending Stress at 500 N-m for S-0 and S-3 Gears

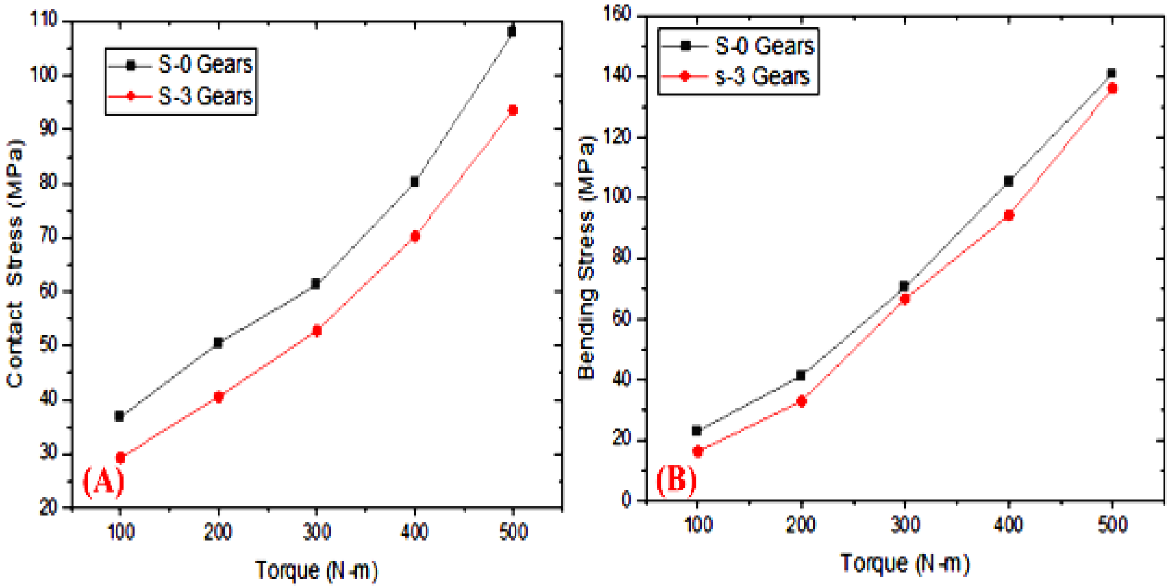

Fig. 13 Stress Variation with Torque for S-0 and S-3 Gears: (A) Contact, (B) Bending

The contact and bending stress analysis in spur gears constructed from pure HDPE and HDPE reinforced with TiO_2-SiO_2 composites reveals several key advantages of the composite materials. The significant reduction in both contact and bending stresses in the S-3 gears under various torque conditions highlights the effectiveness of nanoparticle reinforcement in enhancing gear performance.

The findings emphasize that the incorporation of TiO_2-SiO_2 nanoparticles not only improves mechanical properties but also promotes better stress distribution, thereby increasing the load-bearing capacity and fatigue resistance of HDPE gears. This makes the S-3 composite gears a promising alternative for high-stress applications, where durability and longevity are critical.

Figures depicting stress distribution patterns further illustrate the benefits of the TiO_2-SiO_2 reinforcement. The simulations provided a clear visual representation of the reduced stress levels in the composite gears, corroborating the experimental data. The consistent trend of lower stress levels in S-3 gears across all torque levels indicates their potential for superior performance in real-world applications

Conclusions

In conclusion, the performance evaluation of spur gears made from pure HDPE and those reinforced with TiO_2-SiO_2 composites demonstrates significant advantages in terms of stress reduction and mechanical performance. The consistent reductions in both contact and bending stresses highlight the effectiveness of nanoparticle reinforcement in enhancing the durability and load-bearing capacity of HDPE gears.

The simulation results, supported by theoretical calculations, validate the potential of TiO_2-SiO_2 reinforced HDPE as a viable alternative for high-stress applications in various industries. As gear design continues to evolve, the insights gained from this study offer a promising avenue for developing advanced materials that can withstand demanding operational conditions while ensuring optimal performance and reliability.

REFERENCES

[1] Hribersek, M., Erjavec, M., Hlebanja, G., Kulovec, S. "Durability testing and characterization of POM gears", Eng. Fail. Anal. 124, p. 105377, **2021**. DOI: 10.1016/j.engfailanal.2021.105377

[2] Jain, M., Patil, S. "A review on materials and performance characteristics of polymer gears", Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci. 237 (12), pp. 2762 – 2790, **2023**, DOI: 10.1177/09544062221142155

[3] Ustynenko, O., Cherelev, S., Ondruška, J., Protasov, R., Yepifanov, V., Bondarenko, O., Andrienko, S. "Optimal Design of Spur Gears With Increased Contact Ratio", Strojnícky časopis – Journal of Mechanical Engineering *75* (1), 163 – 172, **2025**. DOI: 10.2478/scjme-2025-0017

[4] Singh, A. K., Siddhartha, Singh, P. K. "Polymer spur gears behaviors under different loading conditions: A review", SAGE Publications Ltd., **2018**. DOI: 10.1177/1350650117711595

[5] Dimić, A., Mišković, Ž., Mitrović, R., Ristivojević, M., Stamenić, Z., Danko, J., Bucha, J. & Milesich, T. "The Influence of Material on the Operational Characteristics of Spur Gears Manufactured by the 3D Printing Technology", Strojnícky časopis – Journal of Mechanical Engineering 68(3), pp. 261 – 270, **2018**. DOI: 10.2478/scjme-2018-0039

[6] Zengeya, P., Mao, K., Goodship, V. "The effects of cooling rate (mould temperature) on HDPE gears produced through injection moulding", Wear 530 – 531, **2023**. DOI: 10.1016/j.wear.2023.205000

[7] Singh, A. K., Siddhartha, Yadav, S. "Investigations on noise emission from functionally graded materials based polymer spur gears", Mater. Today Proc. 64, pp. 1496 – 1499, **2022**. DOI: 10.1016/j.matpr.2022.04.970

[8] Hribešek, M., Kulovec, S. "Design Optimization and Fatigue Evaluation of Wood Composite Gears", University of Ljubljana, pp. 158 – 166, **2024**. DOI: 10.55295/psl.2024.i20

[9] Hriberšek, M., Kulovec, S., Toubal, L. "Performance Evaluation of Biocomposite Gears Under Fatigue and Wear: Steel Drive Gear Versus Biocomposite Drive Gear and Biocomposite Drive Gear Versus Biocomposite Gear", Fatigue Fract. Eng. Mater. Struct. 48 (4), pp. 1768 – 1781, **2025**. DOI: 10.1111/ffe.14590

[10] Ramanjaneyulu, S., Murthy, B. S. N., Kumar, S. P., Gupta, P. S. V. N. B. "Enhancing HDPE Properties: Impact of Nano-TiO2 and Nano-SiO2 Particles on Mechanical

Properties and Wear Resistance", J. Inst. Eng. Ser. D, **2024**. DOI: 10.1007/s40033-024-00758-w

[11] Naveen, P., Goriparthi, B. K., Mayee, M. C. "Evaluation of mechanical properties on Tio2/GF reinforced nylon66 composites", Mater. Today Proc. 19, pp. 240 – 245, **2019**. DOI: 10.1016/j.matpr.2019.06.758

[12] Pawar, P. B., Utpat, A. A. "Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite for Spur Gear", Procedia Mater. Sci. 6, pp. 1150 – 1156, **2014**. DOI: 10.1016/j.mspro.2014.07.187

[13] Senthilvelan, S., Gnanamoorthy, R. "Wear characteristics of injection-moulded unfilled and glass-filled nylon 6 spur gears", Proc. Inst. Mech. Eng. Part J J. Eng. Tribol. 218 (6), pp. 495 – 502, **2004**. DOI: 10.1243/1350650042794752

[14] Patil, S., Karuppanan, S., Wahab, A. A. "Contact Pressure Evaluation of a Gear Pair along the Line of Action Using Finite Element Analysis", Appl. Mech. Mater. 393, pp. 403 – 408, **2013**. DOI: 10.4028/www.scientific.net/AMM.393.403

[15] Pawar, P. B., Utpat, A. A. "Analysis of Composite Material Spur Gear Under Static Loading Condition", Mater. Today Proc. 2 (4–5), pp. 2968 – 2974, **2015**. DOI: 10.1016/j.matpr.2015.07.278

[16] Kumar Tiwari, S., Kumar Joshi, U. "Stress Analysis of Mating Involute Spur Gear Teeth", International Journal of Engineering Research & Technology (IJERT) 1 (9), **2012**. [online] Available at: https://www.ijert.org/research/stress-analysis-of-mating-involute-spur-gear-teeth-IJERTV1IS9380.pdf

[17] Ramanjaneyulu, S., Suman, K. N. S., Phani Kumar, S., Suresh Babu, V. "Design and Development of Graphene reinforced Acetal copolymer plastic gears and its performance evaluation" Mater. Today Proc. 4 (8), pp. 8678 – 8687, **2017**. DOI: 10.1016/j.matpr.2017.07.216

[18] Kumar, P., Hirani, H., Agrawal, A. "Fatigue failure prediction in spur gear pair using AGMA approach", in Materials Today: Proceedings, Elsevier Ltd, pp. 2470 – 2477, **2017**. DOI: 10.1016/j.matpr.2017.02.099

[19] Phani Kumar, S., Suman, K. N. S., Nagaraju, B., Ramanjaneyulu, S. "Contact Stress Analysis of Structural Steel Gears Under Misalignment of Shafts", pp. 283 – 296, **2019**. DOI: 10.1007/978-981-13-7643-6_23

[20] Ambade, V. V., Vanalkar, A. V., Gajbhiye, R. "Involute Gear Tooth Contact And Bending Stress Analysis", Int. J. Comput. Eng. Res., p. 8, **2013**. [online] Available at: https://www.researchgate.net/publication/361436867

[21] Rathorem R. K., Tiwari, A. "Bending Stress Analysis & Optimization of Spur Gear", International Journal of Engineering Research & Technology (IJERT) 3 (5), **2014**. [online] Available at: https://www.ijert.org/research/bending-stress-analysis-optimization-of-spur-gear-IJERTV3IS052083.pdf

[22] Zorko, D., Kulovec, S., Duhovnik, J., Tavčar, J. "Durability and design parameters of a Steel/PEEK gear pair", Mech. Mach. Theory 140, pp. 825 – 846, **2019**. DOI: 10.1016/j.mechmachtheory.2019.07.001

[23] Simhadri, P. K., Suman, K. N. S., Rao, M. S. S. S., and Ramanjaneyulu, S. "A Dual-pronged approach for evaluation of contact stresses in nylon hybrid composite gears under misalignment", Eng. Res. Express 5 (4), p. 045061, **2023**. DOI: 10.1088/2631-8695/ad0b61

[24] Saxena, A., Parey, A., and Chouksey, M., "Effect of shaft misalignment and friction force on time varying mesh stiffness of spur gear pair", Eng. Fail. Anal. 49, pp. 79 – 91, **2015**. DOI: 10.1016/j.engfailanal.2014.12.020

[25] Bae, S. M., Seo, K. J., Kim, D. E. "Effect of friction on the contact stress of a coated polymer gear", Friction 8 (6), pp. 1169 – 1177, **2020**. DOI: 10.1007/s40544-020-0363-6

[26] Joshi, A., Kumar Karma, V. "Effect on Strength of Involute Spur Gear by Changing the Fillet Radius Using FEA", Int. J. Sci. Eng. Res. 2 (9), **2011**.

[27] Yılmaz, T. G., Doğan, O., Karpat, F."A comparative numerical study of forged bi-metal gears: Bending strength and dynamic response", Mech. Mach. Theory 141, pp. 117 – 135, **2019**. DOI: 10.1016/j.mechmachtheory.2019.07.007

[28] Liu, W., Wang, L., Zhang, X., Huang, H., Liu, Y., Min, M."Exploring the Effects of Nano-CaCO3 on the Core–Shell Structure and Properties of HDPE/POE/Nano-CaCO3 Ternary Nanocomposites", Polymers (Basel) 16 (8), p. 1146, **2024**. DOI: 10.3390/polym16081146