JOURNAL OF AERONAUTICAL MATERIALS
ISSN: 1005-5053

Vol. 43, Issue-01, 2023
pp. 683-694

BENDING AND TORSION PERFORMANCE STUDY OF PLASTIC GEARS USING FEA

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Abstract

Nowadays, gears made of polymer and advanced thermoplastics find increasing application of mechanical power transmission due to their superior properties. This paper reports the transmission efficiency and dynamic characteristics of Polyimide Nano composites (PNC), HDPE 40(High- Density Polyethylene) and Nylon 66 spur gears. Numerical studies were conducted to predict bending and torque characteristics. The stress and deformation were investigated under static conditions. Also, the effects of stress and applied torque on the transmission efficiency of all the three spur gears are reported. The static and torque analysis were obtained using ANSYS. The enhancement in mechanical properties of pristine polyamide HDPE 40 gears results in higher power transmission efficiency compared to PNC and Nylon 66 gears.

Key words: PNC, HDPE40, Nylon66, Static, Dynamic, and ANSYS 15.0.

1.0 Introduction

Gears are used to transmit rotary motion and power. Recently, polymers are replacing metals in light-duty applications such as measuring devices, medical instruments, computer spare parts, printing machines, mobile phones and ATM machines, due to light weight, anti-corrosive property, easy manufacturability, and able to run under dry and critical loading condition. Many experimental and theoretical studies were conducted to study the performance of metallic gears [1–4]. However, there are only a few articles available on the study of performance of polymeric gears [5–10]. For gears made of metals, the gear module is the most influential parameter on gear mesh mechanical efficiency for the high-speed and high-torque operating conditions, followed by gear tooth surface roughness and viscosity of lubricant [11]. Sliding friction between the gear teeth is recognized as one of the main factors of power loss in geared transmission as well as a potential source of vibration and noise. In this study the effects of the geometrical characteristics of the teeth and the operating conditions on the distribution of the stresses and deformations induced by the loads in the gears as a function of the wear is proposed by using analytical and numerical methods. More over in this study the influence of the transmitted torque and dynamic output is present. The advantages of plastic, nylon and polymers gearings are easy to manufacture in various shapes and size and also, they have greater consistency. Since, there are many parameters responsible for failure of gears especially, bending stress, normal stress, principal stress, Stress due to torque and stress due to dynamic condition etc.

The current scarcity of resources and energy request form the manufacturing industries to be efficient in absolute terms. This translates into a continual research for light and durable materials to reduce material and energy requirements. Polymers, Nylon and Composites have shown to fit well in these requirements and have been increasingly in use in various aspects of engineering especially, light weight applications. They have recently been involved in the application of gear due to their relative light weight, toughness and wear resistance inherent to various inclusions in the main matrix. Diab et al. [12] studied the friction between gears for a wide range of rolling conditions using elastic hydrodynamic lubrication (EHL) simulator and proposed new traction law. Xu et al. [3] have studied the prediction of friction-related mechanical efficiency losses of parallel-axis gear pairs and proposed computational model. The model incorporates a gear load distribution with friction model, and a mechanical efficiency formulation for the prediction of instantaneous mechanical efficiency of a gear pair under typical operating, surface, and lubrication conditions. It is reported that the proposed model is accurate with 0.1% deviation with the experimental results. Xu and Kahraman [4] proposed a similar model for hypoid gear pairs for the prediction of effect of addendum and contact ratio on gear. The performance of a gear pair depends upon the friction, loading condition geometry and material [13]. In modern power transmission system requires highly efficient gears for that evaluation of stress and deformation and torque is very important [2]. Based on this area research revealed that teeth failure by bending stress cause of bending fatigue and surface failure. Also, the highest stress occurs at two points of gears, one is the point at which force acts and root of the tooth. Litrin et al. [14] has been established a new method to reduce bending stress by introducing circular root fillet in comparison of square root fillet. Finding of output velocity also very important factor to evaluate characteristics of gear material. Helbanja et al. [15] investigate about velocity factors and he presented velocity factor approximation.

In order to improve power transmission efficiency of the polymeric gears, it can be reinforcing the matrix by short fibers [16]. Presence of strength fiber on the molding surface deteriorates the good surface roughness. Moreover, the orientation of the fibers governs the gear stiffness, and it is very difficult to provide the orientation in the effective direction throughout the gear tooth geometry. Thus, only a fraction of short fiber content is effectively used to enhance the stiffness of polymer tooth. Polymer nanocomposite (PNC) materials are new emerging materials which uses the nano-sized particle or platelets as reinforcement. The nano-size particle has large specific surface areas and has good interfacial adhesion with compatible polymer. The molecular level interaction between the nano-size reinforcement and polymer significantly improves the many of their mechanical properties, especially stiffness and strength [17]. Nano-size reinforcement increases the crystallinity of the polymer and reduces the polymeric chain mobility. Nano-size reinforcement also increases the glass transition temperature and barrier properties of the polymer. The Laboratory of Mechanics and Eco-Materials of the University of Quebec à Trois-Rivières has developed plastic composite eco-materials reinforced by wood fibers for various applications. These composite materials are based on polyethylene and polypropylene of plant origin, reinforced by wood fibers such as aspen and birch. Although having some common models for their characterization, each composite material, even consisting of the same matrix and the same reinforcement, unlike their constitution rate and additive elements, has its own characteristics, so that standards composites do not present generalized models as for metals. In addition to that, for particular applications, the existing standards are not complete as they do not cover all the aspects concerned, as is the case with gears made of plastic, nylon materials and polymer composites [18].

The current scarcity of resources and energy request form the engineering and manufacturing industries to be efficient in absolute terms. This translates into a continual search for light and durable materials to reduce material and energy requirements. Composites have shown to fit well in these requirements and have been increasingly in use in various aspects of engineering. They have recently been involved in the application of gear due to their relative light weight, toughness and wear resistance inherent to various inclusions in the main matrix. It is in this context that the study of the effects of the geometrical characteristics of the teeth and the operating conditions on the distribution of the stresses and deformations induced by the loads in the gears as a function of the wear is proposed. More particularly in this study the influence of the transmitted torque is present. Normally, a Metal Matrix Composite (MMC) gear provides unique advantages such as light weight, high strength, and good dimension ability and corrosion resistance. Due to that reason MMC is preferable for many applications. However, there is a cost problem for MMC when compared to polymer composite, HDPE and nylon materials. One can agree on advantages of plastic gearings, which are low density resulting in reduced weight and lower moment of inertia, elasticity and impact resistance, low coefficient of friction, corrosion resistance, manufacturing cost in terms of mass production, good performance in noise, vibration and harshness (NVH) effects.

Limitations of plastic gears are in lower load carrying capacity under static and dynamic condition which result in low mechanical strength compared to metal gears. On the other hand, the huge number of available materials is growing almost at an exponential rate and various manufacturing industries produce materials with similar properties as well. The field of study of the materials is very vast and deals with metals and alloys [19], the ceramics and new materials like the polymers, nylon and composites. Proper combination of such materials can result in long and reliable operation of transmission applications and a cost-effective solution. The main goal is development of advanced power transmission drive components from non- metallic materials (gear pairs), which will suit the customer demands and improve gearbox lifetime. It includes optimization and development of materials, improving guidelines for gear and tool designing and expanding of material database in terms of static, torque and dynamic aspects which will be the main contribution for design engineer in a real industrial environment. Harish Kumar et al. [20] fabricated composite spur gear with 70% of weight reduction when compared to steel material without compromising the strength of tooth. Tavwade et al. [21] proposed a polymer spur gear for the substitute of metallic gears for automobile application to reduce weight and NVH effect. Tanuj Srivastava et al. [22] provide a new design method of composite material spur gear tooth for static and torque analysis using FEA. Wotodzo et al. [23] have presented a comparison of metallic spur gear with stir casted Al-Sic composite spur gear and concluded that Al-Sic provide 60%of wight reduction with improved harness and tensile strength.

This paper describes the load carrying capacity, effect of torque and dynamic performance of PNC, Nylon66 and HDPE40 spur gears estimated using analytical and numerical (FEA) analysis. Normally, gears are positive drive mechanism which is provide constant velocity ratio and high efficiency in power transmission. In this work a spur gear model and dimension which is available in automobile gear box is taken in to consideration. Because, among all type of gears the spur gear with involute profile is the simplest form while considering design aspect. An attempt has been made the teeth bending stress, strain and torque stress, strain values. Moreover, the output velocity, stress and acceleration of PNC, Nylon66 and HDPE40 materials has been validated. In order to obtain static, torque and dynamic analysis of these three materials the FEA software ANSYS has been utilized. The gear model was developed using CREO 3.0 software and it is imported to FEA software. These three materials were analyzed using analytical and numerical methods also compared and concluded that PNC material provide better performance when compared to other two materials.

Nomenclature:

Z_1 and Z_2 – Number of teeth on Pinion and Gear
Module - m
Pitch circle Radius of Pinion and Gear - r, R
Pitch circle Diameter of Pinion and Gear - d, D
Centre Distance - C
Circular pitch - Pc
Diametral pitch - Pd
Gear ratio - G
Addendum circle radius of Pinion and Gear - r_A , R_A
Addendum of Pinion and Gear - a_p, a_w
Speed of Gear - N
Velocity of gear – v
Power- P
Tangential load on tooth – F_t
Pitch line Velocity -V
Beam Strength -F_s
Dynamic Load -F_d
Maximum Wear Load -F_w
Pressure Angle – φ
Face width- b
Lewis form factor- Y
Ratio factor- Q
Load Stress factor - K_w
Torque - T
Thickness of teeth – t

2.0 Materials and Methods

The mechanical properties of plastics depend not only on the material but also on production and operating conditions. The following strength properties are relevant to dimensioning gear wheels: yield stress, tensile strength and breaking stress. The materials properties of all the three materials are presented in Table. 1.

- Polyimide Nano composites (PNC) – [24]
- HDPE 40 (High- Density Polyethylene) -[25]

- Nylon 66 - [26]

Table 1. Materials properties

S. No	Properties	Unit	PNC	HDPE 40	Nylon 66
1.	Density	kg/m^3	1180	948	1140
2	Elasticity Modules	MPa	5750	3450	3500
3	Poisson's ratio	-	0.310	0.33	0.34
4.	Yield strength	MPa	104	21.9	90.0
5	Tensile strength	MPa	98	30	93.1

3.0. ANALYSIS OF PLASTIC GEARS

3.1. Analytical analysis of Gear

In the numerical analysis the following data's and specifications are taken into consideration. The model calculation and results are given below. Nylon and HDPE gear, the deformation is very high due to low stiffness and, hence, there exist a major difference in load sharing compared to that of gear PNC. To understand the effect of PNC, HDPE40, Nylon 66 gears velocity in load sharing, an analytical calculation has been carried out in Equation (1) and (2). The beam strength, dynamic load and bending stress with maximum wear load also calculated for all the three materials are tabulated in Table. 2.

3.1.1. Model Calculation of Gear

The following data's taken into consideration for analysis of gear material

Power P= 32 x 10^3 W

Speed N_1 = 600 rpm

Angle φ =20^0

Velocity v= 12m/s

3.1.2 Spur gear made up of PMC

Specification of Gear and Pinion for PMC

Module = 9 mm

No of teeth on Pinion Z1 = 22 mm

No of teeth on Gear Z2 = 88 mm

Pitch circle Radius of Pinion r = 99 mm

Pitch circle Radius of Gear R = 396 mm

Centre Distance C = 495 mm

Circular pitch Pc =28.27 mm

Diameteral pitch P_d =0.1 tooth/m

5.1.1. Pitch line Velocity (V) –(1)

$$V = \frac{\pi d n}{60}$$

$$= \frac{\pi * 0.198 * 600}{60}$$

= 6.22 m/sec.

5.1.2 Beam Strength (F_s) –(2)

$F_s = \pi * m * b * \sigma_b * y$

= 258005 N

5.1.3. Dynamic Load (F_d)

$F_d = F_c / C_v$ = 12831 N

Table 2. Result (Analytical for Tangential Load)

S.No	Material	Pitch line Velocity (V) (m/s)	Beam Strength (F_s) (N)	Dynamic Load (F_d) (N)	Bending Stress due to Torque (N/mm^2)	Max Wear load (F_w) (N)
1	PNC	6.22	268005	12831	73.232	67137.89
2	HDPE 40	6.53	849677	2716.24	4.69	7708.8
3.	Nylon 66	5.15	200369	1110315	81.603	59696

4.0. NUMERICAL ANALYSIS (FEA) OF PLASTIC GEARS

Nylon and HDPE gear, the tooth deflection is very high due to low stiffness and, hence, there exist a major difference in load sharing compared to that of PNC gear. To understand the effect of PNC, HDPE40, Nylon 66 gears tooth deflection in load sharing, a Finite Element Analysis (FEA) is carried out using commercial software package ANSYS. The triangular shaped plane strain elements are used to mesh the gear geometry. The FEA model and meshing of gear model can be obtained in FEA code ANSYS Software with fine mesh. It's given below in fig.1.

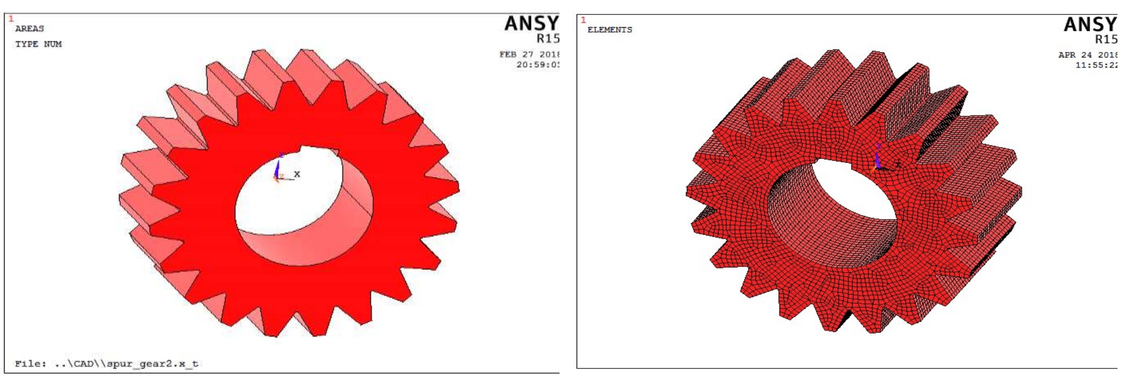


Fig. 1(a). FEA model of gear **Fig. 1(b). Meshed view of gear**

Fig. 1. Model of Spur Gear

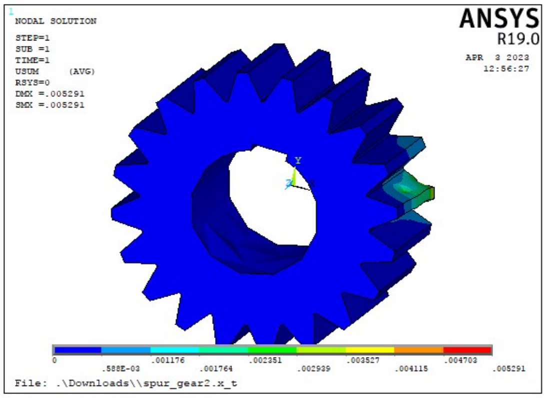
4.1 Static Analysis

4.1.1 Bending analysis

In order to obtain bending analysis, the following Boundary Conditions were made.

- Inner area of gear is fixed
- Load applied on the surface of the tooth.

Load of 250 N/m2. The bending analysis of gear can be obtained using FEA code Ansys 19.0 software. The figures are shown and values are tabulated below. Fig. 2(a) and 2(b) showed deformation of PNC and HDPE 40. Fig. 2(C) &(D) showed deformation of PNC and HDPE 40.



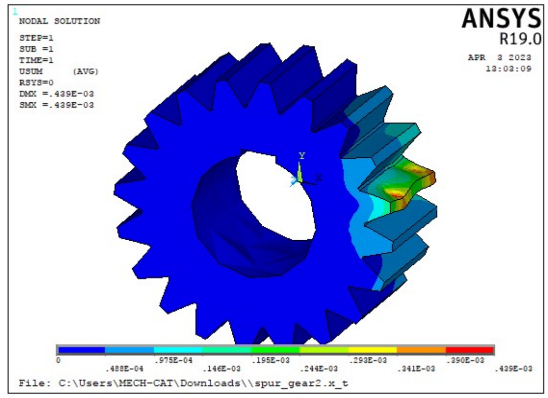
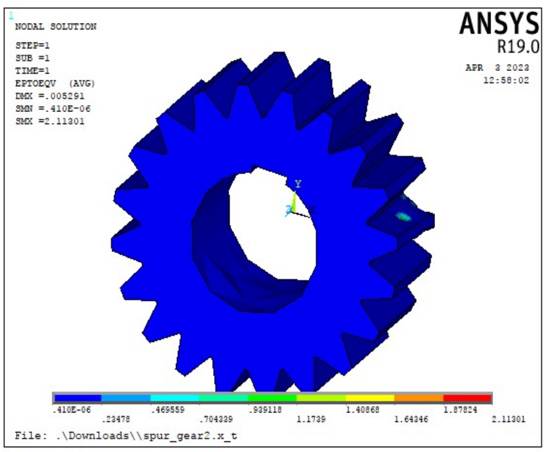


Fig. 2(a). Deformation of PNC **Fig. 2(b). Deformation of HDPE40**



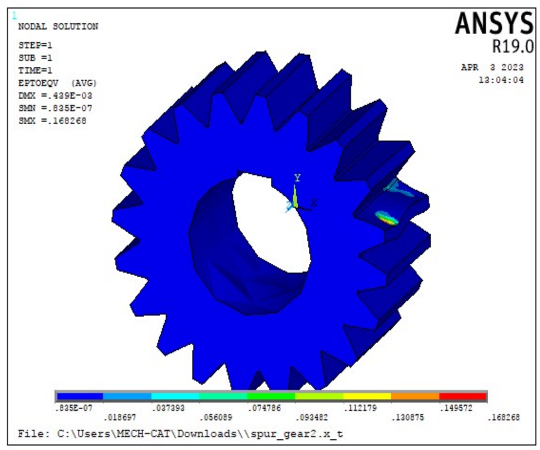


Fig. 2(c). Stain value of PNC **Fig. 2(d). Stain value of HDPE40**

Fig. 2 Deformation and Strain analysis on PNC and HDPE40

4.1.2. Stress Analysis

The boundary condition for the bending analysis of gear is the inner surface of gear is arrested and 250 Pascal pressure loads applied on tooth of gear surface as shown in Fig.3. The shafts are support in gears with bearings and the transmission efficiency is calculated in this type of arrangement.

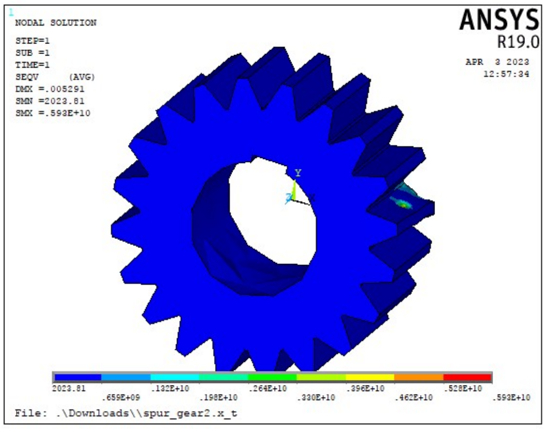


Fig. 3(a). Stress value of PNC

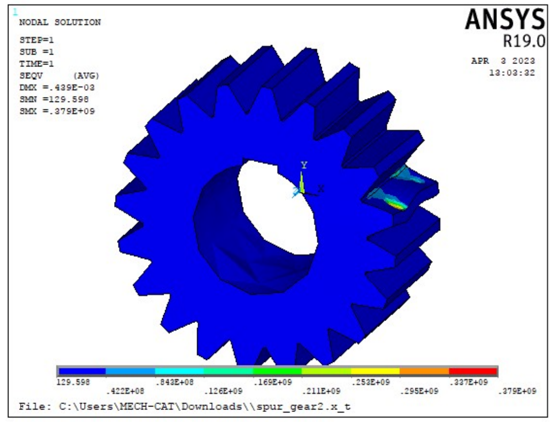


Fig. 3(b). Stress value of HDPE40

Fig. 3. Stress analysis on PNC and HDPE40

In this Fig. 3, it has been observed that HDPE 40 materials has very good stress observing capacity and less strain when compared to PNC. It is also observed that the transmission efficiency of HDPE 40 materials will be greater than that of PMC.

4.2. Torque analysis

3.4.1. Boundary conditions

The boundary condition for the bending analysis of gear is the inner surface of gear is arrested and 250 Nm loads applied on tooth of gear surface as shown in Fig.2. The shafts are support in gears with bearings and the smaller gear mesh with larger in this arrangement. In order to obtain accurate result in this type has been followed.

3.4.2. Deformation Analysis- Torque

The torque load applied on of surface of gear teeth in this analysis. The boundary condition as same as taken in the bending analysis, deformation, stress and strain values are obtained from FEA as shown below for both the materials.

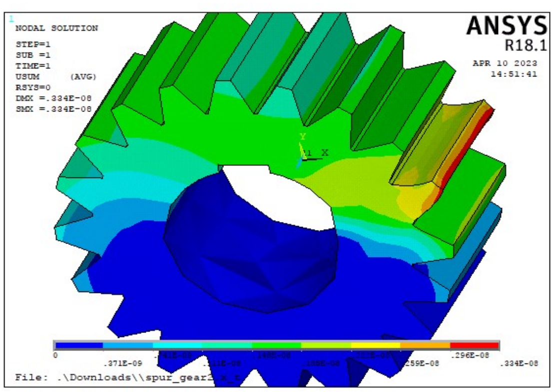


Fig. 4(a). Deformation value of HDPE 40

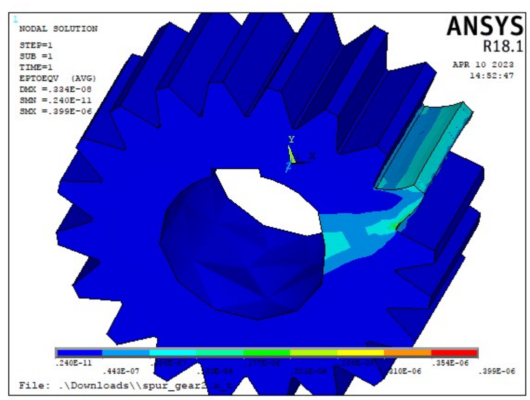


Fig. 4(a). Strain value of HDPE40

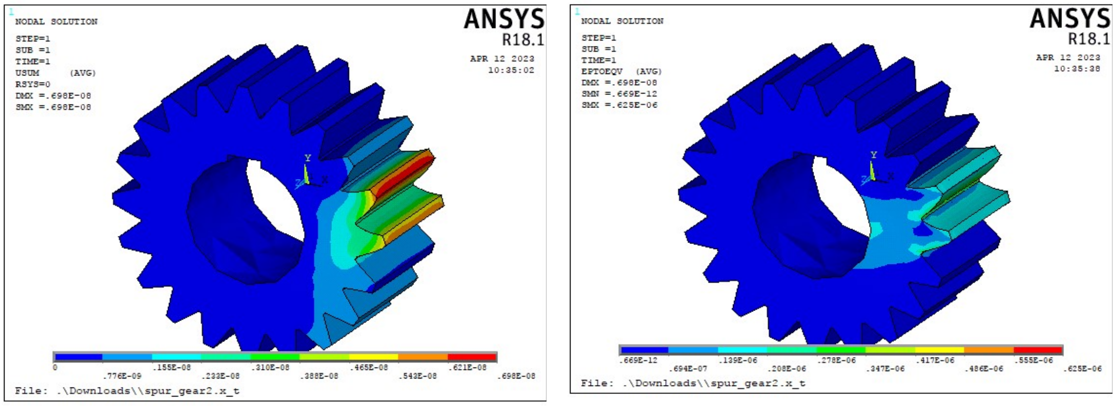


Fig. 4(a). Deformation value of PNC **Fig. 4(a). Strain value of PNC**

Fig. 4 Torque Deformation and Strain analysis PNC and HDPE40

3.4.3. Stress Analysis - Torque

The torque load 250 Nm applied on of surface of gear teeth in this analysis. The boundary condition as same as taken in the bending analysis, deformation, stress and strain values are obtained from FEA as shown below for both the materials. Torsional stress is calculated from FEA code ANSYS 18.1 software and tabulated in table.3 and table.4. It's given below**.**

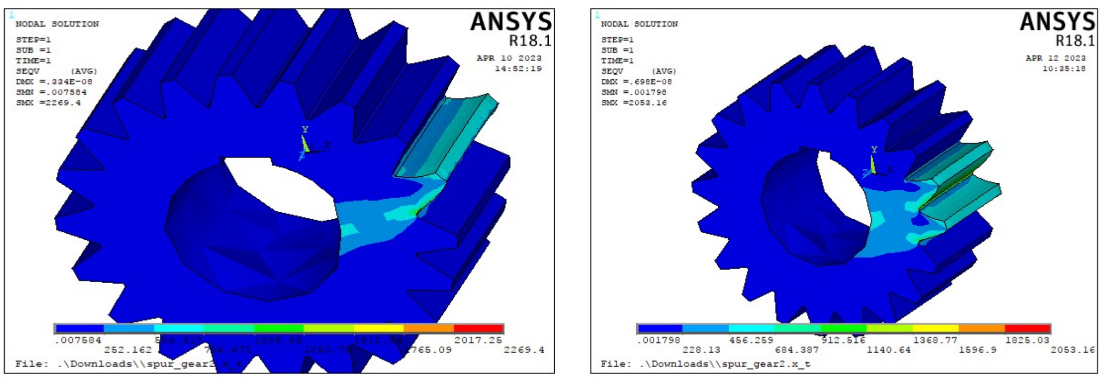


Fig. 5(a). Stress value of PNC **Fig. 5(a). Stress value of HDPE40**

Fig. 5. Torque Stress analysis of PNC and HDPE40

Fig. 4 showed that deformation and strain due to torque load for HDPE40 and PNC materials gear. Also, in Fig. 5 stress of both the materials are presented. In this Fig. 4&5, it has been observed that HDPE 40 materials has very good stress observing capacity and less strain when compared to PNC when it is subjected to torque load. Its revealed that HDPE materials will be produced enhanced performance when compared to other materials while it is subjected to dynamic loading.

5.0. Results & discussion

The bending stress and torsional stress are calculated from FEA code ANSYS 15.0 software and tabulated in Table.3 and Table.4. It's given below**.**

Table 3. Bending analysis -Numerical (FEA) method

S. No	Material	Stress (N/mm2)	Strain	Deformation(mm)
1	PNC	5.93E-9	2.11	0.005
2	HDPE 40	0.337E-9	0.168	0.00049

3	NYLON 66	8.67E-9	0.66	0.668

Table 4. Torque Load -Numerical (FEA) method

S. No	Material	Stress (N/mm2)	Strain	Deformation(mm)
1	PNC	2269.4	0.625E-6	0.698E-8
2	HDPE 40	2053.16	0.399E-6	0.334E-8
3	NYLON 66	2869.2	0.664E-6	0.668E-8

Table. 2 showed that pitch line velocity, beam strength, dynamic load, bending stress due to torque load and maximum wear load for HDPE40, Nylon 66 and PNC materials gear. Table. 3 presented that stress, strain and deformation value of all the three materials for bending analysis using FEA method. In this Table. 4, showed that stress, strain and deformation values, it has been observed that HDPE 40 materials has very good stress observing capacity and less strain when compared to PNC when it is subjected to torque load in FEA method. Its revealed that HDPE40 materials will be produced enhanced performance when compared to other materials under static and torque loading.

Transmission efficiency (η) = Driven gear torque / Driver gear torque – (3)

Form this equation (3) transmission efficiency has been calculated for all the three material gears, HDPE40 gear produced very good result when compared to other materials.

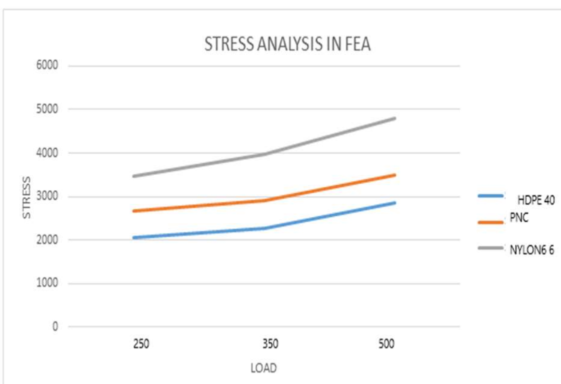


Fig. 6 Stress comparison with various loading condition.

In this Fig. 6, it has been observed that HDPE 40 materials exhibited very stress values at various torque loading condition. This is due to less density and its material property. Its revealed that HDPE materials will be produced better co-efficient of friction, superior damping capacity and good area of contact. The analytical and numerical results revealed that, due to its material property the amount of sliding velocity and sliding velocity power loss will be very less when compared to other materials. Moreover, in Table 2, dynamic load value of HDPE40 is very low, form that it is observed that rolling velocity will be high and frictional loss will be reduced while it is subjected to dynamic condition.

Conclusion:

The performance of polymer Nano composite, high- density polyethylene (HDPE)40 and nylon66 gears were investigated at various bending and torque levels using analytical and numerical (FEA) methods. The HDPE 40 gears exhibits better performance when compared to other gears. Torque analysis has been carried out at various levels (FEA) because, applied torque has detrimental effect on the efficiency of the polyamide nanocomposite (PNC), HDPE40 and NYLON 66 gears. Due to its less density and high specific strength, the HDPE40 gear produced enhanced transmission efficiency and showed superior performance while its subjected to various bending and torque levels when compared to other two materials. Further research could be made to find most appropriate performance study of HDPE40 gear for getting further enhancements in gear efficiency.

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