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# Analysis of Polymer Spur Gears

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## ABSTRACT

*Polymers have been playing an important role in each and every industry due to their high specific properties and their applications are growing day by day. Though their specific properties of polymers are high but their absolute properties when compared with metals are low. This restricts the usage of polymers in engineering applications. Hence in the escalating of world technology the mechanical properties of polymers can be improved in existing polymer. Polymer Nano composites are one of the latest technologies invented to enhance the target polymer in many applications such as mechanical properties, thermal properties etc. Owing to their poor mechanical properties in engineering applications are found very few. Hence, in the present study it is aimed to enhance the mechanical properties of thermoplastics to enable their usage in engineering applications such as automotive bumpers, gears etc. Out of many nylon 6 and nylon 6, 6 are prominent which possess high strength and stability among polymers.*

*Hence in present study it is aimed to enhance the properties of nylon 6 and nylon 6, 6 composite by using Nano reinforcement. As Graphene have superior properties to make nylon 6 and nylon 6, 6 composite potential reinforcing agent. Uniform dispersion of Graphene's and interfacial adhesion between Graphene's and nylon are critical factors that are to be improved for enhancement of mechanical properties of nylon 6 and nylon 6, 6. The present work aims at improving the mechanical properties of Graphene reinforced nylon composites by modifying Graphene surface so as to promote uniform dispersion and to improve bonding between Graphene and nylon.*

*Effect of Graphene's content and its inclusion in Nylon 6 and Nylon 6, 6 gears are determined by wear test in gear test rig and linear wear test on pin on disc equipment. Numerical analysis for stress and deformation of graphene involved nylon 6 and nylon 6, 6 gears are evaluated in ansys. The obtained results indicate 0.8% Graphene included Nylon 6, 6 have better wear performance compared to remaining compositions of graphene with Nylon 6 and Nylon 6, 6.*

***Keywords:*** *Polymer Gears, wear rate, Gear Test Rig, Ansys.*

## I. INTRODUCTION

### *1.1 Polymers*

Polymers had been widely use now-a-days in many fields. Their properties make them useful in much industrial applications, such as coating, packaging labels and automotive sectors etc., in the escalating of world technology requires improvement in the existing polymer. Hence, polymer composites had been discovered to fulfill the need. The present study investigates the effect of adding Graphene particles on mechanical properties of Nylon 6 and Nylon 6, 6.

Based on this scenario by using melt intercalation method, Nylon 6 and Nylon 6,6 is mixed at different ratios(0.2wt% 0.4wt% 0.8wt% of Graphene) in a machine called twin screw extruded machine in order to get pallets by cutting process. Then the pallets will be processed in injection molding machine for standard specimens.

### *1.2 Nylon 6*

Nylon 6 is a polymer developed by Paul Schlack at IG Farben to reproduce the properties of nylon 6, 6 without violating the patent on its production. It is a semi-crystalline polyamide.

**Table 1: Physical Properties of Nylon 6**

| Physical properties | Values in metric units |
|---|---|
| Density | 1.14 g/cc |
| Melt flow | 23-27 g/10 min |

**Table 2: Mechanical Properties of Nylon 6**

| Mechanical properties | Values in metric units |
|---|---|
| Tensile strength | 79 mpa |
| Elongation at break | 130% |
| Flexural strength | 100 mpa |
| Modulus of elasticity | 2900 mpa |
| Hardness, rockwell | 115 r |
| Impact strength, notched | 7 kj/m$^2$ |

### *1.3 Nylon 6, 6:*

DuPont researchers led by Dr. Wallace Carothers, invented nylon 6,6 polymer in the 1930s. Nylon 66 (nylon 6-6, nylon 6/6 or nylon 6, 6) is a type of polyamide or nylon Nylon 6,6 is made of two monomers each containing 6 carbon atoms, hexamethylenediamine and adipic acid, which give nylon 66 its name.

**Table 3: Physical Properties of Nylon 6, 6**

| Physical Properties | Values in Metric Units |
|---|---|
| Density | 1.14 g/cc |
| Melt Flow | 23-27 g/10 min |

**Table 4: Mechanical Properties of Nylon 6, 6**

| Mechanical Properties | Values in Metric Units |
|---|---|
| Tensile Strength | 82 Mpa |
| Elongation At Break | 200% |
| Flexural Strength | 103 Mpa |
| Modulus Of Elasticity | 3102 Mpa |
| Hardness, Rockwell | 115 R |
| Impact Strength, Notched | 7 KJ/m$^2$ |

### *1.3 Graphene*

Graphene is, basically, a single atomic layer of graphite; an abundant mineral which is an allotrope of carbon that is made up of very tightly bonded carbon atoms organized into a hexagonal lattice.

**Table 5: Properties of Grapheme.**

| Appearance | Black Powder |
|---|---|
| Odour | Odourless |
| Melting Point | Powder Melts above 3000$^0$C |
| Bulk Density | 1 g.cm$^3$ approx. |
| Solubility in water | Dispersible in water |
| Stability | Stable on air |

## II. Experimental Details

### *2.1 Specimen preparation*

#### *2.1.1 Preparation of nylon 6 and nylon 6, 6 with Graphene.*

Nylon 6 and Nylon 6, 6 with Graphene blends were prepared via melt intercalation method by twin screw extruder. The process undergo at different temperature ranges from 220$^0$C to 235$^0$C, 212$^0$C to 228$^0$C and 193$^0$C to 207$^0$C. Graphene is blended with Nylon 6 and Nylon 6, 6 at different weight ratios 0.2%, 0.4% and 0.8% in extrusion process.

*Figure 1: Twin Screw Extruder.*

*Figure :2 Nylon 6+0.2% Graphene*

*Figure : 3 Nylon 6+0.4%Graphene.*

*Figure .4: Nylon6+0.8.%Graphene.*

*Figure 5: Nylon 6,6+0.2%Graphene*

*Figure :6 Nylon 6,6+0.4% Graphene.*

*Figure 7 : Nylon 6,6+0.8% Graphene.*

### *2.2 Testing of gears*

The graphene nylon gear to be tested is connected to a D.C motor and meshes with an identical metal gear. Metal gear is driven by D.C motor and can run up to a speed of 1500 rpm. Nylon graphene gears were conducted at rotational speeds, 600, 800, 1000 rpm at different torque levels, 1, 2, 3 N-M under unlubricated dry conditions.

Rotational speed of the test gear is gradually increased to the test speed and maintained constant throughout the test. Tests were continuously run until the gear failure is observed or until 5 millions of cycles run whichever is earlier. At least three specimens were tested at each torque level. The gears which were prepared from the injection moulding machine for nylon and different compositions of nylon are as follows.

Figure *8: Nylon 6 Gears.*

Figure *9: Nylon 6+Graphene.*

*Figure 10: Nylon 6,6 Gears*

*Figure 11: Nylon 6,6+Graphene.*

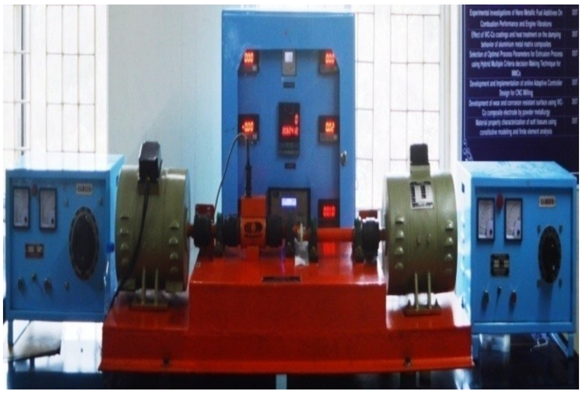

*Figure 12: Gear Test Rig Machine.*

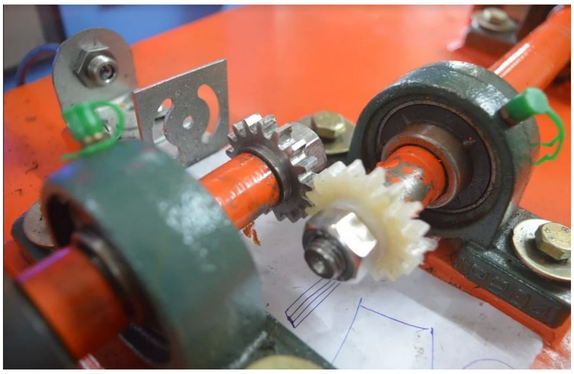

*Figure 13: Mating with steel gear.*

### *2.3 Linear Wear (pin-on-disc)*

Wear is a process of removal of material from one or both of two solid surfaces in solid state contact. Dry sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine. The pin was held against the counter face of a rotating disc (EN31 steel disc) with wear track diameter 60 mm. The pin was loaded against the disc through a dead weight loading system. The wear test for all specimens was conducted under the normal loads of 40kg, 60kg and 80kg.

*Figure 14: Nylon 6+grapheme.*

*Figure: 15 Nylon6,6+Graphene.*

Graphene included Nylon 6 and Nylon 6, 6 materials are taken as Pin samples at a length of 30mm and 12mm in diameter as shown in figure 14 and figure 15. The wear rate was calculated from the height loss technique and expressed in terms of wear volume loss per unit sliding distance.

The figure below shows Pin-on-Disc equipment on which linear wear test is performed.

*Figure 16: Pin on Disc Side View*

*Figure 17: Pin on Disc Front View*

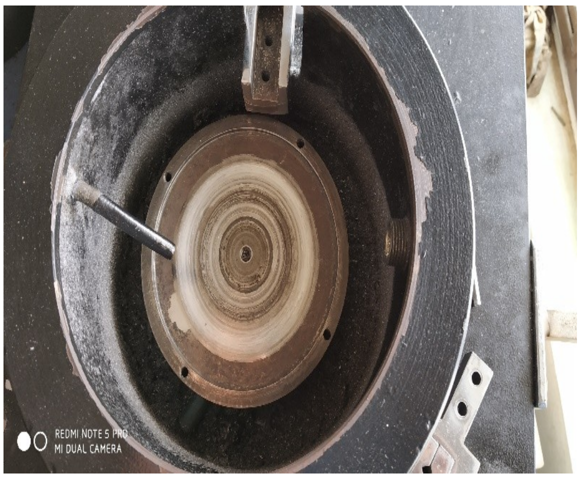

*Figure 18: Pin on Disc Equipment Top View*

## III.RESULTS AND DISCUSSION

### *3.1 Gear test rig observations*

The above tables shows the results of Nylon6 and Graphene included nylon 6 gears are rotated for number of cycles at different speeds 600.800,1000rpm for the torques of 1,2 and 3N-M.

### *Nylon 6:*

**Table 6: The Number of Cycles at Different Torques at 600rpm**

| 600RPM | | | |
|---|---|---|---|
| TORQUE | 3 | 2 | 1 |
| NYLON 6 | 3.9L | 8L | 18L |
| 0.2% | 4.9L | 13.6L | 25L |
| 0.4 | 12.7L | 17L | 31L |
| 0.8 | 22L | 30.3L | 50L |

**Table 7: The Number of Cycles at Different Torques at 800rpm**

| 800RPM | | | |
|---|---|---|---|
| TORQUE | 3 | 2 | 1 |
| NYLON 6 | 4.4L | 15L | 18L |
| 0.2 | 5.32L | 20.1L | 27L |
| 0.4 | 13.3L | 26.3L | 34L |
| 0.8 | 14.5L | 34.7L | 50L |

**Table 8: The Number of Cycles at Different Torques at 1000rpm**

| 1000RPM | | | |
|---|---|---|---|
| TORQUE | 3 | 2 | 1 |
| NYLON 6 | 5.1L | 23L | 20L |
| 0.2 | 7.01L | 26L | 29.2L |
| 0.4 | 9.33L | 27.1L | 38.3L |
| 0.8 | 18.7L | 36.1L | 50L |

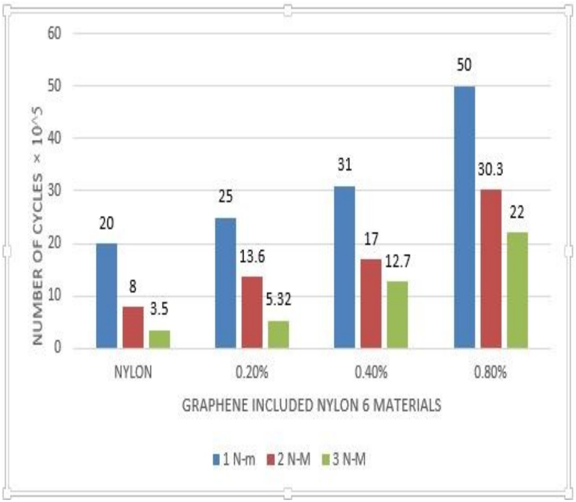


*Figure 19: Different torques at 600rpm*

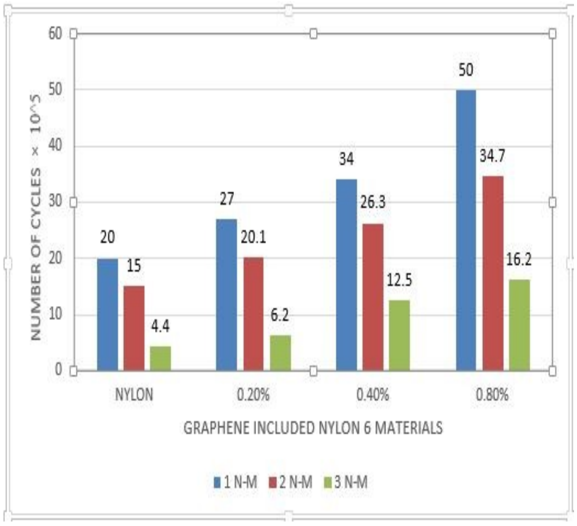


*Figure 20: Different torques at 800rpm*

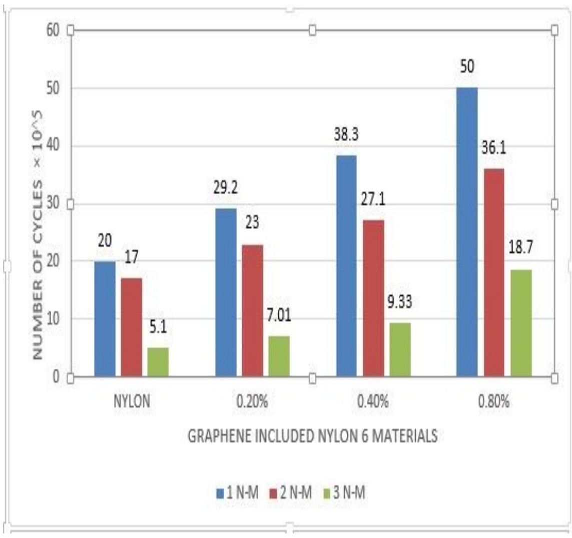


*Figure 21: Different torques at 1000rpm*

### *Nylon 6,6*

**Table 9: The Number of Cycles at Different Torques at 600rpm**

| 600RPM | | | |
|---|---|---|---|
| TORQUE | 3 | 2 | 1 |
| NYLON 6,6 | 4.2L | 9L | 18L |
| 0.2 | 5.3L | 14.1L | 27L |
| 0.4 | 13.6L | 18.3L | 32L |
| 0.8 | 24L | 32.3L | 50L |

**Table 10: The Number of Cycles at Different Torques at 800rpm**

| 800RPM | | | |
|---|---|---|---|
| TORQUE | 3 | 2 | 1 |
| NYLON 6,6 | 5.7L | 16L | 18L |
| 0.2 | 6.70L | 21.2L | 27.5L |
| 0.4 | 15.3L | 27.8L | 34L |
| 0.8 | 24.3 | 35.1L | 50L |

**Table 11: The Number of Cycles at Different Torques at 1000rpm**

| 1000RPM | | | |
|---|---|---|---|
| TORQUE | 3 | 2 | 1 |
| NYLON 6,6 | 6.1L | 24L | 20 |
| 0.2 | 9.01L | 27L | 32.7L |
| 0.4 | 0.89L | 29.3L[1] | 39.4L |
| 0.8 | 26.4L | 38.3L | 50L&AB OVE |

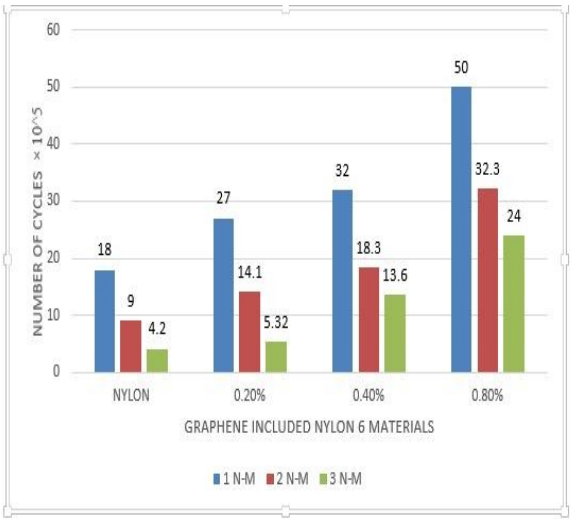


*Figure 22: Different torques at 600rpm*

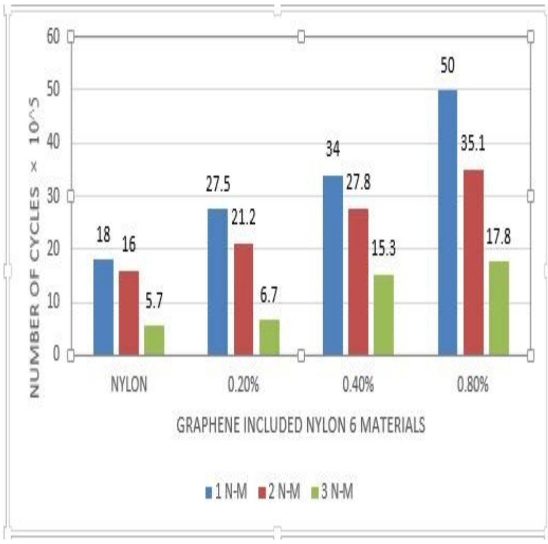


*Figure 23: Different torques at 800rpm*

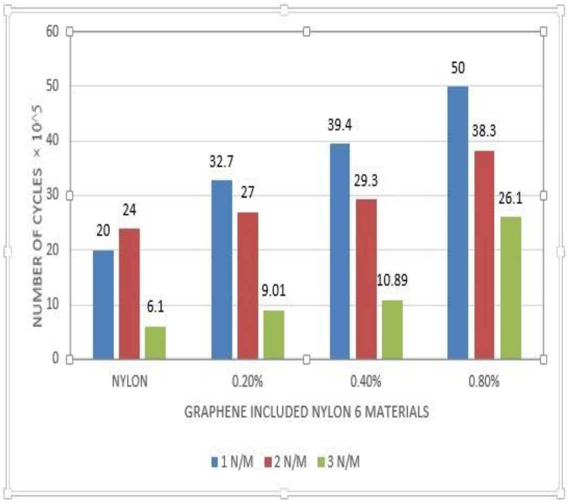


*Figure 24: Different torques at 1000rpm*

**Table 12: Weight loss for Nylon 6 Due to Wear**

| s.no | Specimen name | Initial weight | Final weight | Weight loss | Speed (rpm) | Weight (kg) |
|---|---|---|---|---|---|---|
| 1 | Nylon-6 | 0.552 | 0.526 | 0.026 | 800 | 80 |
| 2 | 0.2% +nylon6 | 0.553 | 0.531 | 0.022 | 800 | 80 |
| 3 | 0.4% +nylon6 | 0.554 | 0.534 | 0.020 | 800 | 80 |
| 4 | 0.8% +nylon6 | 0.556 | 0.543 | 0.013 | 800 | 80 |

**Table 13: Weight loss for Nylon 6, 6 due to Wear**

| s.no | Specimen name | Initial weight | Final weight | Weight loss | Speed (RPM) | Weight (kg) |
|---|---|---|---|---|---|---|
| 1 | Nylon-6, 6 | 0.552 | 0.529 | 0.023 | 800 | 80 |
| 2 | 0.2% +nylon6, 6 | 0.553 | 0.532 | 0.021 | 800 | 80 |
| 3 | 0.4% +nylon6, 6 | 0.554 | 0.535 | 0.019 | 800 | 80 |
| 4 | 0.8% +nylon6, 6 | 0.556 | 0.545 | 0.011 | 800 | 80 |

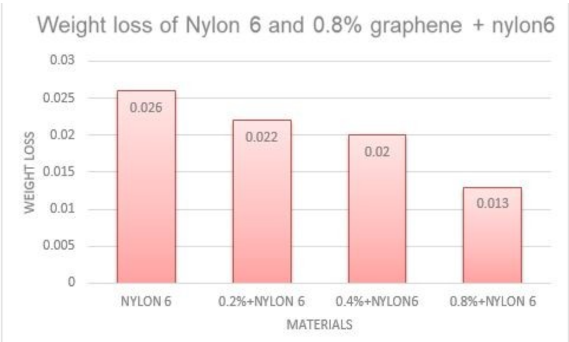


*Figure 25: Weight Loss of Nylon 6 and 0.8% Graphene+Nylon 6*

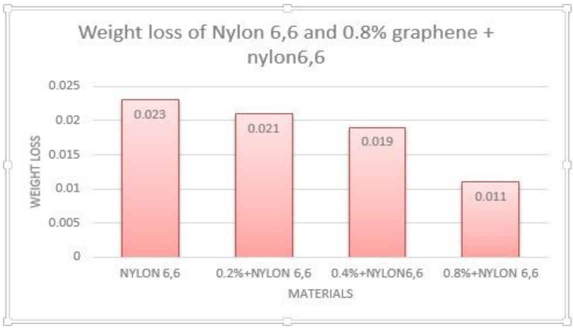


*Figure 26: Weight Loss of Nylon 6 and 0.8% Graphene+Nylon 6, 6*

### *3.3 Equivalent stresses and deformation*

Equivalent stresses and deformations are obtained in ANSYS solution for nylon and for three different weight fractions of graphene included nylon at three different loads.

**Table 14: Equivalent Stress and Deformation for Nylon 6**

| Materials | Load | Equivalent (von-misses) Stress | Total Defor-mation |
|---|---|---|---|
| nylon-6 | 1 N-M | 0.42604 | 0.007776 |
| nylon-6 | 2 N-M | 0.85209 | 0.015552 |
| nylon-6 | 3 N-M | 1.2781 | 0.023328 |
| nylon-6+0.2 graphite | 1 N-M | 0.42501 | 0.007083 |
| nylon-6+0.2 graphite | 2 N-M | 0.85001 | 0.014166 |
| nylon-6+0.2 graphite | 3 N-M | 1.275 | 0.021249 |
| nylon-6+0.4% graphite | 1 N-M | 0.42487 | 0.007000 |
| nylon-6+0.4 %graphite | 2 N-M | 0.84973 | 0.014000 |
| nylon-6+0.4% graphite | 3 N-M | 1.2746 | 0.021000 |
| nylon-6+0.8% graphite | 1 N-M | 0.42404 | 0.006542 |
| nylon-6+0.8% graphite | 2 N-M | 0.84808 | 0.013084 |
| nylon-6+0.8% graphite | 3 N-M | 1.2721 | 0.019626 |

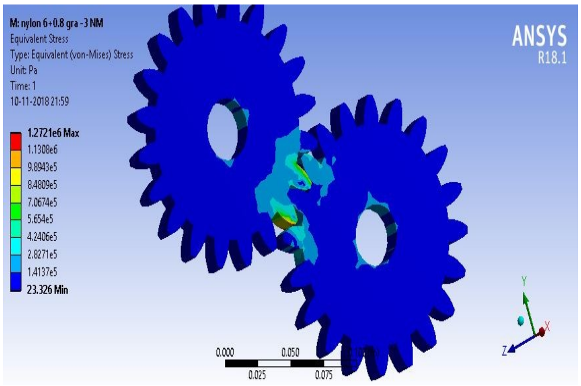


*Figure 27: 0.8% + nylon 6 stress.*

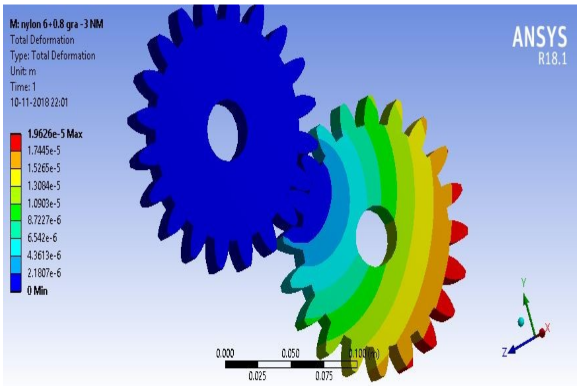


*Figure 28: 0.8% + nylon 6 deformation.*

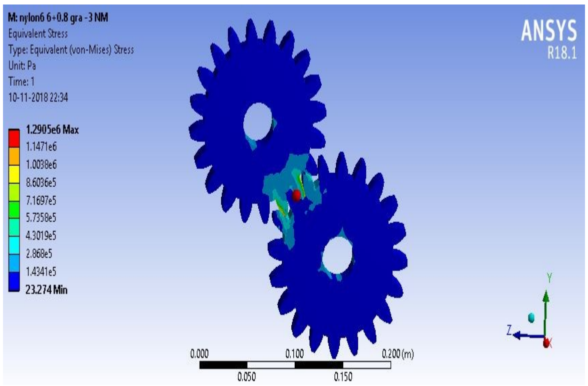


*Figure 29: 0.8% + Nylon 6,6. Stress*

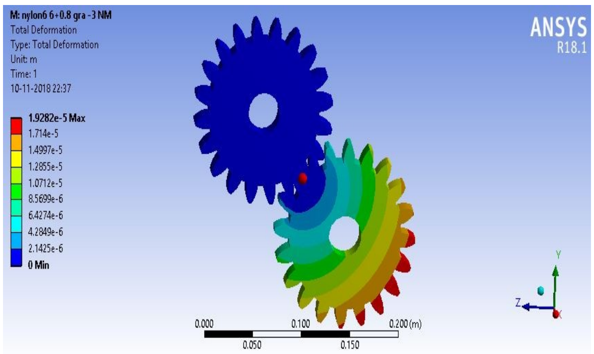


*Figure 30: 0.8% + Nylon 6,6 Deformation*

**Table 15: Equivalent Stress and Deformation for Nylon 6, 6**

| Materials | Load | Equivalent (von -misses) Stress | Total Deformation |
|---|---|---|---|
| nylon-6, 6 | 1 N-M | 0.43249 | 0.0077186 |
| nylon-6, 6 | 2 N-M | 0.86497 | 0.0154370 |
| nylon-6, 6 | 3 N-M | 1.2975 | 0.0231560 |
| nylon-6, 6+0.2 graphite | 1 N-M | 0.43133 | 0.0070119 |
| nylon-6, 6+0.2 graphite | 2 N-M | 0.86266 | 0.0140240 |
| nylon-6, 6+0.2 graphite | 3 N-M | 1.294 | 0.0210360 |
| nylon-6, 6+0.4 graphite | 1 N-M | 0.43114 | 0.0069103 |
| nylon-6, 6+0.4 graphite | 2 N-M | 0.86228 | 0.0138210 |
| nylon-6, 6+0.4 graphite | 3 N-M | 1.2934 | 0.0207310 |
| nylon-6, 6+0.8 graphite | 1 N-M | 0.43018 | 0.0064274 |
| nylon-6, 6+0.8 graphite | 2 N-M | 0.86036 | 0.0128550 |
| nylon-6, 6+0.8 graphite | 3 N-M | 1.2905 | 0.0192820 |

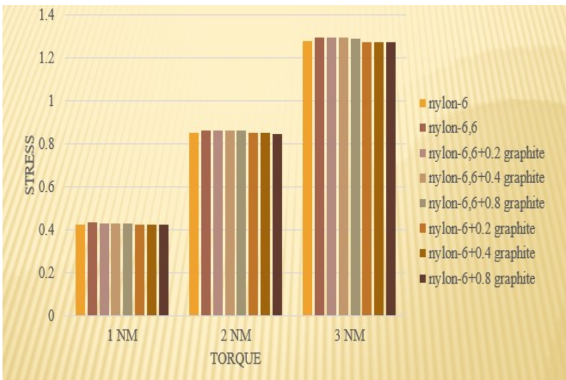


*Figure 31: Stress for Nylon 6 and Nylon 6, 6*

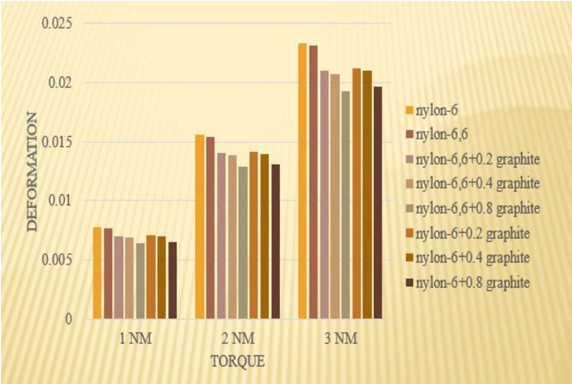


*Figure 32: Deformation for Nylon 6 and Nylon 6, 6*

## VII. CONCLUSIONS

The graphene involved Nylon 6 and Nylon 6, 6 gears was investigated at various rotational speeds and torques. Rotational speed influences the performance of gears at high torques. At torque 3 N-M of 1000rpm 0.8% weight fraction of graphene shows improved life than nylon 6 and nylon 6, 6 gears.

- After the experiments and tests performed on different percentages of Graphene examined that performance of gears are increased due to Graphene inclusion.
- 0.8% weight fraction of graphene exhibits superior behavior compared to nylon 6 and nylon 6, 6 gears due to its high strength.
- From nylon 6 and nylon 6, 6 gears, 0.8% graphene included nylon 6, 6 gears rotates more number of cycles when compared to 0.8% nylon 6.
- From the PIN-ON-DISC linear wear results, it shows 0.8% graphene included nylon 6, 6 have a lesser wear rate when compared to 0.8% nylon 6.
- The static structural analysis for stress and deformation among all the compositions of nylon, 0.8% graphene included Nylon 6, 6 materials have lowest deformation as well as stress.
- By incorporation of GN, the integrated effect of the increased strength can greatly reduce deformations and fragmentations of the worn surfaces of the composites, thus reducing the real contact area, consequently, increasing wear resistance.

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