# Static Analysis of HDPE Polymer Composite Spur Gear Using Finite Element Method

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**Abstract-** *In this experiment composite material of different compositions are fabricated having HDPE (High Density Polyethylene) as matrix, carbon fiber powder as reinforcement and silicon carbide powder as filler using vertical injection molding method. Specimens of different compositions are tested in UTM for tensile and flexural test and suitable composition is selected after studying their results in testing. Spur gear is designed in CATIA V5 using standard design and static analysis is done using ANSYS workbench and comparison is made between cast steel spur gear and HDPE polymer composite spur gear. Composite material with light weight, high strength and cheap properties can be used to replace metallic spur gear in future.*

***Keywords**:* HDPE, Carbon fibre, Silicon carbide, Injection molding, Static analysis, Spur gear replacement.

## 1.0 INTRODUCTION

Gears are toothed members which transmit power/ motion between two shafts by meshing without any slip. Hence, gear drives are also called positive drives. The increasing demand for quiet power transmission in machines, vehicles, elevators and generators, has created a growing demand for a more precise analysis of the characteristics of gear systems.

The spur gear is simplest type of gear manufactured and is generally used for transmission of rotary motion between parallel shafts. The spur gear is the first choice option for gears except when high speeds, loads, and ratios direct towards other options. Other gear types may also be preferred to provide more silent low-vibration operation. A single spur gear is generally selected to have a ratio range of between 1:1 and 1:6 with a pitch line velocity up to 25 m/s. The spur gear has an operating efficiency of 98-99%. The pinion is made from a harder material than the wheel.

## 1.1 NEED OF COMPOSITE SPUR GEAR

Composite spur gear weight is very less in comparison to metallic spur gear. A part from this composite spur gear is cheap and has very good strength in comparison to metallic spur gear. Composite spur gear can replace metallic spur gear in future due to these properties.

## 1.2 COMPOSITE MATERIAL

It is made up of two or different materials having its properties advanced than previous material having two phases namely matrix and reinforcement. Reinforcement phase held matrix phase together for making material firm and stiff.

## 2.0 OBJECTIVES OF PRESENT WORK

i. Fabrication of polymer composite with HDPE as matrix, carbon fiber powder as reinforcement and silicon carbide as filler in different proportions.

ii. To evaluate the Mechanical characteristics of the prepared composite materials this includes its tensile and flexural strength.

iii. To calculate optimum composition of HDPE reinforced composite with carbon fiber powder as reinforcement and silicon carbide as filler.

iv. Numerical analysis of composite material spur gear in ANSYS workbench in static loading condition after modeling in CATIA V5.

## 2.1 SCOPE OF PRESENT WORK

Literature survey concludes that none of researcher has done project which use HDPE matrix reinforced with carbon fiber powder and silicon carbide as filler to fabricate composite material by injection molding process.

Composite materials fabricated by this method are believed to have more superior mechanical properties then pure HDPE. These high strength materials with low weight and wear can be used in spur gear as replacement for cast steel. A part from this it can be used in other gears like helical gear, bevel gear, rack and pinion etc. Replacement of this cast steel by these high strength composite materials will reduce weight as well as cost of manufacturing for steel gear. Powder form of carbon fiber has melting point of 1150-1200 °C. A part from this silicon carbide has high strength with melting point of 2700° C. this will give strength for gear which is required during loading condition.

## 3.0 METHODOLOGY

In this experiment selection of material is done initially which is HDPE as matrix, carbon fiber powder as reinforcement and silicon carbide powder as filler. These materials are mixed in different proportion and composite material is made using injection molding method. Tensile and flexural tests of composite materials are done in UTM. After testing is done material having high UTS and bending properties is selected for static analysis in ANSYS. Modeling of spur gear is done in CATIA V5 before static analysis where design data are taken from research paper.

## 3.1 SELECTION OF MATERIALS

### 3.1.0 SELECTION OF MATRIX

HDPE has been selected as matrix as it is a polyethylene thermoplastic made from petroleum with a high strength-to-density ratio. The density of HDPE can range from 0.93 to 0.97 g/cm3 or 970 kg/m3. Although the density of HDPE is only marginally higher than that of low-density polyethylene, HDPE has little branching, giving it stronger intermolecular forces and tensile strength than LDPE. It is also harder and more opaque and can withstand somewhat higher temperatures (120oC/248oF for short periods). HDPE is the non-toxic, tasteless, odorless, extremely low moisture absorption and has a very low co-efficient of friction and hence wear resistance. HDPE is among the most widely used polyolefin because of its high strength, very low cost, excellent process ability and also high chemical resistance. The use of High Density Polyethylene as matrix material improves in the mechanical and tribological properties of the hybrid polymer matrix composite, which can be used for variety of applications in the manufacturing of gear.

**Figure 3.0** HDPE

### 3.1.2 FIBER REINFORCEMENT

The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties and to provide strength to the finished part. The most commonly used reinforcement materials are carbon/graphite fibers (The terms graphite and carbon are often used interchangeably).This is due to the fact that many of the desired performance characteristics require the use of carbon/graphite fibbers. Fibers are about 5–10 micrometers in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion.

**Figure 3.1** Carbon fiber powder

### 3.1.3 FILLER MATERIAL

Fillers are particles added to material (plastics, composite material, and concrete) to lower the consumption of more expensive binder material or to better some properties of the mixture material. For this project we have used silicon carbide as a filler material. Silicon carbide is an excellent abrasive. It has high strength low thermal expansion, high thermal conductivity, high hardness, high elastic modulus, excellent thermal shock resistance, superior chemical inertness.

**Figure 3.2** Silicon carbide

### 3.2 COMPOSITION OF SPECIMEN

Samples of composite specimens are prepared by mixing them in different proportions. There are five compositions which are as follow:

A) Sample 1: HDPE (100%)

B) Sample 2: HDPE (90%) and carbon fiber(10%)

c) Sample 3: HDPE (88%), carbon fiber (10%) and silicon carbide (2%)

D) Sample 4: HDPE (86%), carbon fiber (10%) and silicon carbide (4%)

E) Sample 5: HDPE (84%), carbon fiber (10%) and silicon carbide (6%).

**Table 3.2** Sample Calculation Table

| Sample | HDPE (%) | Carbon fibre (%) | Silicon carbide(%) | HDPE(gm) | C(gms) | SiC(gms) | Total(gms) |
|---|---|---|---|---|---|---|---|
| 1 | 100 | 0 | 0 | 40.824 | 0 | 0 | 40.824 |
| 2 | 90 | 10 | 0 | 38.45 | 4.27 | 0 | 42.72 |
| 3 | 88 | 10 | 2 | 38.18 | 4.339 | 0.8679 | 43.39 |
| 4 | 86 | 10 | 4 | 37.895 | 4.406 | 1.763 | 44.064 |
| 5 | 84 | 10 | 6 | 37.63 | 4.4798 | 2.687 | 44.7984 |

- Density of HDPE = 0.97gm/cc
- Density of Carbon fiber Powder = 1.7gm/cc
- Density of silicon carbide = 3.71gm/cc

Volume of the mould, V =120mm×120mm×3mm=43.2cc.

### Formulae used

AC = A HDPE + A carbon fibre + A silicon carbide → (1)

Where

AC = mass / density of the composite

A HDPE = mass/ density of the resin

A carbon fiber = mass / density of the carbon fiber

A silicon carbide= density of the silicon carbide

W c/ ρ c = W HDPE / ρ HDPE l+ W carbon fiber / ρ carbon fiber + W silicon carbide /ρ silicon carbide → (2)

Where

WC = mass of the composite

W HDPE = mass of the matrix

W carbon fiber = mass of the reinforcement

Similarly W silicon carbide = mass of the filler

### 3.3 PREPARATION OF SPECIMEN BY INJECTION MOLDING

Injection molding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products are manufactured using injection molding, which vary greatly in their size, complexity, and application. Injection moldings machines have many components and are available in different configurations, including a horizontal configuration and a vertical configuration. Samples of different compositions have been prepared by vertical injection molding machine.

The injection unit is responsible for both heating and injecting the material into the mould. The first part of this unit is the hopper, a large container into which the raw plastic is poured. The hopper has an open bottom, which allows the material to feed into the barrel. The barrel contains the mechanism for heating and injecting the material into the mould.

This mechanism is usually a ram injector or a reciprocating screw. A ram injector forces the material forward through a heated section with a ram or plunger that is usually hydraulically powered. In this way composite materials are prepared in a mild steel die using vertical injection molding. These specimens are then cut by water jet machining later using ASTM standard for tensile and flexural test. The size of die used is 120mm*120mm*3mm using NC machining.

**Figure 3.3** NC machining

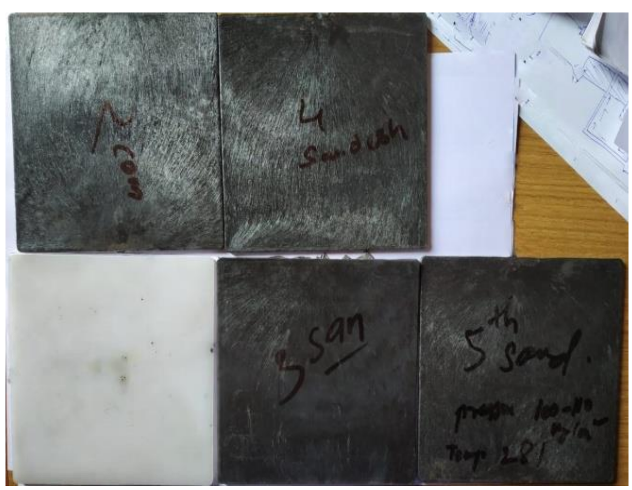

**Figure 3.4** Specimen prepared by injection molding

### 3.4 CUTTING OF SPECIMEN AS PER ASTM STANDARD

The prepared Composite materials are cut into standard ASTM Dimensions using abrasive water jet machine. The pressure of jet is 3000 psi which was CNC controlled and has precise cutting. ASTM E8 has been used for tensile test while ASTM D 790 has been used for flexural test.

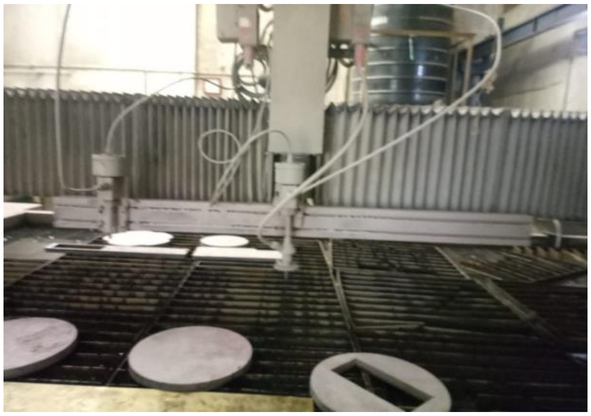

**Figure 3.4** Water jet machining

**Figure 3.5** Cutting of Specimen as Per ASTM Standard

## 4.0 TESTING AND RESULTS

Tensile and bending test is done in UTM and results of experiments are tabulated below.

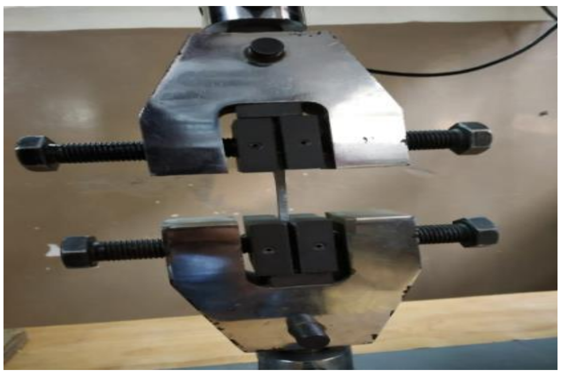

**Figure 4.**0 Tensile test

### 4.1 TENSILE TEST

**Table- 4.1:** Tensile test

| Sample No. | Composition | Peak Load(N) | Break load(N) | Ultimate Tensile Strength(N/mm$^2$) | Young's modulus(N/mm$^2$) |
|---|---|---|---|---|---|
| A | HDPE (100%) | 280 | 3.13 | 15.56 | 164.38 |
| B | HDPE (90%) +Carbon fibre (10%) | 305 | 3.13 | 16.95 | 193.76 |
| C | HDPE (88%) +carbon fibre (10%) + silicon carbide (2%) | 231 | 3.13 | 12.85 | 141.56 |
| D | HDPE (86%) +carbon fibre (10%) +silicon carbide (4%) | 243 | 12.89 | 13.48 | 886.7 |
| E | HDPE (84%) +carbon fibre (10%) + silicon carbide (6%) | 277 | 6.37 | 15.39 | 298.34 |

**Figure 4.2** Specimen after tensile test

### 4.2 FLEXURAL TEST

**Table 4.2:** Flexural test

| Sample No. | Composition | Peak Load(N) | Break Load(N) | Flexural Strength(N/mm$^2$) |
|---|---|---|---|---|
| A | HDPE (100%) | 90 | 0.94 | 25.11 |
| B | HDPE (90%) +Carbon fibre (10%) | 160 | 7.5 | 1.73 |
| C | HDPE (88%) +carbon fibre (10%) + silicon carbide (2%) | 67 | 1.22 | 18.55 |
| D | HDPE (86%) +carbon fibre (10%) +silicon carbide (4%) | 33 | 1.9 | 9.05 |
| E | HDPE (84%) +carbon fibre (10%) + silicon carbide (6%) | 61 | 0.68 | 17.01 |


**Figure 4.2** Flexural test

Considering above results of tensile and flexural test sample E has good mechanical properties so we consider sample E for static analysis.

## 5.0 SPECIFICATION AND DESIGN CALCULATION

Model = TATA SUPER ACE
Engine = TATA475 TCIC (BSIII)
Engine capacity =1405cc
Maximum engine output = 70hp@4500rpm
Maximum engine torque = 13.8 kg-m@2500rpm
Fuel tank capacity = 38 liters
Tires = 165R14LT8PR
Wheel base = 2380mm
Width = 1565mm
Length = 4340mm
Height = 1858mm
Front track = 1340mm
Rear track = 1320mm

Calculations
Torque (T) = 13.8kg-m@2500rpm
T = 13.8 kg-m
T = 13.8*10 N-m
T = 138 N-m

T = 138000 N-mm
N = 2500 rpm.
Power (P) = 2*3.14*2500*T/60
P = 2*3.14*2500*138/60

P = 36128 Watt
Power (P) = 36.128 K Watt.
Torque (T) = F*(d/2)

Where,
F-load,
d- Pitch circle diameter (z*m=180mm)

T= F*(d/2)
F = T/ (d/2)
F = 138000/90
Load (F) = 1533.33N
Using Lewis equation,
Tangential load, F =b*y*pc*σ b
Pc = 3.14*module
Pc = 31.4mm
Y= Lewis form factor=0.134mm
b = face width = 54mm
The maximum allowable stress= 4.182N/mm2.
Ultimate tensile strength for cast steel = 540Mpa
Ultimate tensile strength for composite = 15.39Mpa
Allowable stress for cast steel = ultimate tensile strength/3
= 540/3 = 180N/mm2> 4.182N/mm2
Allowable stress for composite = ultimate tensile strength/3
= 15.39/3 = 5.13N/mm2>4.182N/mm2
So, the design is safe.
Calculations of Gear Tooth Properties
Pitch circle diameter (p.c.d) = z*m = 18*10 = 180mm
Base circle diameter (Db) = D cos α
= 180*cos20
= 169.145mm
Outside circle diameter = (z+2)*m= (18+2)*10 = 200mm
Clearance = circular pitch/20 = 31.4/20 = 1.57mm
Dedendum = Addendum + Clearance = 10+1.57 = 11.57mm
Module = D/Z = 180/18 = 10mm
Dedendum circle diameter = P.C.D -2*dedendum
= 80-2*11.57= 156.86mm
Fillet radius = Circular pitch/8 = 31.4/8 = 3.9mm
Pitch circle diameter (Pc) = m*z = 10*18 = 180mm
Hole depth = 2.25*m = 2.25*10 = 22.5mm
Thickness of the tooth = 1.571*10 = 15.71mm
Face width (b) = 0.3*180= 54mm
Center distance between two gears = 180mm
Diametric pitch = Number of teeth/P.C.D= 18/180= 0.1mm

### 5.1 STATIC ANALYSIS OF CAST STEEL AND HDPE SPUR GEAR

Torque (T) = 140N-m: Speed (N) = 2500 Rpm

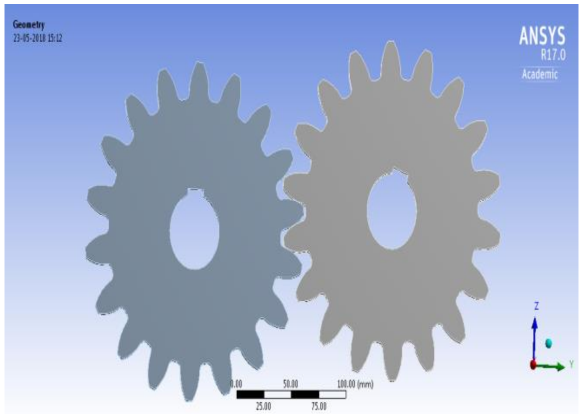


**Figure 5.1.0** Gear model using CATIA V5

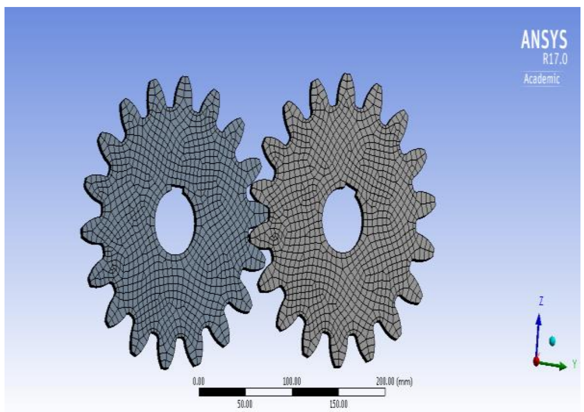


**Figure 5.1.1** Meshing of gear

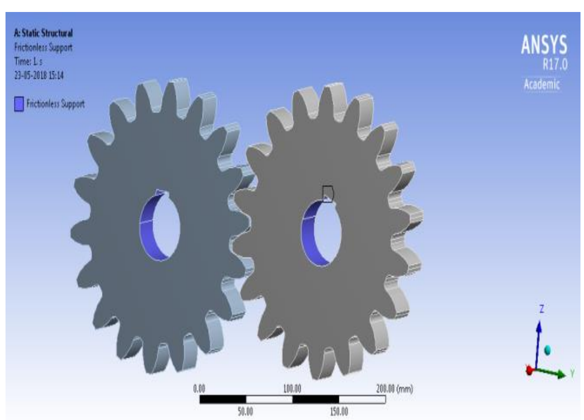


**Figure 5.1.2** Applying frictionless support

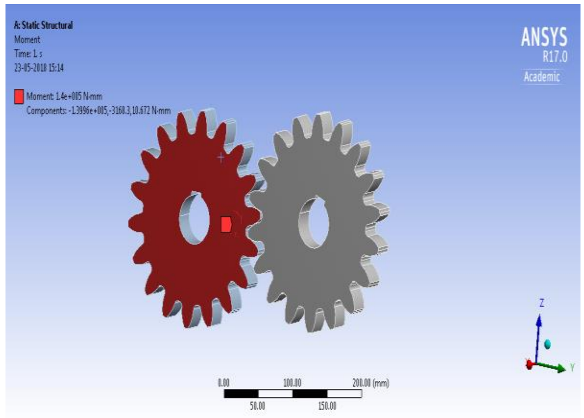


**Figure 5.1.3** Applying moment

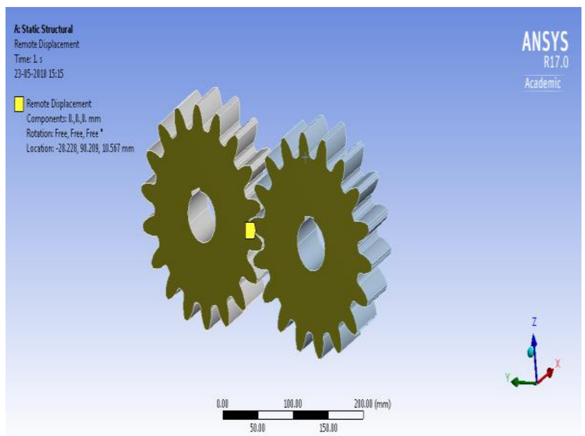


**Figure 5.1.4** Remote displacement

### 5.2 FEM ANALYSIS OF CAST STEEL SPUR GEAR

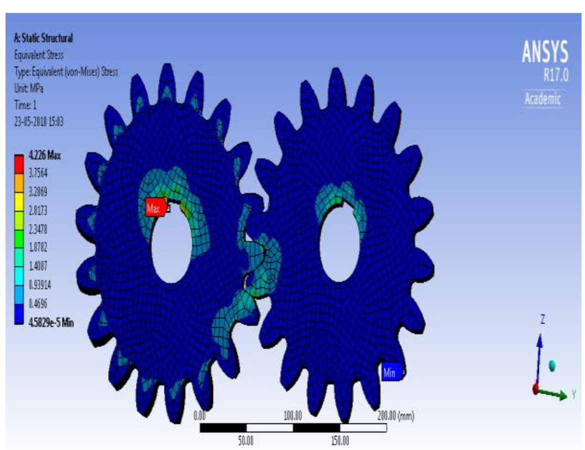


**Figure 5.2.0** Von Mises Stress

In this stress analysis maximum von mises stress is 4.226 Mpa.

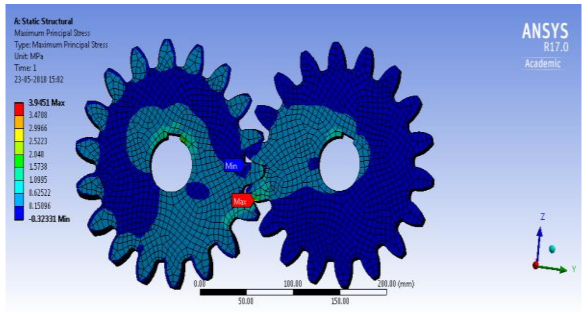


**Figure 5.2.1** Maximum principal stress

In this analysis maximum principal stress is 3.9451 Mpa.

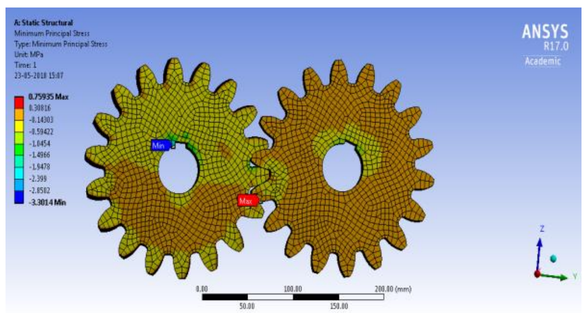


**Figure 5.2.**2 Minimum Principal Stress

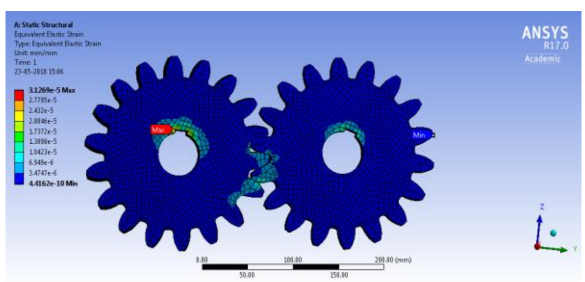


**Figure 5.2.3** Equivalent Elastic Strain

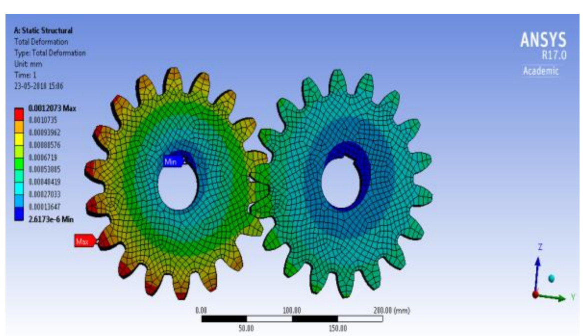


**Figure 5.2.4** Total Deformation

### 5.3 FEM ANALYSIS OF HDPE COMPOSITE SPUR GEAR

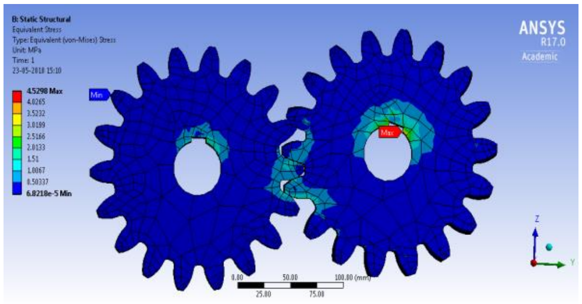


**Figure 5.3.0** Von Mises Stress

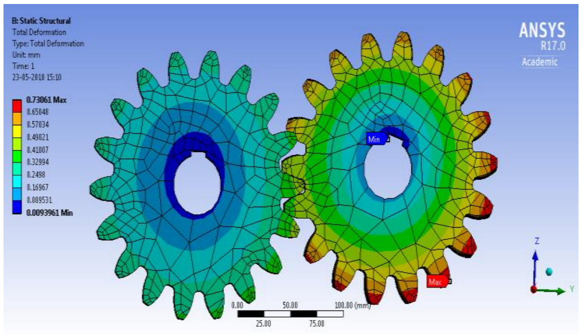


**Figure 5.3.1** Total Deformation

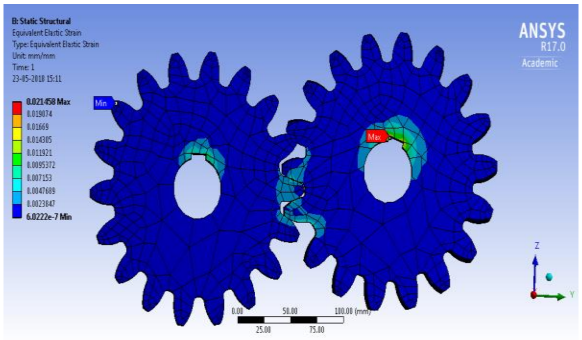


**Figure 5.3.2** Equivalent Elastic Strain

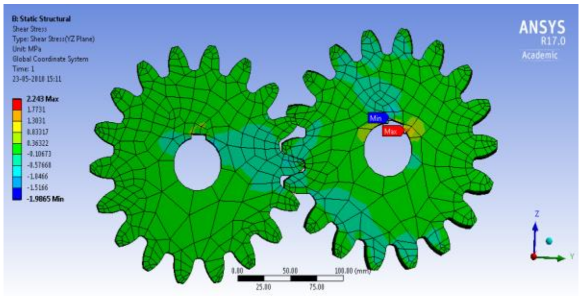


**Figure 5.3.3** Shear Stress

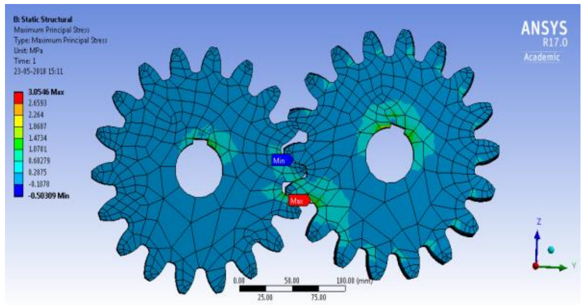


**Figure 5.3.4** Maximum Principle Stress

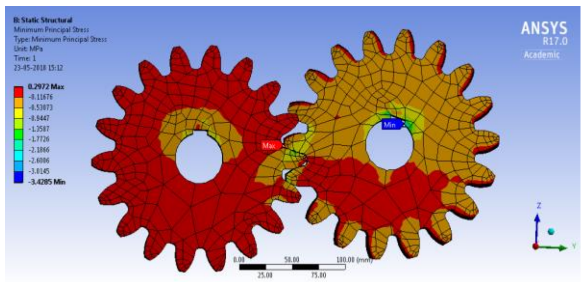


**Figure 5.3.5** Minimum Principal Stress

## 5.4 COMPARISON OF RESULTS

**Table5.4** Comparison of Results

| Failure Theories | Cast Steel | Composite Materials | Difference |
|---|---|---|---|
| Equivalent Von-mises stress (MPa) | 4.226 | 4.5298 | -0.3038 |
| Shear stress(yz plane) | 1.4121 | 2.2243 | -0.8122 |
| Total deformation (mm) | 0.0012073 | 0.73061 | -0.7294 |
| Maximum Principle stress (MPa) | 3.9451 | 3.0546 | 0.8905 |
| Minimum shear stress (MPa) | 0.75935 | 0.2972 | 0.46215 |
| Equivalent Elastic Strain | 3.13E-05 | 0.021458 | -0.021426 |

## 5.5 CONCLUSIONS

From our experimental results and numerical analysis of HDPE composite material spur gear we can conclude that replacement of cast steel spur gear is possible with HDPE composite spur gear up to torque of 140N-m and speed of 2500Rpm. Strength of material is also good and it can be used as alternative for metallic gear as weight is reduced drastically. These results of conclusion are mentioned below:

- HDPE (84%) +carbon fiber powder (10%) + silicon carbide (6%) is best composition which can be used as spur gear alternative to cast steel spur gear.
- Weight for cast steel spur gear is 21kg but it is 1.5 kg for HDPE composite material.
- It can be used for torque of 140N-m and speed of 2500Rpm.
- It can be used for factor of safety of 3.

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## BIOGRAPHIES

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Sunil Pradhan is BE mechanical engineering graduate from VTU, Belgaum. His fields of interests are industrial engineering and material science.

Devaraj E. holds ME in machine design from Bangalore University and currently pursuing his PhD in composite material research in biomaterials. His fields of interest are machine design, material science.