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DESIGN AND STRESS STRAIN ANALYSIS OF COMPOSITE SPUR GEAR IN AUTOMOBILE

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ABSTRACT

To Design and draw a spur gear and Analyse the stress distribution of the cast steel and the composite material. Spur gear is one of the most commonly used component in power transmission between two parallel shafts, they are widely used in mechanical power transmission.Engineering components made of composite materials have find increasing applications ranging from space craft to small instruments. Overwhelming advantages such as higher dimensional stability, light weight, and minimal attack by environment when compared with other ordinary cast steel gears. Modern level advanced carbon composite materials have opened a new level of soundless, high resilience, lubricant free and precision gearing in power and motion transmission. A proper understanding and prediction of gear failure is an important pre-requisite for any reliable application. In this project, a spur gear is designed using advanced modelling software (Solidworks) and is meshed and analyzed using analysis software by the application of torque load. Finally, by comparing the analysis result of both composite spur gear and the existing cast steel spur gear.

KEYWORDS: Gear, cast steel, carbon fiber, epoxy resin, Ansys software, Solidworks design software.

INTRODUCTION

Overview of Gears: Gear is one of the most common component which is widely used mechanical power transmission system. A gear or cogwheel has a cut teeth or cogs which mesh with another cutted toothed part to transmit torque. Gears always produce a change in torque which gives a mechanical advantage of controlling the motion or torque, the change of the torque is controlled by their gear ratio. The tooth of the two mating gears should have same shapes ,if two or more meshing gears are working in a sequence then they are called gear train .a gear can also mesh a linear toothed part called rack. The gears are very effective in transmitting power from one shaft to another because of its high degree of reliability and compactness.

Now a days the gear technology are widely used in rapid shifts of industries such as automobile manufacturing, shipbuilding and other office works because of its high degree of precession. A gearbox is usually employed for the transmission system to reduce speed, increase speed, change the direction of the motion etc. a gearbox consist of a set of gears of various sizes, shafts and bearings that are mounted in a closed lubricated housing. The purpose of gearbox is to control the input give to it from the engine and give away the required power. In this analysis of the involute spur gears in gear box was studied using a nonlinear FEM.

Gears are called positive driver because they are toothed members which transmit torque and motion between two parallel shafts by meshing without any slip. In any pair of gear assembly the smaller gear is called pinion and the bigger one is called gear. When pinion is the driver we get a step down drive in which the output speed will be deceased

and the torque increases. On the other side, when the gear is the driver it results in step up drive in which the speed increases and the torque decreases. Basically the output speed and the torque is indirectly proportional to each other. Now a days the increase in demand for the power transmission in machines, vehicles, elevators and generators has created grown demand for more precise analysis of the characteristics of gear systems.

Spur Gear:

Fig 1: Spur gear

Spur Gears: - Spur gears are simple, easily manufactured gears and are usually the first choice when exploring gear options. Spur gear is of the simplest type of gear which is generally used for transmission of rotary motion between parallel shafts. Sometimes, many of the spur gears are used at once to create very large gear reductions. Spur gears are often used for speed reduction or increase, resolution, accuracy, torque multiplication and enhancement for positioning systems. The tooth of spur gear run parallel to the gear axis and can only transfer motion in between parallel-axis. Spur gears mate one tooth at a time, resulting in high stress on the mating teeth and noisy operation. This is because the spur gear is really loud. Each time a gear tooth engages a tooth on the other gear, the teeth collide, and this impact makes a noise. It also increases the stress development on the gear teeth.

To minimize the stress and noise in the gears, most of the gears in the car are helical**.** A spur gear is generally selected to have a gear ratio range between 1:1 and 1:6 with a pitch line velocity. The operating efficiency of spur gear is about 98-99%. The driving gear is made from a harder material than the wheel. A gear pair should be selected to have the highest number of teeth consistent with a suitable safety margin in strength. The minimum number of teeth on a gear with a normal pressure angle of 20 degrees is 18.

LITERATURE REVIEW
The gear stress analysis, the predictions of gear dynamic loads, the gear transmission error and the optimal design for gear sets are some of the major concerns in the gear design.

K. Mao, 2006 The polymer gear wear rate will be increased, when the load applied reaches a critical value for a specific geometry. The gear surface will wear slowly with a low specific wear rate if the gear is loaded below the critical one. The reason for the sudden increase in wear rate is due to the gear operating temperature when it reaches the material melting point under the critical load condition. The actual gear performance was completely dependent on the load.

R. Yakut, 2009 The load carrying capacity and the occurring damage of gears which are made of PC/ABS blends were studied. PC is a hard material whereas ABS is a soft material. PC and ABS polymers combine with each other, the PC/ABS blends have suitable mechanical properties for gear application. In this study the advantages of using PC/abs composite plastics material as spur gear was investigated. This PC/ABS polymer gears are tested by applying 3 different loads and at different numbers of revolutions on the FZG experiment.

K. Mao, 2007 The detailed analysis of the flash temperature of polymer composite gear and heat partition between gear tooth problems is treated as an unsteady one where the intensity distribution and velocity of the heat source changes as meshing proceeds. By assuming a numerical approximation is adopted using finite different methods and

the results are shown as close to those found using semi-analytical methods and by assuming no internal hysteresis and the material properties are constant.

J.L. Moya, A.S. Machado, 2007 We have performed a theoretical analysis of the procedure to determine the Lewis Factor and we have also performed the contact analysis of spur gear to find out the stress distribution between the gear teeth's.

V. Siva Prasad This paper depicts design and stress strain analysis of spur gear and it is proposed to substitute the metallic gears of sugarcane juice machine with polymer gears to reduce the noise and weight. A virtual model of spur gear was generated in PRO-E, Model is taken in ANSYS 10.0 for analysis by applying normal load condition. The main objective of this paper to analysis the different polymer gears namely nylon, polycarbonate and their viability checked with the counterpart metallic gear like cast iron. Concluding the study using the FEA methodology, it can be proved that the composite gears, if well designed and analysed, will give the useful properties like as a low cost, noise, Weight, vibration and perform its operation similar to the metallic gears. Based on the static analysis Nylon gear are suitable for the use of sugarcane juice machine under limited load condition in comparison with cast iron spur gears.

Design of Spur Gear

Module (M)
The module is the ratio between the pitch diameter to the number of teeth. The unit of the module is millimeters. Below is a diagram showing the relative size of teeth machined in a rack with module ranging from module values of 0.5 mm to 6 mm
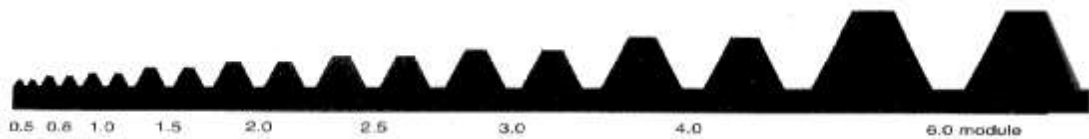

Fig 2: Module ranges

NORMAL PRESSURE ANGLE
An important variable affecting the geometry of the gear teeth is the normal pressure angle. This is generally standardized at 20º. Other pressure angles should be used only for special reasons and using considered judgment.
CONTACT RATIO
The gear design is such that when in mesh the rotating gears have more than one gear in contact and transferring the torque for some of the time. This property is called the contact ratio. This is a ratio of the length of the line-of-action to the base pitch.

Design Calculations and Specifications

Specifications
Model = Compact SUV
Engine = Top mounted intercooler, Intercooled, mHawk CRDe, 4 Stroke, Turbo charged, DI
Engine capacity =2179cc
Max. Gross power: 120 bhp (89 kW) @ 4000 rpM
Max. Gross torque: 290 N·m (210 lbf·ft) @ 1800-2800 rpm
Gear Box: 5 speed manual and 6 speed automatic
Front Brakes: Disc & Caliper type, Twinpod & Tandem booster (with anti-lock braking system)
Fuel tank capacity = 60 liters (13 imp gal; 16 US gal)
Tyres = P235/70 R16, Radial Tubeless
Rear Brakes: Drum Type
Front Brakes: Disc & Caliper type, Twinpod & Tandem booster (with anti-lock braking system)
Turning circle radius: 5.6 m (18 ft) for 2WD
Wheel base =105.5 in (2,680 mm)

Width = 71.5 in (1,816 mm)
Length =176.9 in (4,493 mm)
Height = 77.8 in (1,976 mm)
Curb weight = 5,534 lb. (2510kg) (2WD)

Calculations:
Torque (T) = 25.5kg-m @2500rpm
T = 25.5 kg-m
T = 25.5×10 N-m
T = 225 N-m
T = 2225000 N-mm
N = 2500 rpm.
Power (P) = 2×3.14×2500×T/60
P = 2×3.14×2500×225/60
P = 58875 Watt
Power (P) = 58.875 K Watt.
Torque (T) = F×(d/2)
Where,
F-load,
d- Pitch circle diameter (z×m=170mm)
T= F×(d/2)
F = T/ (d/2)
F = 255000/90
Load (F) = 2833.33N
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= 8.7413N/mm^2.
Ultimate tensile strength for cast steel = 540Mpa
Allowable stress for cast steel = ultimate tensile strength/3
　　　　　　　　= 540/3 = 180N/mm2> 8.7413N/mm^2
Allowable stress for composite = ultimate tensile strength/3
　　　　　　　　= 52/3 = 17.33N/mm2>8.7413N/mm^2
Ultimate tensile strength for the glass filled polyamide = 38.1Mpa
Allowable stress for composite = ultimate tensile strength/3
　　　　　　　　= 38.1/3 = 12.7N/mm^2>8.7413N/mm^2

So, the design is safe.

Calculations of Gear Tooth Properties

Pitch circle diameter (p.c.d) = z×m = 17×10 = 170mm
Base circle diameter (Db) = D cos α
　　　　　　= 170×cos20
　　　　　　= 159.745mm
Outside circle diameter = (z+2)×m= (17+2)×10 = 190mm
Clearance = circular pitch/20 = 31.4/20 = 1.57mm
Dedendum = Addendum + Clearance = 10+1.57 = 11.57mm
Module = D/Z = 170/17 = 10mm

Dedendum circle diameter = P.C.D -2×dedendum
$\qquad$ = 80-2×11.57= 156.86mm
Fillet radius = Circular pitch/8 = 31.4/8 = 3.9mm
Pitch circle diameter (Pc) = m×z = 10×21 = 210mm
Hole depth = 2.25×m = 2.25×10 = 22.5mm
Thickness of the tooth = 1.571×10 = 15.71mm
Face width (b) = 0.3×210= 63mm
Center distance between two gears = 210mm
Diametral pitch = Number of teeth/P.C.D
$\qquad$ = 17/170= 0.1mm

MATERIALS AND METHODS
Cast Steel
Cast steel is the first type of steel which allowed alloys to add to the iron. Prior to this method, manufacturers are unable to get steel hot enough to melt. By heating blister steel in a clay crucible which is placed directly into the fire, Huntsman allowed the metal to reach upto 2900°F (1600°C). Melting allowed other elements, such as nickel, to be mixed into the metal, thus strengthening the steel.
Cast steel has a harsh surface finish. It regularly has surface openings made by gas rising amid the warming procedure. A flexible metal, this kind of steel is extremely intense, having four times the elasticity of cast iron. Rigidity is the amount of weight made by pulling an article and can withstand before it breaks.
One concern when utilizing cast steel is whether the surface gaps stretch out into the inside of the metal. Assuming this is the case, these gaps could make shortcomings that influence the soundness of the steel. Measuring the volume of water that can be filled the openings will give a decent sign of whether the gaps reach out far into the metal.
Hardness
The hardness of cast steel differs relying upon the blend of carbon and different fixings. The heat levels utilized when blending the metal also influence the hardness of the completed metal item. Commonly, bring down levels of carbon and high compound substance come about a gentler metal. More elevated amounts of carbon with less included permits accomplishes a cast steel with more prominent hardness yet bring down yield quality, which is the adaptability of the metal.
Durability
Various tests are used to find out the strength and durability of cast steel before it begin to breakdown. These tests include drop tests, impact tests, fracture tests and tear tests. In this area low allow concentrations and high carbon are actually detrimental.
Ductility
The ductility of steel is the measurement of how much shaping or molding it can take and how small the sheets can become without breaking down. This determines largely by the material mixtures of the cast steel and how it is formed. In general, tempered or quenched steel has higher ductility levels and the ability to deform without breaking, than traditional annealed steel, which gives a softer metal.
Fatigue
The fatigue property of cast steel represent how much pressure and use the steel can take before breaking down. The fatigue property of cast steel shows its predicted life.

Properties of Cast Steel
Density = 7870 kg/m^3
Young modulus = 200 GPa
Poisson's ratio = 0.29
Tensile strength = 518.8 MPa
Ultimate Tensile Strength = 540 MPa
Yield Tensile Strength = 415 MPa
Bulk modulus = 140 GPa

Composite Material

The composite material can be characterized as a blend of two or a larger number of materials that outcomes in preferable properties over those of the individual segments utilized alone. Rather than metallic composites, every material holds its different substance, physical, and mechanical properties.

The two constituents are support and a framework. The primary favorable circumstances of composite materials are their high quality and solidness, consolidated with low thickness, when contrasted and mass materials, taking into account a weight lessening in the completed part.

The reinforcing stage gives the quality and firmness. By and large, the fortification is harder, more grounded, and stiffer than the grid. The reinforcement is typically a fiber or a particulate. Particulate composites have measurements that are roughly equivalent in all bearings. They might be round, platelets, or whatever other normal or unpredictable geometry. Particulate composites have a tendency to be much weaker and less firm than consistent fiber composites, however they are normally substantially less costly.

Carbon Fiber

The main reason for the reinforcement is to give better levels of quality and stiffness than the composite. In a consistent fiber-reinforced composite, the strands give basically the greater part of the quality and solidness. Indeed, even in molecule fortified composites, critical changes are gotten.

Carbon strands show direct stretch strain conduct to disappointment, the expansion in quality additionally implies an increment in the lengthening to-disappointment. The business strands consequently show extensions of up to 2.2%, which implies that they surpass the strain capacities of ordinary natural lattices.

Carbon strands are accessible from various residential and outside producers in an extensive variety of structures having an even more extensive scope of mechanical properties. The earliest industrially accessible carbon strands were delivered by thermal deterioration of rayon antecedent materials. The procedure included exceedingly controlled strides of thermal treatment and pressure to shape the fittingly requested carbon structure. Carbon filaments are additionally fabricated from pitch forerunner for forte applications. Pitch fiber properties ordinarily incorporate high modulus and thermal conductivity.

Fig 3: Carbon fiber

Epoxy Resin

Epoxy resins are frequently used in filament-wound composites and are also suitable for molding prepress. They are stable to chemical attacks and are excellent adherents having slow shrinkage during curing process and no emission of volatile gases. These advantages, however, make the use of epoxies rather expensive. Also, they cannot be expected beyond a temperature limit of 140ºC. They are use in high technology areas where service temperatures are higher, as a result, is ruled out. Epoxy-reinforced concrete and carbon-reinforced epoxy structures and glass-reinforced are used in bridge structures and building.

The applications for epoxy-based materials are broad and incorporate coatings, cements and composite materials, for example, those utilizing carbon fiber and fiberglass reinforcements. The science of epoxies and the scope of financially accessible varieties permit cure polymers to be created with an extremely expansive scope of properties. As a rule,

epoxies are known for their incredible bond, substance and thermal resistance, great to-fantastic mechanical properties and great electrical protecting properties.

Properties of Composites (50% Carbon Fibers in Epoxy Resin Matrix)
Density = 1800 kg/m³
Young modulus = 450 GPa
Poisson's ratio = 0.30
Tensile strength = 52 MPa
Compressive strength = 600 Mpa

Glass Filled Polyamide
Glass-filled polyamide, or glass-filled plastic, is a mouldable composite material. It contains short glass-strands in a matrix of a polymer material. It is utilized to fabricate an extensive variety of basic segments by injection or compression moulding.

Either thermoplastic or thermosetting polymers might be utilized. A standout amongst the most broadly utilized is nylon. The principal mouldable composite was Bakelite. This utilized wood flour filaments as a part of phenolic pitch. As the strands were just short this material had moderately low mass quality, yet at the same time enhanced surface hardness and great mouldability.

An extensive variety of polymers are presently created in glass-filled assortments, including polyamide (Nylon), acetal homopolymers and copolymers, polyester, polyphenylene oxide (PPO/Noryl), polycarbonate, polyethersulphone Mass embellishment compound is a pre-blended material of sap and strands supplied for trim. Some are thermoplastic or thermosetting, others are artificially cured and are blended with an impetus (polyester) or hardener (epoxy) before moulding.

Properties of Glass Filled Polyamide
Yield Strength: 5910 Mpa
Tensile Strength: 38.1 Mpa
Poisson's Ratio: 0.314
Mass Density: 840 Kg/m³
Shear Modulus: 3300 Mpa

RESULTS AND DISCUSSION
Static Structural Analysis
The static structural analysis calculates the stresses, displacements, strains, and forces in structures caused by loads that does not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that the loads and the structure's response are assumed to change slowly with respect to time. A static structural load can be performed using the ANSYS WORKBENCH solver. The types of loading that can be applied in a static analysis include:
   a. Steady-state inertial forces
   b. Temperature (for thermal strain)
   c. Externally applied forces and pressures
   d. Imposed displacements (nonzero)

Design software offers a scope of devices to empower the era of a complete advanced representation of the item being designed. Not withstanding the general geometry apparatuses there is additionally the capacity to produce geometry of other coordinated outline teaches, for example, mechanical and standard pipe work and finish wiring definitions. Apparatuses are likewise accessible to bolster community improvement. Various idea plan apparatuses that give in advance Modern Outline ideas can then be utilized as a part of the downstream procedure of building the item. These extent from applied Mechanical outline portrays, figuring out with point cloud information and exhaustive freestyle surface instruments. The spur Gear models are made by utilizing Solidworks programming. The models are demonstrated as follows.
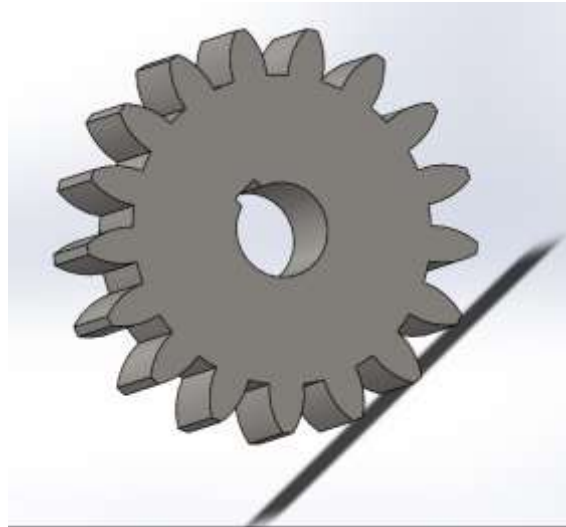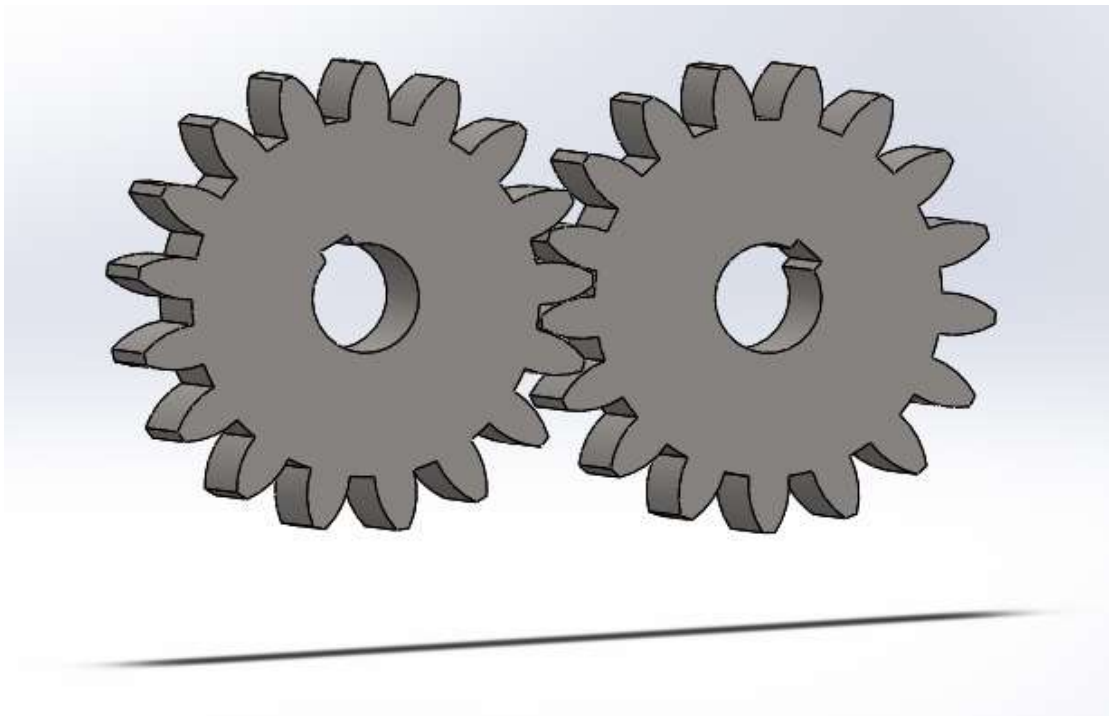
Fig 4: Spur Gear

Fig 5: Assembly of spur gear

Analysis Results of Spur Gear in different Materials

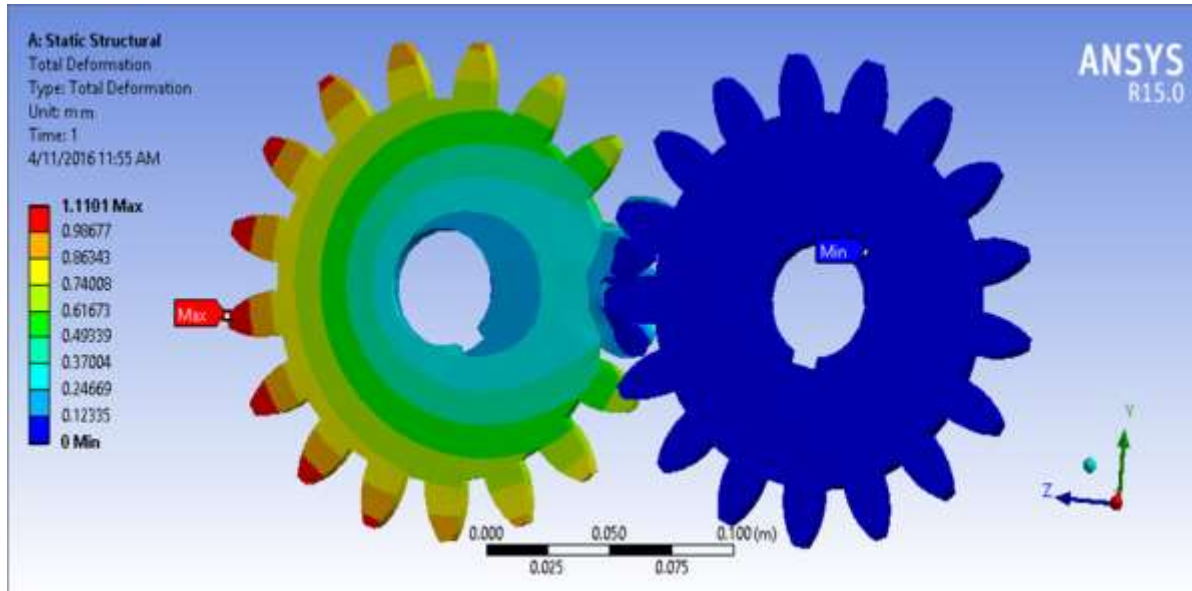Report of cast steel spur gear at TORQUE T=140 Nm
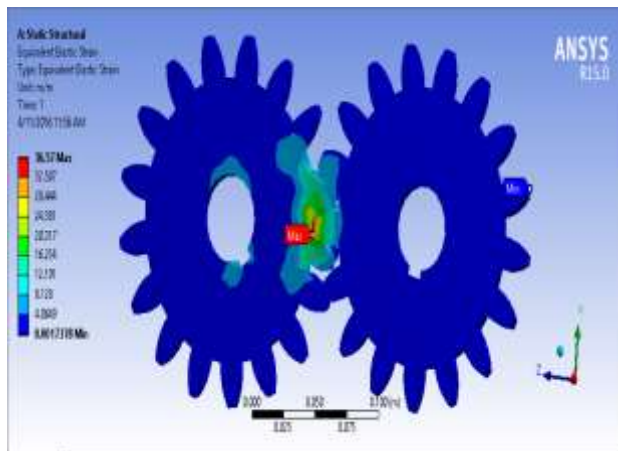

Fig 6: Total deformation in cast steel

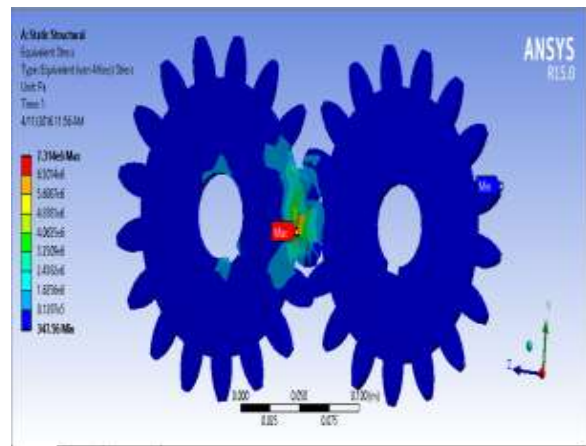*Fig 7: Equivalent Elastic Strain of cast steel*

Fig 8: Equivalent stress of cast steel

Analysis Results of composite material (carbon epoxy)
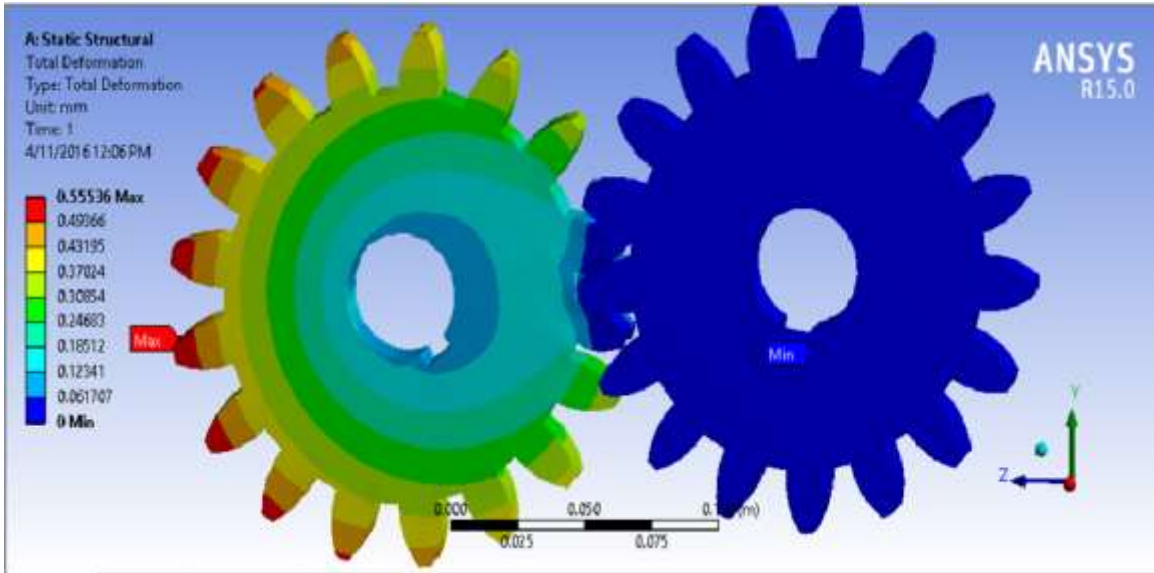
Report of cast steel spur gear at TORQUE T=140 Nm

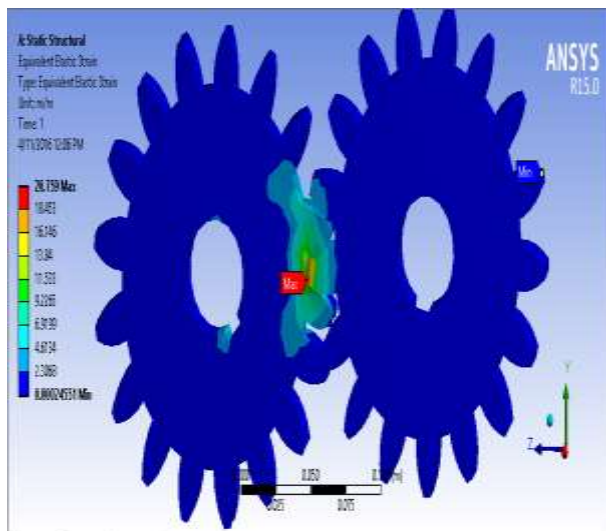*Fig 9: Total Deformation of carbon epoxy material*

Fig 10: Equivalent Elastic Strain of carbon epoxy   *Fig 11: Equivalent Stress of carbon epoxy*
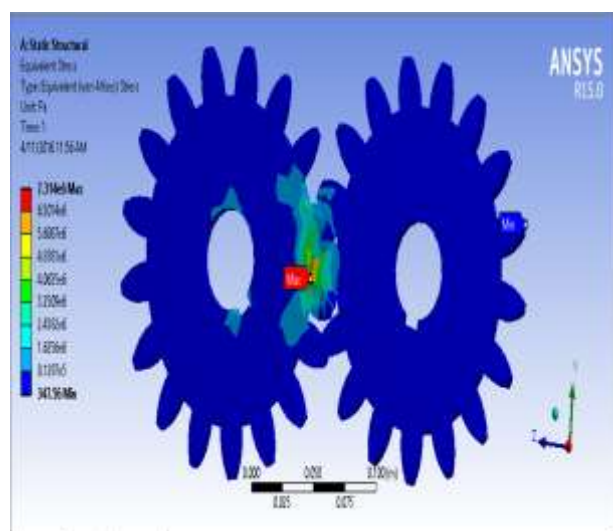
Analysis Results of composite material (Glass Filled Polyamide)

Report of cast steel spur gear at TORQUE T=140 Nm

Fig 12: Total Deformation in glass filled polyamide

Fig 13: Equivalent Elastic strain of glass filled polyamide   *Fig 14: Equivalent stress of glass filled polyamide*

Tables:

Table 1:. Comparison of various properties of the materials

	Cast steel		Composite (Carbon)		Difference
Torque (T)	140Nm	170Nm	140Nm	170Nm	
Total Deformation	1.1101	1.601	0.55536	1.122	0.55474
Equivalent Elastic strain	36.57	59.933	20.759	39.921	15.811
Equivalent Stress (von-Mises)	7.314e6	1.077e7	4.3417e6	9.413e6	2.973e6
Max Shear Elastic Strain	66.341	80.204	31.002	58.214	35.339
Max Shear Stress	8.471e6	9.122e6	5.368e6	6.101e6	3.103e6

Table 2:. Comparison of various properties of the materials

	Cast steel		Composite (GFP)		Difference
Torque (T)	140Nm	170Nm	140Nm	170Nm	
Total Deformation	1.1101	1.601	0.8269	1.324	0.2832
Equivalent Elastic strain	36.57	59.933	29.273	46.482	7.297
Equivalent Stress (von-Mises)	7.314e6	2.077e7	5.7818e6	1.013e7	1.5322e6
Max Shear Elastic Strain	66.341	80.204	44.346	69.682	21.339
Max Shear Stress	8.471e6	9.122e6	6.062e6	8.756e6	2.409e6

CONCLUSION

The literature survey of the composite gear was performed. The study in stress distribution and weight reduction of spur gear for composite materials and cast steel has been done.

On the basis of the study, the analysis of both composite materials and cast steel are analyzed in the application of gear box which is used in automobile vehicles. From these analysis we found the stress values for composite materials is less as compared to the cast steel spur gear.

So from the analysis results, we conclude that, the stress induced, deformation and weight of the composite spur gear is less as compared to the cast steel spur gear and followed by Glass filled polyamide. So, Composite materials are capable of using in automobile vehicle gear boxes instead of existing cast steel gears with better results.

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