

Contact Stress Analysis of Fly Ash/ Graphite Particulate Reinforced Aluminium Matrix Hybrid Composite Spur Gear

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ABSTRACT : Metal matrix composites (MMC's) are made by tailored a reinforcing material into a metal matrix. They are prepared by powder metallurgy and stir casting, although several technical challenges exist with casting technology. Achieving a homogeneous distribution of reinforcement within the matrix is one such challenge, and this affects directly on the properties and quality of composite.

The aluminum alloy composite materials consist of high strength, high stiffness, more thermal stability, more corrosion and wear resistance, and more fatigue life. Aluminum alloy materials found to be the best alternative with its unique capacity of designing the materials to give required properties.

In the present work a composite is developed by adding fly ash/graphite powder in Aluminum metal by weight ratio 5%, 10% and 15. The composite is prepared by stir casting route. Mechanical tests such as tensile test, hardness test, and microstructure test are conducted. It is proposed to use this material for power transmitting elements such as gears which are subjected to continuous loading. Finally modeling and finite element analysis of gear is done using Creo 2.0 and ANSYS 12.0 Work bench.

The contact stress in the mating gears is the key parameter in gear design. Deformation of the gear is also another key parameter which is to be considered. Gears generally fail when the working stress exceeds the maximum stress. This study shows that the complex design problem of spur gear which requires fine software skill for modeling and also for analyzing. The project aims at the minimization of both contact stress as well as deformation using the composite materials. The results of the two dimensional FEM analysis from ANSYS are presented. These stresses were compared with the theoretical Hertz's equation values. Both results agree very well. This indicates that the FEM model is accurate.

KEYWORDS: Al-Fa/Gr composite, Contact Stress Finite element analysis, MMC's, Spur gear, Stir casting.

I.INTRODUCTION

Aluminium based composites are combinations of materials. They are made up of combining two or more materials in such a way that the resulting materials have certain design properties or improved properties i.e. this materials are tailor made materials. Aluminium fly ash/graphite alloy composite materials are widely used for a many number of applications like automobile spare parts, aerospace structures, industry and so on

Sandeep Kumar et al [1] the author investigated mechanical and tribological properties of stir cast aluminium matrix composites containing single and multiple reinforcement. Addition of alumina to aluminium has shown increase in its mechanical and tribological properties. The industrial wastages like fly ash, coconut ash also improved the tensile and yield strength. N. Nanda Kumar al [2] studied the behavior of aluminium alloy based composites, reinforced with silicon carbide particles and graphite. The reinforcements in aluminium alloy increases the ultimate tensile strength. The micro structural studies revealed the fairly uniform distribution of the particles in both Al6061-SiC and Al6061-Graphite composites. T. Shoba Rani et al [3] the contact stresses of materials such as nylon, cast iron and polycarbonate. They observed that in order to get good efficiency, life and less noise cast iron gears can be replaced by nylon gears because of the fact that the deflection of cast iron is more than that of nylon. Abhay A Utpat et al [4] in this work metallic gears of steel alloy and Aluminium Silicon Carbide composite have been manufactured Composites provide

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much improved mechanical properties such as better strength to Weight ratio, more hardness, and hence less chances of failure. Gears manufactured from composite provides almost 60% less weight compared to steel gear, while power rating of both gears remains almost same. FE Analysis also shows less chances of failure in Al-SiC gear. Almost 3-4% difference has been observed between theoretical and FEA values of bending stress. Vivek Karaveer et al [5] investigated the contact stress analysis of spur gears and showed that the results of Hertz equation and FEA are comparable. The materials used in their study were, cast iron and steel. Moreover the contact stress was determined during the transmission of torque of 15000 lb-in or 1694.7725 Nm using finite element analyses. Dhavale A.S et al [6] paper explores when gear is subjected to load, high stresses developed at the root of the teeth, Due to these high stresses, possibility of fatigue failure at the root of teeth of spur gear increases. The moment of 15000 lb-in or 1694.7725N-m using finite element analyses. Putti Srinivasa Rao et al [7] studied the contact stress analysis of different materials such as aluminium, steel alloy and cast iron. The minimum contact stress was observed aluminium. The author validated the results both ansys and hertz theory.

II. EXPERIMENTAL

2.1 Materials:

Al was used as matrix material and fly ash/graphite particles were added as reinforcements to prepare composites in this study. The chemical composition of Al used as matrix material. To increase the wet ability of fly ash/graphite particles in the molten Al, wt. % of magnesium (Mg) was added to molten aluminum during casting. Coverall powder is added for removing the impurities in the molten metal .Fly ash particles of below 74 μ m and above 53 μ m and graphite particles are 74 μ m.

2.2 Preparation of composites:

Fly ash/graphite reinforced AMCs were prepared by stir casting process. Aluminium was melted in furnace and when the temperature of the liquid Al reached at 800°C, Mg was added in the melt. Heat treated fly ash/graphite particles were added in molten metal through funnel at 700°C.

Fly ash particles were preheated at 800°C for about 48 hours for the fly ash color was changed from dark grey to brownish due to the departure of un burn carbon content associated in the as received condition as shown in figure 1 (a) and (b). The fig(c) shows another reinforcement graphite powder.



Fig 1 (a) Before preheated fly ash

(b) After preheated fly ash

(c) Graphite powder.

Electrical resistance furnace assembled with graphite impeller used as stirrer was used for stirring purpose. After adding fly ash/graphite particles the liquid metal-reinforcements mixture was stirred for 10 minutes at an rpm of 600. Finally composites were poured in preheated metal die at 670°C. The melt was allowed to solidify in the mould. The composite samples are shown in fig 2(d).

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Fig 2 (a) Stir casting set up



(b) S.G. Iron die.



Fig (c) Pouring the molten metal into the S.G. Iron die



(d) AL-Fa/Gr composite samples.

2.3 Experimental Testing:

2.3.1 Microstructure:

Microstructures of the composites were observed to reveal the distribution of fly ash/graphite particles in Al matrix. Samples were polished using emery papers of different grades and then cloth polished with fine alumina powder on disk polishing machine. Microstructures were seen in an etched condition using optical microscope at 400X magnification. The composite shows the uniform distribution of reinforcement in the fig 3(a) & 3(b).

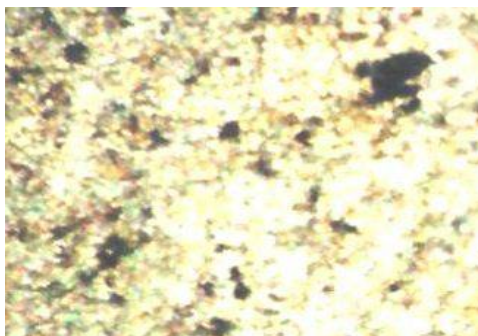
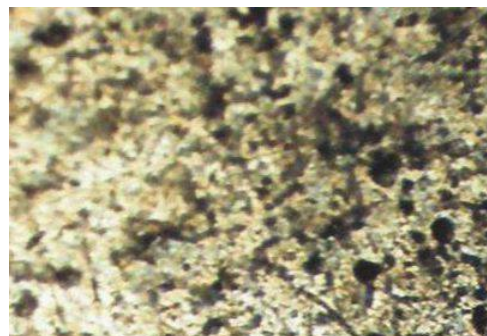


Fig 3 (a) 5% Al- Fa/gr composite



(b) 15% Al-Fa/gr composite.

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2.3.2 Hardness test:

Vickers hardness of the samples was determined using Banbros (Model: LV 700) Hardness tester. A diamond indenter was impressed on material at a load of 5 kg for 10 seconds. To avoid the segregation effect of the reinforcements in the matrix, four readings were taken for each sample. The hardness of the composite is increased with the reinforcement because adding the fly ash reinforcement the hardness is increased as shown in fig 4(a).

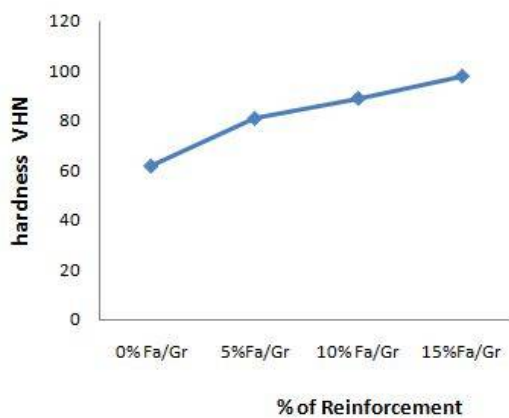


Fig 4 (a) Hardness of composites



(b) Banbros (Model: LV 700) Hardness tester.

2.3.3 Tensile test:

Tensile test was performed using universal testing machine. The test was conducted with strain rate of 2mm/min at room temperatures. Tensile test specimens were prepared as per ASTM E8 standards as shown in fig 5(a). The fractured tensile test specimens are shown in fig 5(b). The tensile strength is increased with percentage of reinforcement as shown in fig 5(c).



Fig 5 (a) Specimen for tensile test

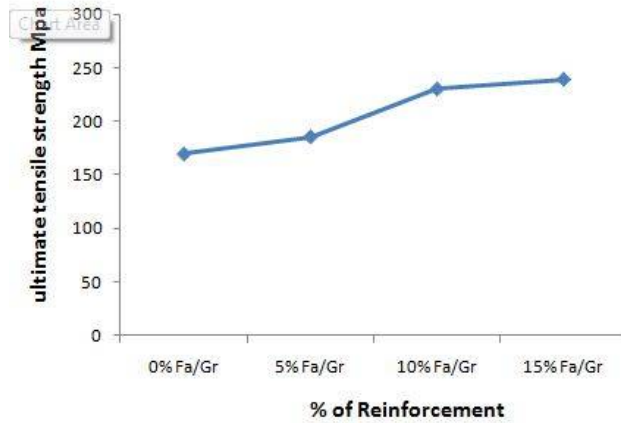


(b) Fractured tensile test specimens.

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(c) The variation of the tensile strength with the % of reinforcement.

2.3.4 Density:

Density is also a major factor influencing the selection of a material for any application. Density is defined as the mass per unit volume. Mass of the specimen was estimated by measuring the weight of the specimen using an electronic weighing machine having accuracy up to 0.001 mg. The density of the alloy and composites was measured by Archimedes principle using equation

$$MMC = \left(\frac{m}{m - m_1} \right) \times H_2O \tag{1}$$

Where MMC - the density of the Al-Fa/Gr composite
 m - Mass of the composite sample in air
 m₁ - mass of the same composite sample in distilled water and
 H₂O - density of distilled water-998 kg/m³

The measured density shows the density is decreased with the % of increase in reinforcement because the densities of the graphite and fly ash are less as compared to aluminium. The graph as shown in fig 6.

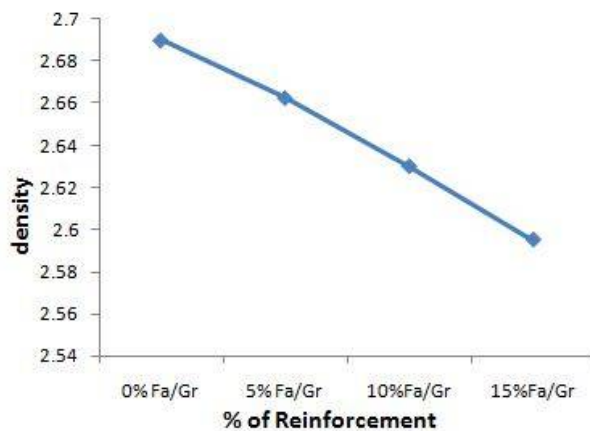


Fig 6 The variation of density with the % of reinforcement.

2.3.4 Poisson's ratio:

$$\text{Poisson's ratio: } \mu = (\mu_m \times V_m + \mu_f \times V_f) \tag{2}$$

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Where, μ, μ_m, μ_r – Poisson’s ratio of the composite, matrix and dispersed phase respectively; V_m, V_f – volume fraction of the matrix and dispersed phase respectively.

The poisons ratio is decreased with the % of reinforcement increased because the poisson’s ratio of the graphite and fly ash are less as compared to aluminium. The graph as shown in fig 7.

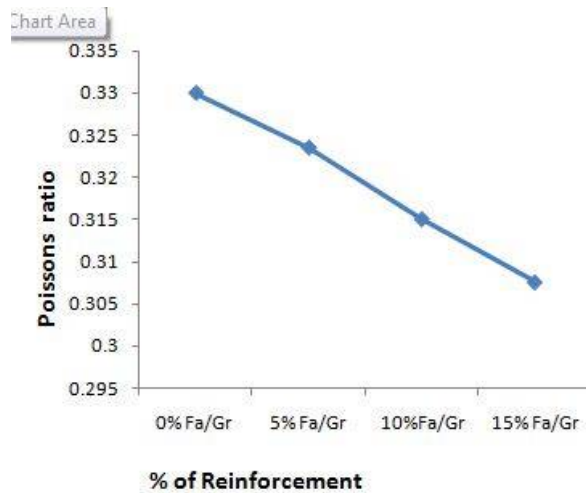


Fig 7 The variation of Poisson’s ratio with the % of reinforcement.

III. DESIGN OF SPUR GEAR

Lewis theory and Hertz theory have been derived to account for various factors which have influence on gear rating. Gear design engineering is not an exact science; it is a mixture of art and science. Two criterions have been considered for designing spur gear i.e. bending strength and contact stress. According to these two theoretical Formulas have been used for designing gears.

- a) Lewis Formula
- b) Hertz Theory

Lewis Formula is used for designing gear. Some of the equations used in design of gear are mentioned here.

3.1 Lewis theory:

$$\text{Torque } M_t = \frac{kW \times 60}{2\pi N} \tag{3}$$

$$\text{Design torque } [M_t] = k \times k_d \times M_t$$

$$\text{Module } (m) = \left\{ \frac{6000000}{\pi} \left[\frac{kW \times C_s \times FS}{Z_p \times N \times Y \times C_v \times \frac{S_{ut}}{3} \times \frac{b}{m}} \right] \right\}^{1/3} \tag{4}$$

$$\psi_m = \frac{b}{m}$$

C_s =Service factor

FS =Factor of safety

Y =Lewis form factor=0.308 (for 20° pressure angle)

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$$C_v = \text{Velocity factor} = \frac{3}{3 + v}$$

$$\text{Induced bending stress } (\sigma_b) = \frac{(i + 1) \times [M_t]}{C \times m \times b \times Y} \tag{5}$$

$$\text{Induced compressive stress } (\sigma_c) = 0.74 \left(\frac{i + 1}{c} \right) \sqrt{\frac{(i + 1) \times E \times [M_t]}{i \times b}} \tag{6}$$

$$\text{Check for module} = m \geq 1.26 \sqrt{\frac{[M_t]}{Y \times \sigma_b \times \psi_m \times Z_p}} \tag{7}$$

$$\text{Check for centre distance} = C \geq (i + 1) \sqrt[3]{\frac{0.74 \times E \times [M_t]}{\sigma_c \times i \times \psi}} \tag{8}$$

3.2 Input parameters:

Power (kW) = 10kW, Speed (N) = 1440 Rpm,
Gear ratio (i) = 1, Number of Teeth (Z) = 18, Pressure Angle (α) = 20 deg

3.2.1 Spur Gear Specifications

Dimensions	Unit	Symbol	Value (For both gears in assembly)
Module	mm	m	5
Addendum	mm	ha	5
Deddendum	mm	hf	6.25
Pitch Circle Diameter	mm	Dp	90
Pressure Angle	deg	α	20
Outer circle diameter	mm	Do	100
Base circle diameter	mm	Db	84.97
Face width	mm	b	27
Tooth thickness	mm	t	7.85

3.3 Theoretical Analysis of Contact Stress of Spur gear using Hertz Equation

PITTING is a surface failure caused by repetitions of high contact stress. The surface fatigue mechanism is not definitively understood. Pitting is generally appears on surfaces of gear teeth, a fundamental cause is excessive loading that raised contact stresses beyond critical levels.

Earle Buckingham (1926) used the Hertz theory to determine the contact stress between a pair of teeth while transmitting power by treating the pair of teeth in contact as cylinders of radii equal to the radii of curvature of the mating involutes at the pitch point. According to Hertz theory as given in , when two cylinders are pressed together, the contact stress is given by,

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$$\sigma_{co} = \frac{2P}{\pi BL}$$

$$\text{Where, } B = \sqrt{\frac{2P \left(\frac{1-\mu_1}{E_1} + \frac{1-\mu_2}{E_2} \right)}{\pi L \left(\frac{1}{d_1} + \frac{1}{d_2} \right)}}$$

Where,

σ_{co} = maximum value of contact stress (N/mm)

P = force pressing the two cylinders together (N)

B = half width of deformation (mm)

L = axial length of cylinders (mm)

d_1, d_2 = diameters of two cylinders (mm)

E_1, E_2 = young's modulus of two cylinder materials (N/mm²)

μ_1, μ_2 = poisson's ratio of the two cylinder materials

IV. FINITE ELEMENT ANALYSIS OF SPUR GEARS

Spur gear is modeled in Creo 2.0 as shown in fig 8. These have been imported into ANSYS 12.0 Workbench as IGES files format further analysis.. The proportions of gear obtained from theoretical analysis have been used for preparing geometric model of gear. The condition for analysis has been assumed as static. For FEA analysis of gear manufactured from composite Young's modulus is calculated from tensile test and Young's Modulus and Poisson's ratio for alloy steel have been taken from design data book. Poisons ratio and density of a composite material is isotropic and can be estimated using the rule-of-mixtures. The bulk modulus and shear modulus can be calculated following relations

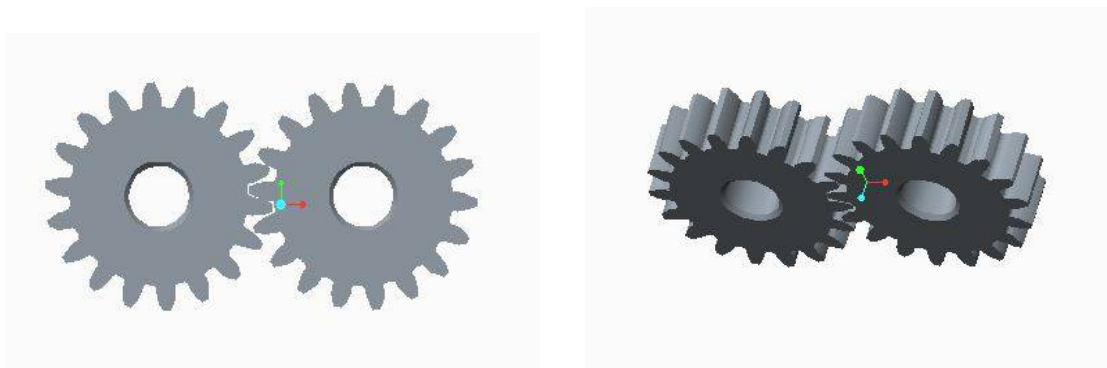


Fig 8 Spur gear modeled in Creo 2.0.

$$\text{Bulk modulus (K)} = \frac{E}{3(1-2\mu)}$$

$$\text{Shear modulus (G)} = \frac{E}{2(1+\mu)} \quad (11)$$

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4.1) Material properties of gear materials:

Material property	Alloy steel	Aluminium Alloy	Al-Fa/Gr composite
Young's modulus (Gpa)	210	80	119.06
Density (gm/cm ³)	7.870	2.69	2.60
Poisons ratio (μ)	0.3	0.33	0.3075
Ultimate tensile strength (N/mm ²)	200	156	238
Bulk modulus(Gpa)	140	78.43	143
Shear modulus(Gpa)	80.76	30.75	63.46

4.2) Stress analysis in ANSYS 12.0 Workbench:

5.2.1 Automatic Mesh Generation

Mesh generation is one of the most critical aspects of engineering simulation.. ANSYS Meshing technology provides a means to balance these requirements and obtain the right mesh for each simulation in the most automated way possible as shown in fig 9.

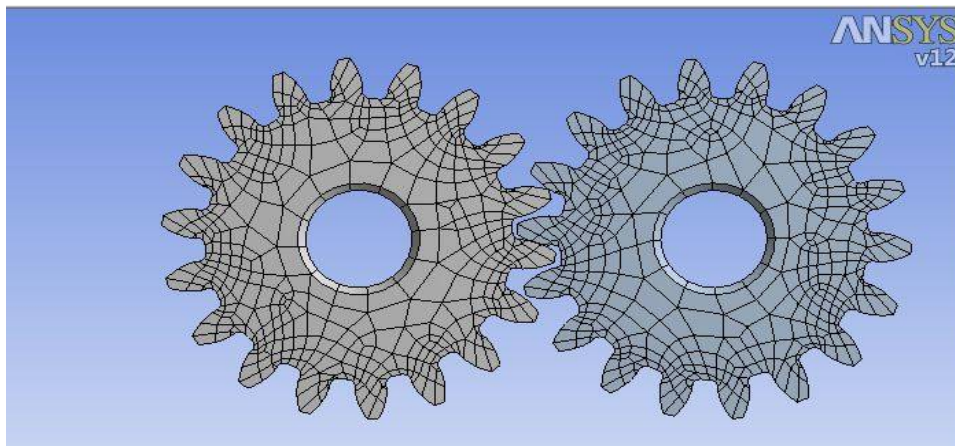


Fig 9 Meshing of Spur gears.

4.2.2 Stress Analysis in ANSYS Mechanical

Fixed support is applied on inner rim of the left gear. Frictionless support is applied on the inner rim of right gear to allow its tangential rotation but restrict from radial translation. Moment of 66314.56 N-mm is applied on the two faces of the rim in clockwise direction as a driving torque. The mating gear is created by translating a copy of the original copy of gear and by giving an interference which is equal to the center distance of the two mating gears. The loading conditions as shown in fig 10.

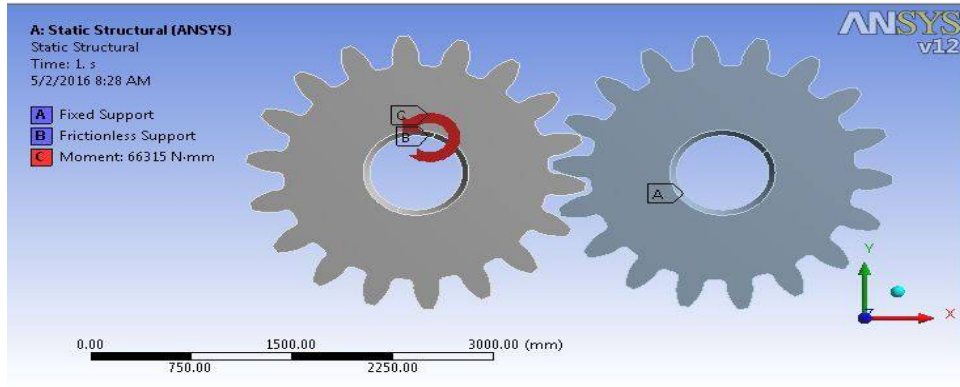


Fig 10 Supports and Loads applied on Spur gears.

4.3) ANSYS Results:

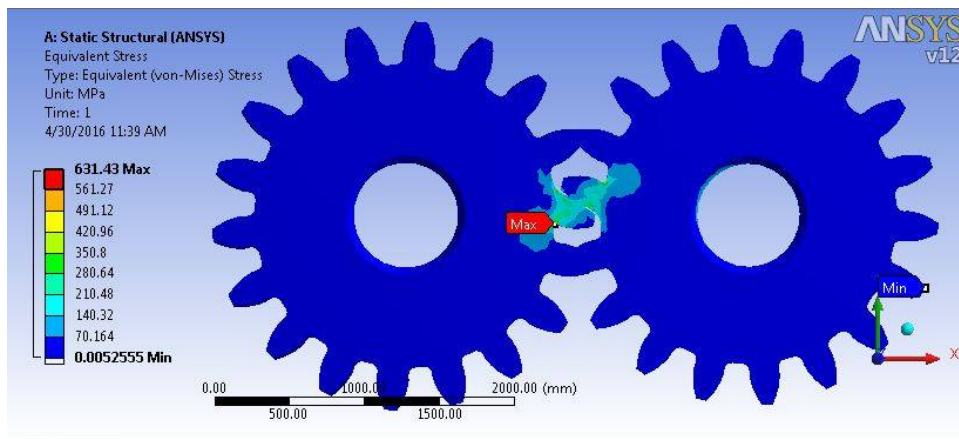


Fig 11 Von moises stress for Alloy steel Spur gear.

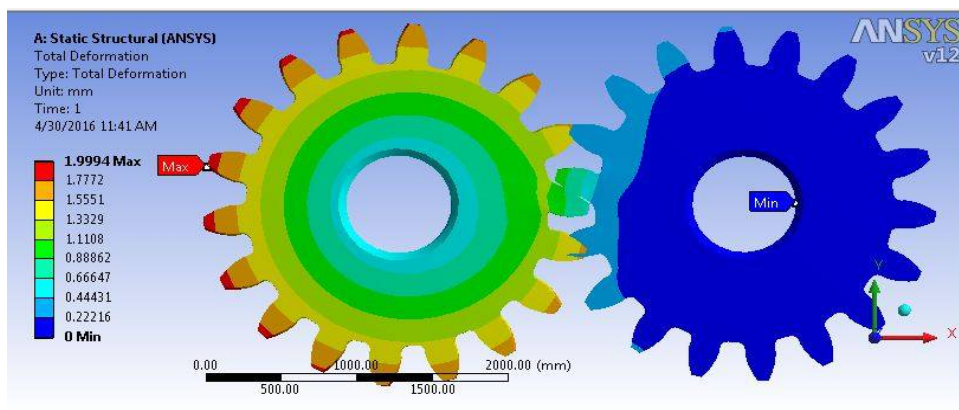


Fig 12 Deformation of Alloy Steel spur gear.

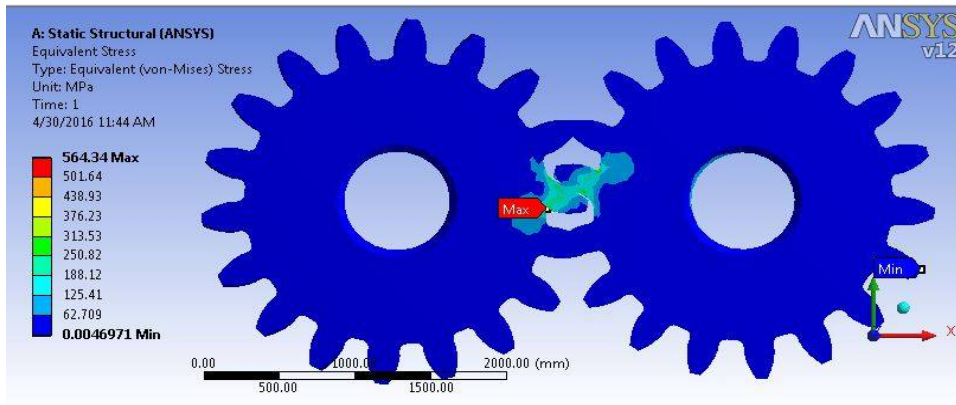


Fig 13 Von moises stress for aluminium Spur gear.

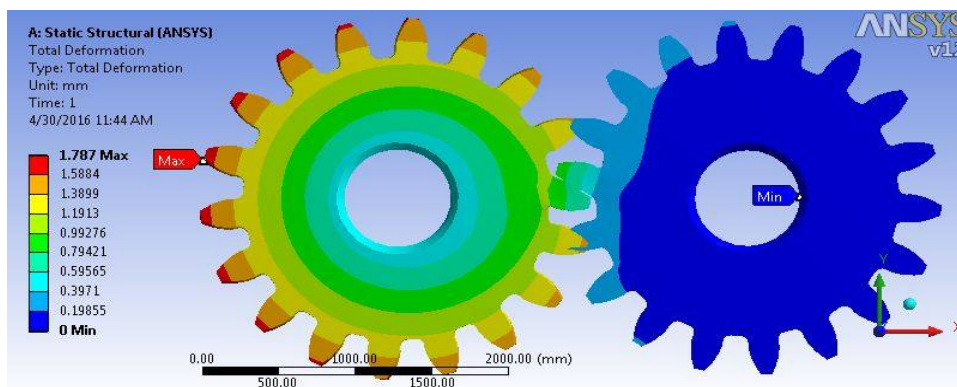


Fig 14 Deformation of Aluminium Spur gear.

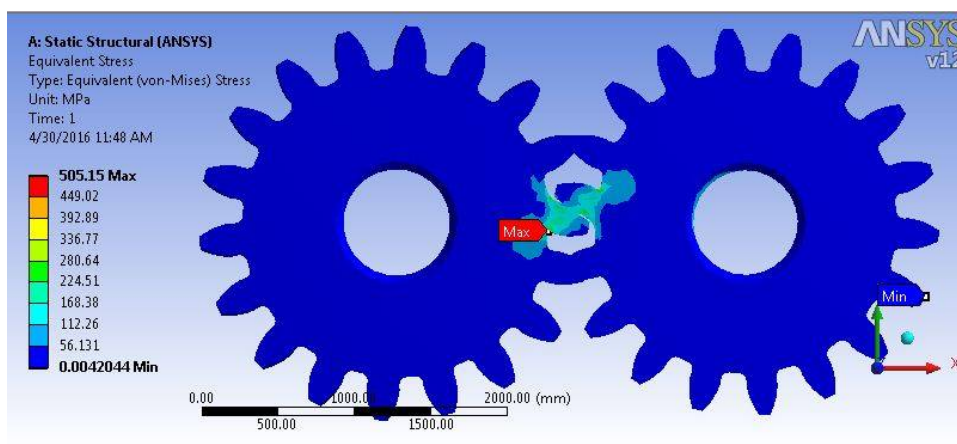


Fig 15 Von moises stress for Al-Fa\Gr composite Spur gear.

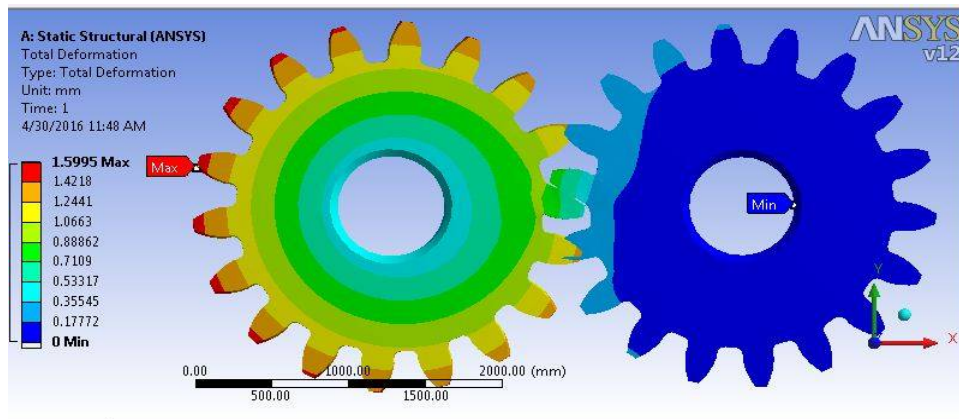


Fig 16 Deformation of Al- Fa/Gr composite Spur gear.

V.RESULTS

The use of composite materials in gear manufacturing provides a range of contact stresses. This range of contact stresses and deformation is useful in the selection of material in different applications. The use of different materials in gear manufacturing provides a range of contact stresses. This range of contact stresses and deformation is useful in the selection of material in different applications. The values obtained by Hertz's equation and Ansys agree with each other with a maximum error of 5% which is acceptable. It shows that the simulation done in ANSYS is compatible and copes up with the hertz equation for a range of materials used in the experiment. Aluminum composite on the other hand provides less contact stress when mated with any of the gears. The lowest contact stress is recorded when aluminum composite.

The Contact stresses from ANSYS and Hertz equation are tabulated as below.

Materials	Contact Stress (Mpa)		
	Hertz Theory	ANSYS	Error
Alloy Steel	604.17	631.43	4.31%
Aluminium	538.75	564.34	4.53%
Al-Fa/Gr composite	486.42	505.15	3.70%

VI.CONCLUSION

Fly ash\ graphite particulate reinforced aluminium matrix composite (AMCs) were prepared by stir-casting with different particle weight fractions 5%, 10%, and 15% the following conclusions can be drawn:

- Gears manufactured from composite provides almost 60% less weight compared to steel gear, while Power rating of both gears remains almost same.
- Hardness of Al-Fa/Gr is much better than the aluminum metal. In case of increased fly ash and graphite content, the hardness, and material toughness are enhanced and highest value is obtained at 15% fly ash and graphite content.
- The self lubrication property is enhanced using graphite powder. So wear rate is minimized.
- Tensile strength over base metal. Better results have been obtained at 15% fly ash and graphite is added

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- The contact stresses, deformations are minimum for composite material as compared to Alloy steel and aluminium.
- The contact stress values both hertz theory and Ansys results are agreed.

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- This work is dedicated to my son in law Harsha Venkata Naga Sai.

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