Design and Analysis of Straight Bevel Gears Under Static and Dynamic Loading

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Abstract : Gears are usually subjected to fluctuating loads, when gears undergo this type of loads then failure occurs in the gear tooth profile, this can be achieved by changing design parameters in the existing design (or) Exploring the alternative materials for gear manufacturing ,in this Research Work we have changed the Design Parameters and Materials of Gear, to improve Mechanical Properties such as better strength to stiffness ratio, high Hardness, and this work concerned with replacing Aluminium Alloy with aluminium Silicon Metal matrix composite material so as to improve performance of Machine and to have longer working life. Efforts have also been carried out for modelling and finite element analysis of gears using ANSYS 14.5. Gears are prone to failure under continuous running conditions. This kind of failure is based on dynamic characteristics such as unbalanced excitations and critical speeds. When the Gears are rotating at high speeds, their dimensions in length changes over time which causes high vibrations and results in rupture cracks and break down. To reduce the failure of the Gears, it needs in detail Roto-dynamic analysis.

***Index Terms* - Hardness, Aluminium Silicon Metal Matrix Composite, ANSYS 14.5, Roto-dynamic analysis**

I. INTRODUCTION

Gears are most efficient power transmitting device in automation industry. Gears are widely used to transmit the power and motion between parallel, intersecting and non-intersecting non parallel shaft [1]. A bevel gear is used for transmitting power at a Constant velocity ratio [2]. TATA 497 TCIC (Bharat Stage-IV) 4 Cylinder in line water cooled, turbo-intercooled common rail direct Injection engine. The pair of bevel gears are needed to be designed to transmit the required amount of torque at required speed. The entire Modelling of bevel gear is done in Solid Works 2017. Due to compact design and load transmitted at low speed, straight bevel gears are designed and bending stresses calculated using Lewis Bending Stress equation. The analytical result is compared with results obtained from ANSYS Workbench 14.5.

II.DESIGN OF BEVEL GEARS

Bevel gears are designed by calculating the required traction force to drive a TATA 497 TCIC (Bharat Stage-IV) 4 Cylinder in line water cooled, turbo-intercooled common rail direct Injection engine. To keep a system compact bevel gears are designed with minimum possible number of teeth. So that the required amount of power can be transmitted without compensating the size of system. Bevel gear is designed with 20º pressure angle. The various forces acting on the gears are calculated and eventually bending strength is determined. The analysis of bending stress in gear tooth is done by using Lewis equation [3]. Some of the equations used in straight bevel gear design are mentioned here

Nomenclature

σ_b - Bending Stress
P_t - Tangential Force
m - Module
b - Face Width
K_o - Overload Factor
K_m - Mounting Factor
J - Geometry Form Factor
K_v - Velocity Factor
S_b - Beam Strength
Y - Lewis Form Factor
A_o - Cone Distance
σ_m - Permissible Bending Stress

$$Pt = \frac{2*\pi*n1*Mt}{60}$$

$$\sigma b = \frac{Ft}{bmj} Ko\ Km\ Kv$$

$$Sb = mb\sigma mY\left[1 - \frac{b}{Ao}\right]$$

III. MATERIAL PROPERTIES

In this paper materials for gears are Aluminium Alloy and Aluminium Silicon Composite. It is a special Aluminium Silicon Composite with 25% Silicon and GBF slag is 18% [3] and [4]. Case-hardening process offers a means of enhancing the strength and wear properties of parts made from relatively inexpensive easily worked materials [5]. The treatments confer a high-hardness wear resistant surface also improve fatigue strength. As bevel gears are small in size and torque transmitted is comparatively high so to withstand case hardening process is needed. So strength and resistance to stress are the criteria for the selection of material

Table I Material Properties

Parameter	Value	Unit
Young's Modulus	138.40	MPA
Poisson's Ratio	0.3	
Ultimate Tensile Strength	710	MPA
Density	2.61	g/cc
Ultimate Compressive Strength	120.31	KN

IV.MODELLING OF GEAR

Gear model for numerical analysis have been prepared in Solid Works 2017 and these has been imported in ANSYS as IGS files for further analysis.

Table II Gear and Pinion Design Parameter

Parameter	Value	Unit
Power transmitted	90	KW
Speed	1800	Rpm
No.of teeth on Pinion	24	Nos.
Pitch circle diameter of pinion	90	mm
Module	3.75	mm
Pressure Angle	20	Degree

Fig. 1 Bevel Gear Model

V. FINITE ELEMENT MODEL

The 3-Dimensional solid model of is imported in ANSYS as STEP file and analysis is performed by finite element program ANSYS Workbench 14.5. Firstly, the 3-D solid model is assembly of two mating gear as shown in figure 1. The no of elements generated are 237774. The FE model of gear is shown in figure 2. The solid 186 is used for analysis of model. The solid 186 is structural solid element which consists of six stresses, normal as well as shear stresses.

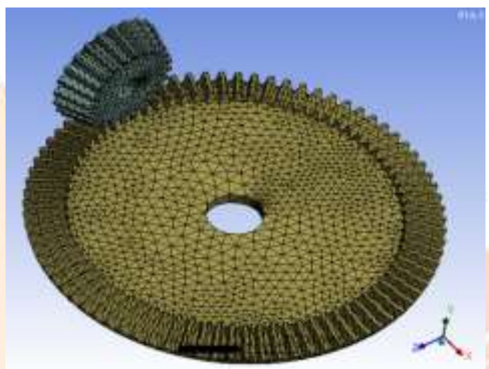

Fig. 2 Meshing of Gear Pair

5.2 LOADING AND BOUNDARY CONDITIONS

The load is applied in the form of moment. The moment of 10610.32954 N in static condition and in Dynamic Condition Speed is given as 1800rpm applied on the two faces of the pinion. The frictionless support is applied on the bore of pinion and gear. Frictionless support places a normal constraint on an entire surface. Translational displacement is allowed in all directions except in and out of the supported plane.

These loading conditions are given from Design of Machine Elements V.B.Bhandari

Table III Load at Under Static Condition

Speed at	Load in N
1800	10610.32954
3600	5305.164
5400	3536.776
7200	2652.5823

Table IV Speed at Under Dynamic Condition

Number of Stages	Speed in Rpm
First Stage	1800
Second Stage	3600
Third Stage	5400
Final Stage	7200

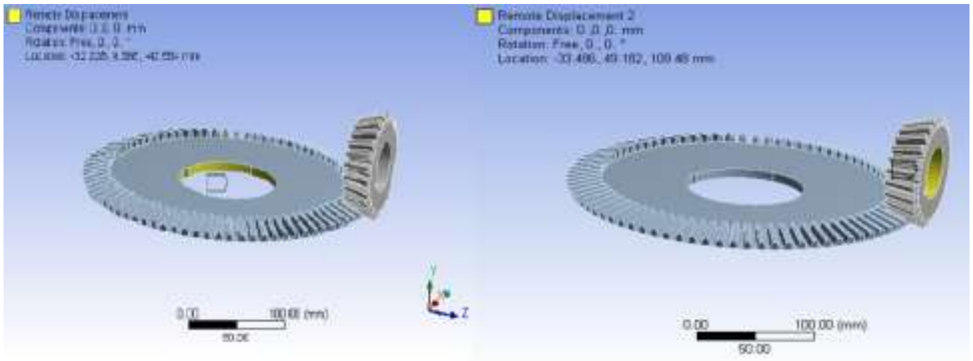

Fig. 3 Frictionless Support on the bore

VII.RESULTS AND DISCUSSION:

5.1 Hardness Test:

Metal Matrix Composite is Produced by using Stir Casting Technique and Hardness value is found by using Micro-Vickers Hardness Tester and Test Piece is Prepared as per ASTM STANDRS ASTMISO2811 test specimen and setup shown in below figure 4& 5.

Fig4. Vickers Hardness Setup

Fig5. Test Specimen

Gear materials must have high harness and low in weight and then life time of gears will increases .when compared with aluminium Hardness value is 56 HV but when Al-Si Composite is Having 80.32 HV so, It is Good Material to use in place of Aluminium, Al-Si Reinforced with GBF Slag which are in the Ratio of 100:18

The equivalents stress plot, deformation plot have been obtained. Figure 6 shows the equivalent stress contour plot. It manifests that the maximum stress after the loading occurs near the root of the teeth and it is approximately 100.82 MPA.

5.2 Static Condition Analysis: when Component under Static we have found there is some Stress are Produced which are Stated in Below

For Composite Material Al-Sic at Different loads in N

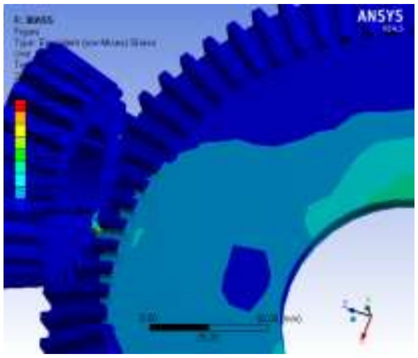

Fig 7.Equivalent Stress at Load is 10610.32954 N

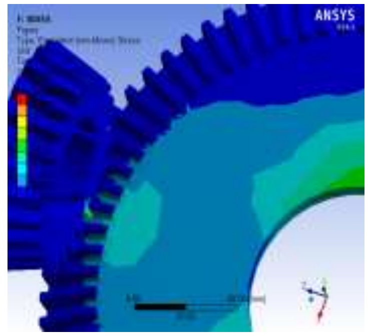

Fig 6.Equivalent Stress at Load is 5305.16474 N

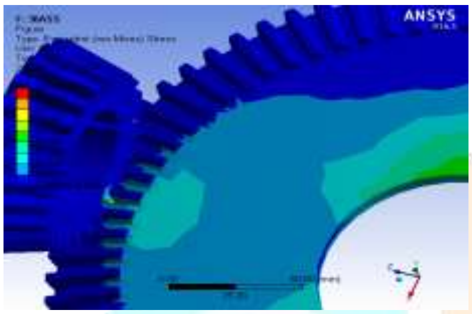

Fig8. Equivalent Stress at Load is 3536.776513 N

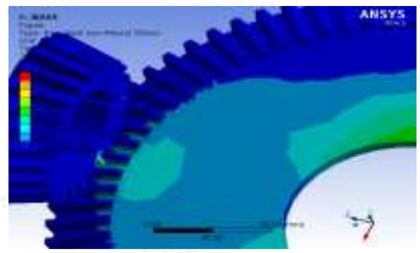

Fig9. Equivalent Stress at Load is 2652.582385 N

Table V: Static Condition Results for Equivalent Stress in MPA

Load in N	Materials	Numerical Value MPA	Analytical Value MPA	% Variation
10610.32954	Al	100.82	102.35	1.156
	Al-Si Composite	76.107	78.2	2.676
5305.164	Al	50.41	52.102	3.24
	Al-Si Composite	34.853	35.903	2.924
3536.776	Al	33.687	36.206	2.968
	Al-Si Composite	23.235	24.321	4.46
2652.5823	Al	25.205	26.30	3.30
	Al-Si Composite	15.49	16	3.18

5.3 Total Deformation: Deformation of a component before failure in analysis part Al-sic is Improved over Aluminium For Composite Material Al-Si

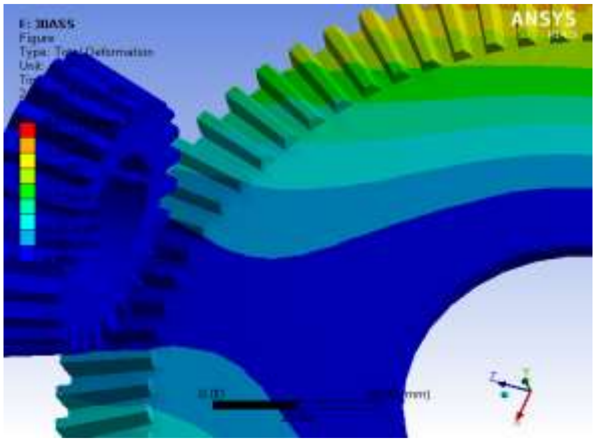

Fig 10. Total Deformation at Load is 10610.32954 N

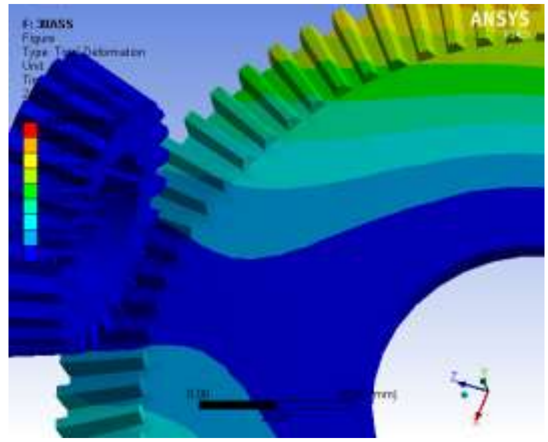

Fig 11. Total Deformation at Load is 5305.16474 N

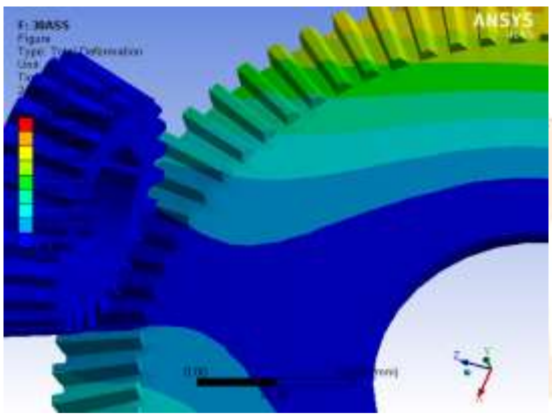

Fig 12. Total Deformation at Load is 3536.776513 N

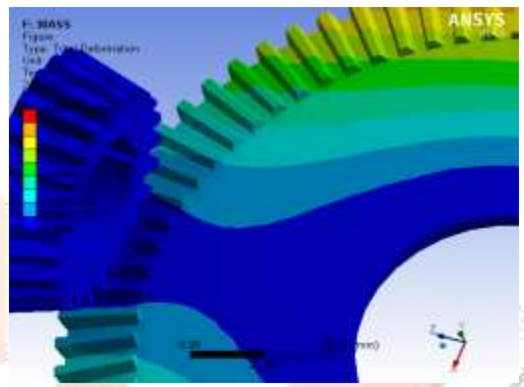

Fig 13. Total Deformation at Load is 2652.582385 N

Table VI: Static Condition Results for Total Deformation mm

Load in N	Materials	Analytical Value mm
10610.32954	Al	0.32377
	Al-Si Composite	0.23725
5305.164	Al	0.16189
	Al-Si Composite	0.091589
3536.776	Al	0.10793
	Al-Si Composite	0.061059
2652.5823	Al	0.080945
	Al-Si Composite	0.040706

5.4 Modal Analysis in Static Condition: Components Natural Frequencies are Stated in Below Table vii & viii

5.4.1 for Aluminium Material:

Table VII Modal Analysis for Aluminium

S.no	No.of Modes	Natural Frequencies in Hz
1	1	464.47
2	2	558.84
3	3	662.67
4	4	738.84
5	5	970.14
6	6	1188.7

5.4.2 for Al-Si Composite:

Table VIII Modal Analysis for Aluminium

S.no	No.of Modes	Natural Frequencies in Hz
1	1	664.133
2	2	720.65
3	3	860.18
4	4	1060.598
5	5	1263.59
6	6	1450.62

5.5 Dynamic Condition Analysis:

The equivalents stress plot, deformation plot have been obtained. Figure 3 shows the equivalent stress contour plot. It manifests that the maximum stress after the loading occurs near the root of the teeth and it is approximately 52.0 MPA

When gears in Dynamic condition we need to provide a Rotational Speed in RPM according to TATA 497 TCIC (Bharat Stage-IV) 4 Cylinder in line water cooled, turbo-intercooled common rail direct Injection engine running at starting speed is 1800RPM. But, a part from this engine will runs as four times higher than it is equal to 7200 RPM, Results are drawn for this different Condition Speeds.

When compared with Aluminium ,Composite Material Al-Si Equivalent Stress Mpa are Decreased as stated in Table IX ,Total Deformation Values in mm are also Decreased as Stated in Table X and Modal Analysis Results also Improved over Aluminium Material.

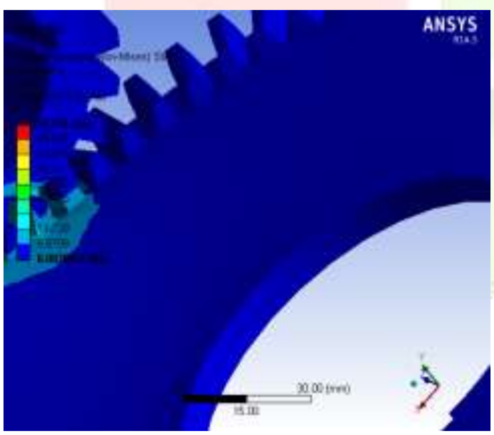

Fig 14.Equivalent Stress at Speed is 1800 RPM

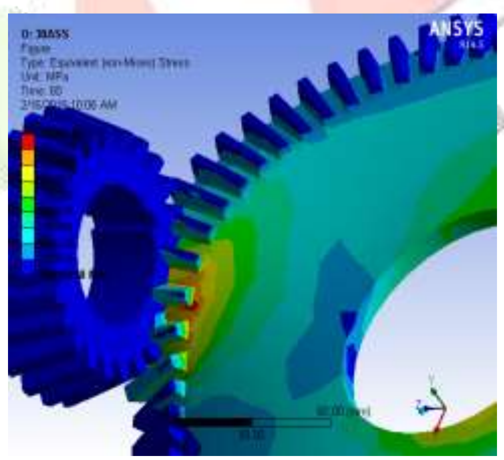

Fig 15.Equivalent Stress at Speed is 3600 RPM

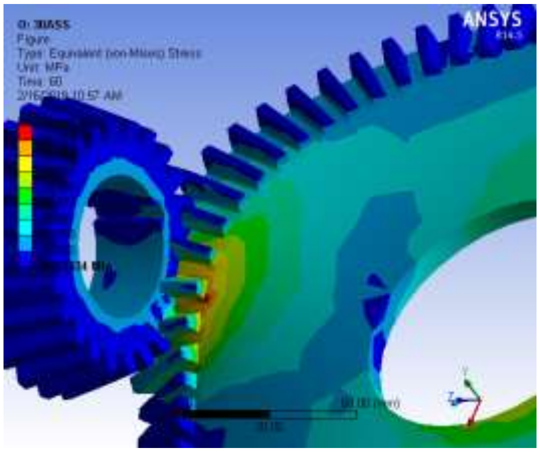

Fig 16.Equivalent Stress at Speed is 5400 RPM

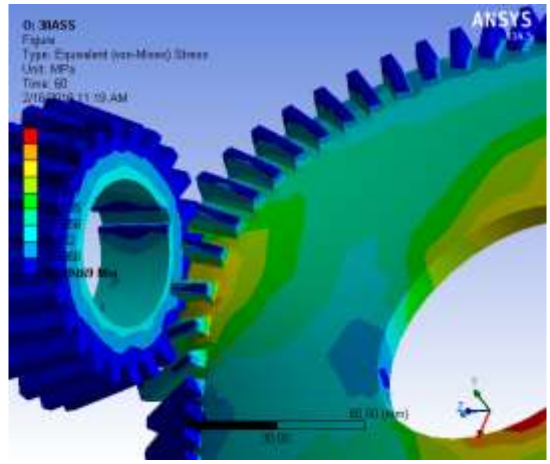

Fig 17.Equivalent Stress at Speed is 7200 RPM

Table IX: Dynamic Condition Results for Equivalent Stress in MPA

Speed in RPM	Materials	Numerical Value MPA
1800	Al	98.283
	Al-Si Composite	52.0
3600	Al	54.292
	Al-Si Composite	32.87
5400	Al	51.506
	Al-Si Composite	32.535
7200	Al	46.165
	Al-Si Composite	34.916

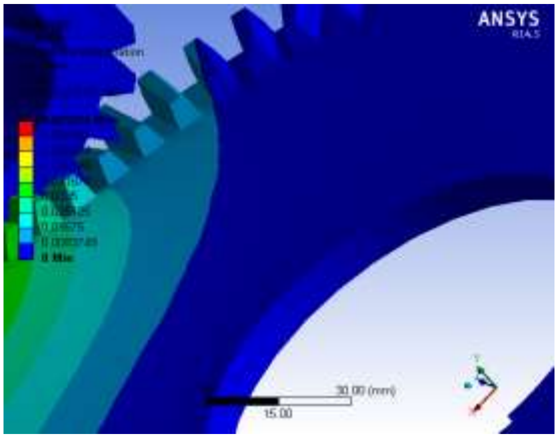

Fig 18. Total Deformation at Speed is 1800 RPM

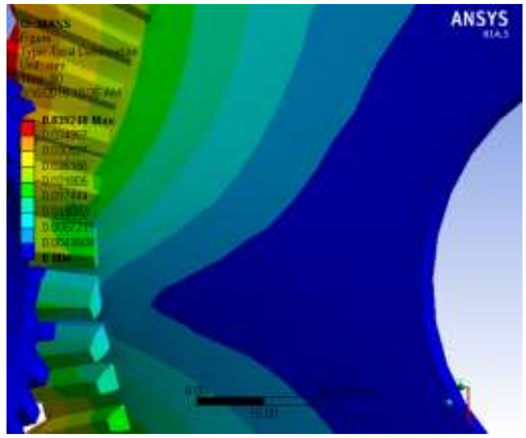

Fig 19. Total Deformation at Speed is 3600 RPM

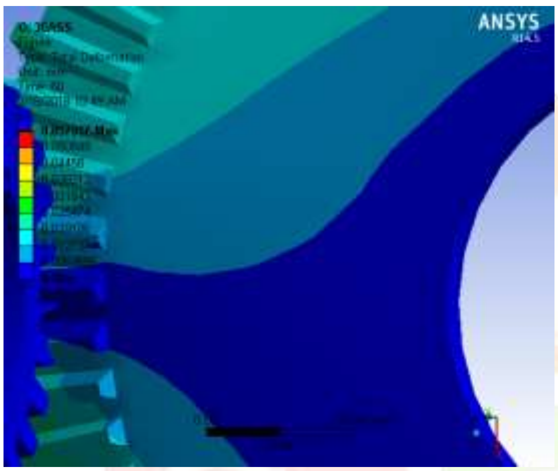

Fig 20. Total Deformation at Speed is 5400 RPM

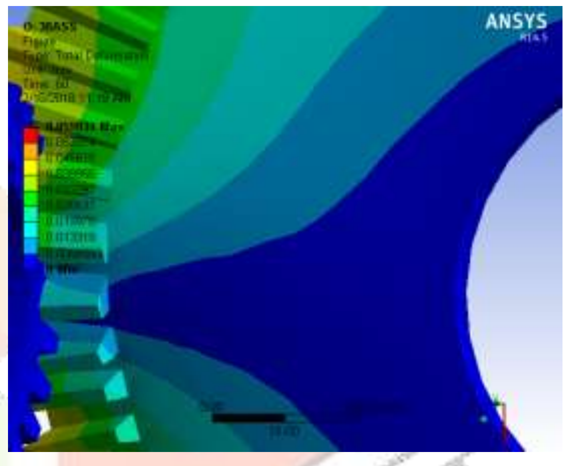

Fig 21. Total Deformation at Speed is 7200 RPM

Table X: Static Condition Results for Total Deformation mm

Speed in RPM	Materials	Numerical Value mm
1800	Al	0.1597
	Al-Si Composite	0.075374
3600	Al	0.093968
	Al-Si Composite	0.039248
5400	Al	0.064797
	Al-Si Composite	0.057317
7200	Al	0.096818

	Al-Si Composite	0.059934

5.6 Roto Dynamic Analysis (Modal Analysis):

In case the lateral or torsional natural frequency (lateral critical speed / torsional critical speed) of rotor system coincides with the frequency of such excitation force, excessive lateral or torsional vibration will result due to resonance, which may severely disturb plant operation or may lead to machinery damage. When gear undergo this type of phenomenon gears will be damage to restrain the life time of gear we will undergo Roto Dynamic Analysis during this amplitude produced is 8 mm

Table XI Modal Analysis for Aluminium

S.no	No.of Modes	Natural Frequencies in Hz
1	1	600.98
2	2	991.84
3	3	1511.8
4	4	28977
5	5	4339.8
6	6	5022.9

Table XII Modal Analysis for Al-Si Composite

S.no	No.of Modes	Natural Frequencies in Hz
1	1	1854
2	2	2654.5
3	3	3681.7
4	4	4682.5
5	5	5525.6
6	6	6159.9

VIII Conclusions:

1. In the present work, static structural analysis for bending strength by ANSYS Workbench has been done and the equivalent stress, total deformation and equivalent strain plots obtained. F.E. Analysis manifests minimum chance of gear failure. Also 1-5% variation has been observed between analytical and numerical bending stress value. The gear pair can be used to transmit the 90KW power without failure of gear and with good factor of safety.
2. Dynamic Analysis Condition also Al-Si Composite Gears are safe when compared with Aluminium Gears Because Of Stress values are reduced in Al-Si Composite Gears.
3. Hardness Value of Aluminium is 56HV, but for Al-Si Composite is 80.32 HV is high.
4. Modal Analysis (Natural Frequencies HZ) Values in static and dynamic condition are improved.

Ix. Acknowledgment:

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