Finite Element Analysis of the Stresses in a Spur Gear in Lathe machine operations.

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ABSTRACT
Generally high stresses are developed at the mating positions of the gear teeth while transmitting the power as they adapt the rate of rotation of machine shaft. The optimal medium for low energy loss and high accuracy is the axis of rotation for high speed machinery. To transmit the power with high velocity ratio spur gears are used. The research work is mostly attempted on mathematical bending stress analysis and compared with finite element analysis. The purpose of this paper is to identify the magnitude of the stresses for a spur gear used in lathe machine while transmitting power for operations such as drilling, tapping and turning. Various case studies are performed. For simulation we used FEA tools such Hypermesh, Abacus. Before going for FEA and Experimental we went through analytical calculations. The stresses are observed by experimentally and compared with the results of FEA.

Keywords: — Stresses, Photo elasticity, FEA, Gear.

1. INTRODUCTION
Gears have the extensive range of industrial applications. They have varied application from different sectors of industries. They are the most conventional means of transmitting power. Gears are capable to change the rate of rotation of machinery shaft and similarly the axis of rotation as well. Gears are the optimal medium for low energy loss and high accuracy in a high speed machinery, such as an automobile power transmission. The prime function of the gears is to convert input provided by prime mover into an output with lower speed and corresponding higher torque. To transmit the power with high velocity ratio typical toothed gears are used. During this phase, they run across high stress at the point of contact. A pair of teeth in action is generally put through to two types of cyclic stresses:

i) Bending stresses in bringing on bending fatigue

ii) Contact stress creating the contact fatigue.

Maximum values of both these types of stresses may not be at the same point of contact. Combined action of both of them is the reason resulting the failure of gear tooth leading to fracture at the root of a tooth under bending fatigue and surface failure, due to contact fatigue. There is elastically surfaces deformation is observed near the point of contact when loads are applied to the bodies. Fig.1 shows Stresses developed due to Normal force in a photo-elastic model of gear tooth. The highest stresses are experienced at that region where the lines are grouped closest together. The highest stress are observed at two locations:

A. At Force F acting at contact point

B. At the base of the tooth near the fillet region

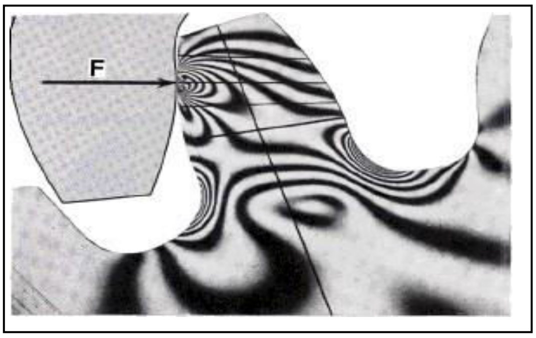

Figure 1 Photo-elastic Model of gear tooth

Pitting and scoring are the surface failures occur certainly due to contact fatigue. In this term a very small material is removed from the tooth surface because of the high contact stresses exist between mating teeth. Pitting is indeed the fatigue failure of the tooth surface. The primary property of the gear tooth which provides resistance to pitting is hardness. So basically pitting can be defined in general terms is a surface fatigue failure due to many repetitions of high contact stress, which occurs on gear tooth surfaces when a pair of teeth is transmitting power. Gear teeth failure due to contact fatigue is a common circumstance observed.

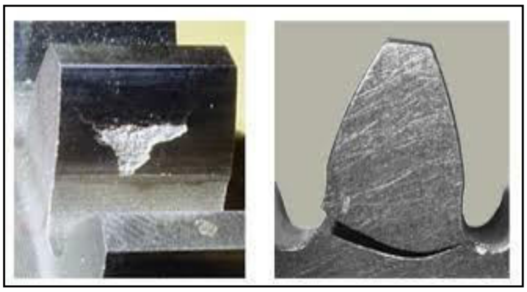

Figure 2 failures of teeth

2. NUMERICAL DATA

Spur Gear Selection

The standard dimensions of the gear are referred from Bhavya lathe machine catalogue book.

Table 1 Standard gear dimensions

Sr. No.	Description	Symbol	Values Gear
1	Number of teeth on Gear	Tg	56
2	Pressure Angle	-	20°
3	Module	M	3
4	Pitch Circle Diameter (mm)	D	168
5	Face width (mm)	W	30
6	Bore Diameter (mm)	-	30

Analytical Calculation

We have considered cases in lathe machine are Drilling, Tapping, and Turning etc. operations are to be performed. So for these operations power, torque, force to be generated. The spur gear is mounted same as the spindle shaft. We have to be calculating the generated forces for these operations. For all operations consider the work material is cast iron. All formulas and values are selected from design data handbook.

Scaling of Tooth

We considered only single tooth of spur gear. In actual gear the size of tooth is small. So for the experimental testing photo elasticity purpose making a prototype of actual sized spur gear tooth. Face width keeping same and all other parameters are multiplied by 4.44. Also calculated the forces on prototype by formula

$\sigma_{(model)} = \sigma_{(Prototype)}$

$\sigma_{actual} = (force/area)_{actual}$

$\sigma_{prototype} = (force/area)_{prototype}$

$Force_{(Prototype)} = \sigma_{(model)} * area_{(prototype)}$

Area of actual = l*h (of projected area)
=30mm*6.75mm
$=202.5mm^2$

Area of prototype = l*h
=30mm*30mm
$=900mm^2$

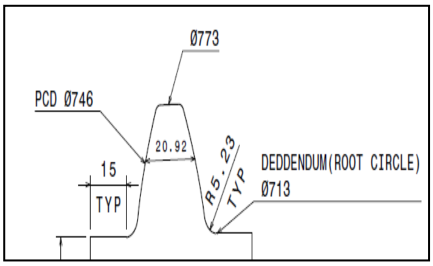

Figure 3 Scaling of spur gear tooth drawing

Sr. No.	Operation	Force (model) (N)	Force(Prototype) (N)
1	Drilling Dia = 18.5	259.17	1151.86
2	Drilling Dia = 18	225.31	1001.37
3	Tapering Dia = 19	168.11	747.15
4	Tapering Dia = 17	150.60	669.33
5	Turning DC = 0.5	71.21	316.48

Table 2 Forces on model & prototype

3 FINITE ELEMENT ANALYSIS

Finite Element Analysis is a simulation technique which estimates the behavior of components and structures for various loading conditions including applied forces, pressures and different boundary conditions. A complex engineering problem with non-standard shape and geometry can be resolved using finite element analysis where a closed form solution is not available. The finite element analysis method provides quantitative as well as qualitative results of stress distribution, displacement and reaction loads at supports etc. for the subject.

CAD Modeling

3D modeling of the gears is done by using Catia V5R20 software, which is mostly used for the purpose of modeling. We considered only single tooth of spur gear. In actual gear, the size of tooth is small. So for the experimental testing we considered a prototype of actual sized spur gear tooth. Modeling of gear is done by using the parameters mentioned in the table 1 and from figure 3 Scaling of spur gear tooth drawing.

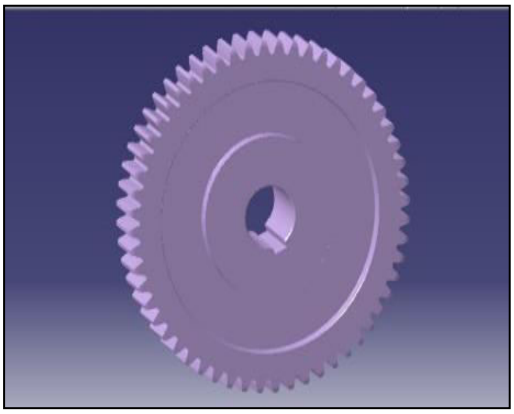

Figure 4.Cad Model of Gear

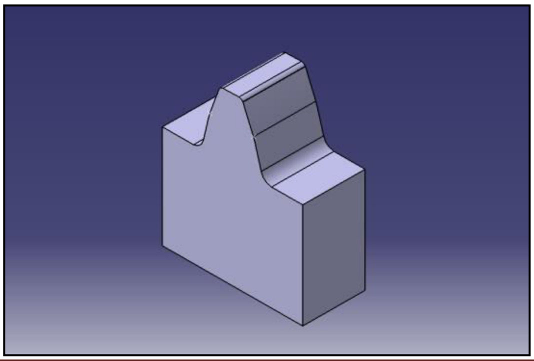

Figure 5 Cad Model prototype of tooth

Pre-processing

In pre-processing the meshing of the model is been carried out using HYPERMESH

13.0. The model is imported from the Catia V5R20 software in the .igs format. The element size for prototype of tooth is kept as 1mm as we require fine mesh for the accurate results. We have maintained tetra collapse quality check for 0.3 solid elements.
Element Type Used

We have used solid tetra elements for meshing. Element type used is c3d10 for abaqus profile.
Following are the images showing how we carried meshing of component of gear tooth.

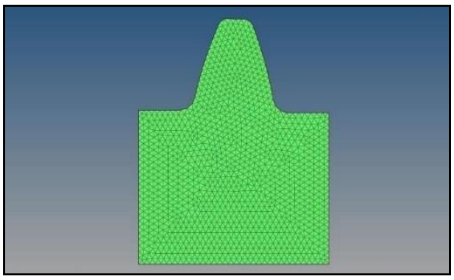

Figure 6 Tetra meshing of tooth

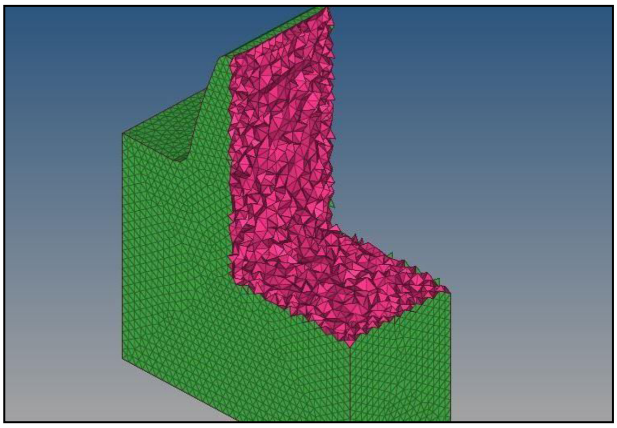

Figure 7 Cut-Section of Meshed tooth

Assigned Material Properties

After the meshing is completed equivalence is checked and then following Young's modulus and Poisson's ratio are assigned for component.

Table No: 3 Material Properties Gear

Property (unit)	**Grey Cast Iron**	**Steel**	**Al-SiC**
Density (Kg/m^3)	7100	7850	2810
Poisson ratio	0.26	0.3	0.15
Young's Modulus (Gpa)	110	210	200

Loads and Boundary Conditions

Lateral load is applied as per calculations. Bottom and half side faces of model is fixed in all directions. After meshing, assignment of materials, load and boundary condition being applied. As per calculation the lateral loads applied on spur gear teeth are 1151.86N, 1001.37N, 747.15N, 669.33N and 316.48N.

Processing

I have done meshing in hypermesh 13.0. That meshed file is exported as.inp format which is used as a input file for abaqus solver. After completing the run, result files .odb and input file .inp are required for post processing. Hyperview is used for post processing purpose.

Post Processing

The process of post processing includes reading and interpreting results. The results can be presented in the form of table, a contour plot, deformed shape of the components. Mostly post-processors provide an animation service, which creates an animation. The result is viewed in Hyperview.

Stresses Observed

The results are noted and images are taken at the stress region of the spur gear tooth.

Drilling Operation: We performed the FEA on prototype of single tooth of spur gear.

Stress intensity of grey cast iron, steel, and Al-sic materials for considered

Case (i) tangential load 1151.86 N

1. For grey cast iron material

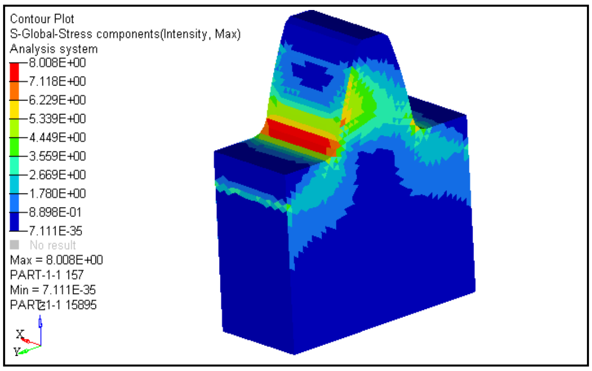

Figure 8 Stress intensity of grey cast iron gear at load 1151.86N

2. For steel material.

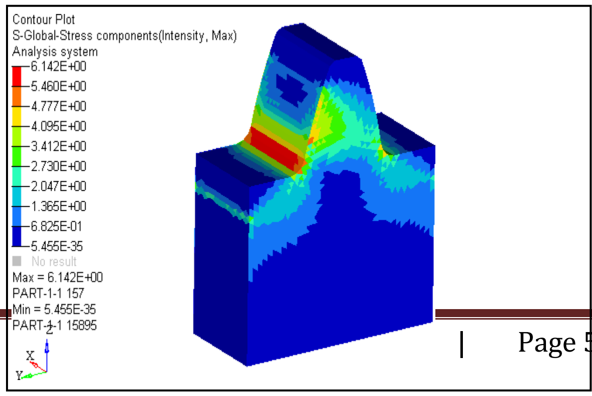

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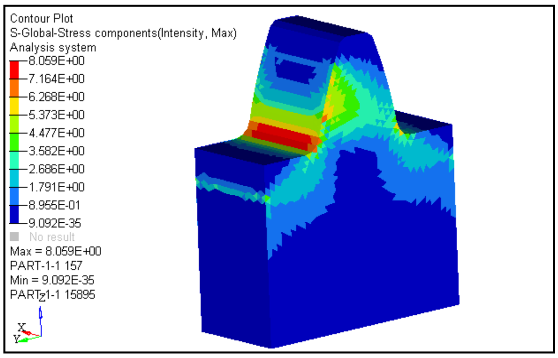
Figure 9 Stress intensity of steel gear at load 1151.86N

3. For Aluminum silicon carbide composite



(Al-Sic) material

Figure 10 Stress intensity of Al-Sic gear at load 1151.86N

Case ii) tangential load 1001.37 N

1. For grey cast iron material

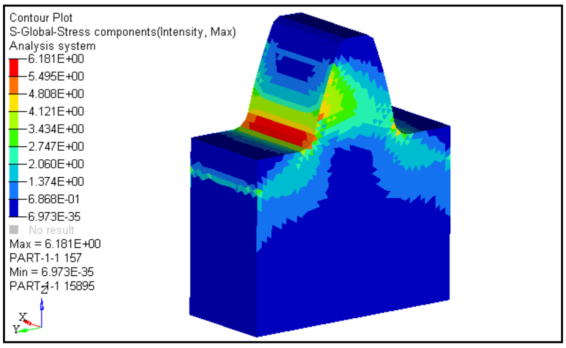


Figure 11 Stress intensity of grey cast iron gear at load 1001.37 N

2. For steel material.

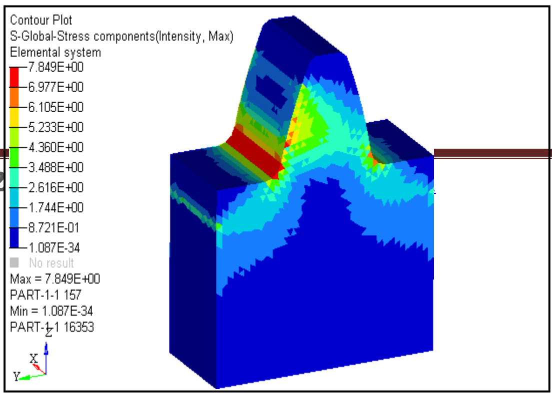


Figure 12 Stress intensity of steel gear at load 1001.37 N

3. For Aluminium silicon carbide composite (Al-Sic) material

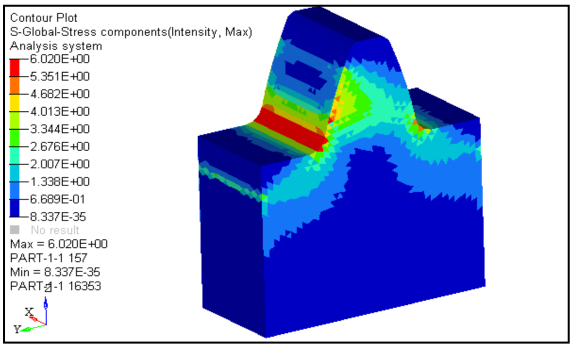


Figure 13 Stress intensity of Al-Sic gear at load 1001.37 N

Tapping Operation

Case i) tangential load 747.15N

1. For grey cast iron material

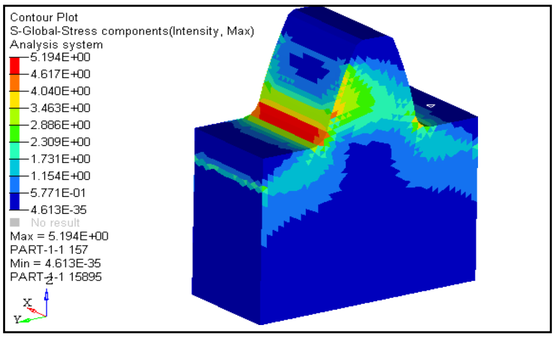


Figure 14 Stress intensity of grey cast iron gear at load 747.15 N

2. For steel material.

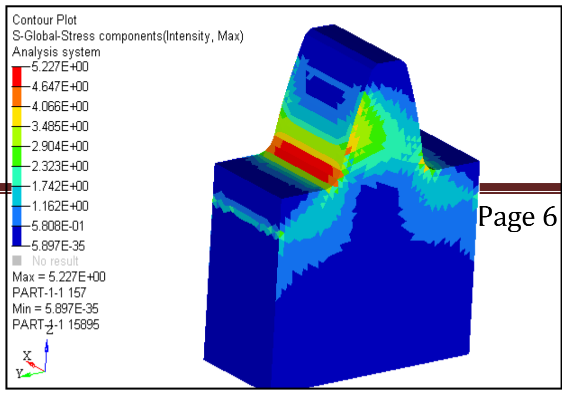


Figure 15 Stress intensity of steel gear at load 747.15 N

3. For Aluminium silicon carbide composite (Al-Sic) material

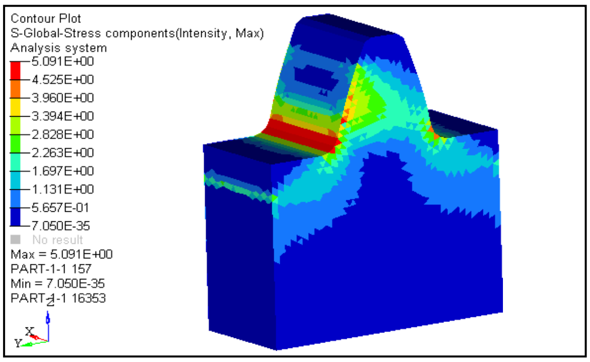


Figure 16 Stress intensity of Al-Sic gear at load 747.15 N

Case ii) tangential load 669.33N

1. For grey cast iron material

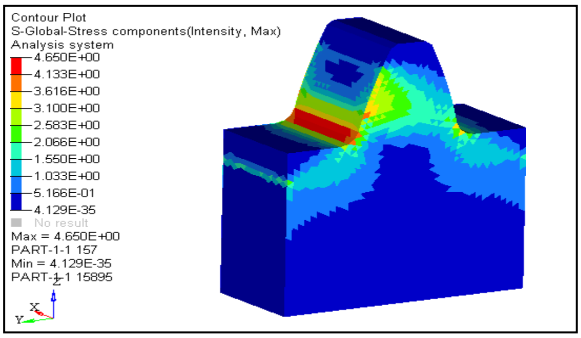


Figure 17 Stress intensity of grey cast iron gear at load 669.33 N

2. For steel material.

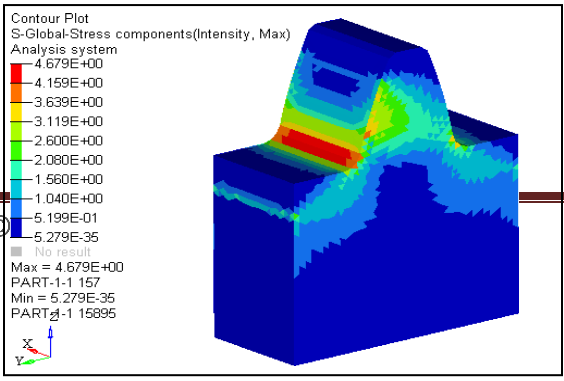


Figure 18 Stress intensity of steel gear at load 669.33 N

3. For Aluminium silicon carbide composite (Al-Sic) material

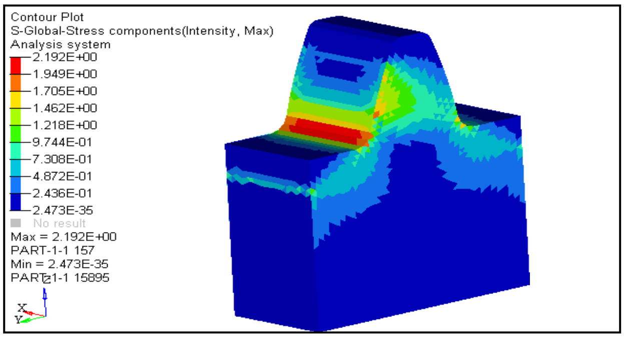


Figure 19 Stress intensity of Al-Sic gear at load 669.33 N

Turning Operation

Case- Tangential load 316.48 N

1. For grey cast iron material

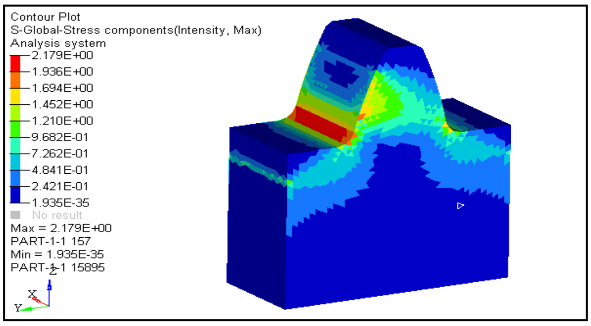


Figure 20 Stress intensity of grey cast iron gear at load 316.48

2. For steel material.

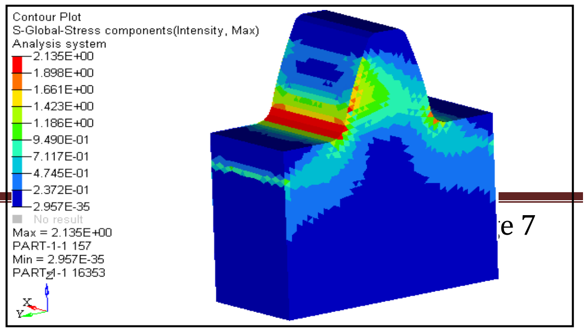


Figure 21 Stress intensity of steel gear at load 316.48

3. For Aluminium silicon carbide composite (Al-Sic) material

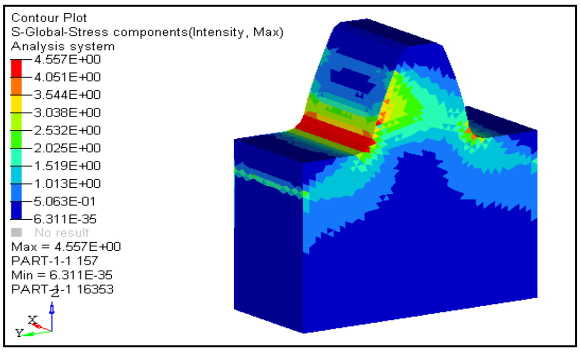


Figure 22 Stress intensity of Al-Sic gear at load 316.48

Finite Element Analysis Result

Sr. No.	Operation	Case D/t mm	Load (N)	Stress intensity (Mpa)		
				Grey cast iron	**Steel**	**Al-Sic**
1	Drilling	Case (i) 18.5	1151.86	8.00	8.05	7.84
		Case (ii) 18	1001.37	6.14	6.18	6.02
2	Tapping	Case (i) 19	747.15	5.19	5.22	5.09
		Case (ii) 17	669.33	4.65	4.67	4.55
3	Turning	0.5	316.48	02.18	02.19	2.13

Table 4.Result of stresses intensity

Weight Analysis of Gear Material

We considered the different composite were their quality of light weight and good strength has compared to conventional material. Thus for the analysis purpose gear made in catia V5 and analysis were done using the Hypermesh analyzing tool which shows that's there has been the considerable reduction in weight of the gear which is shown in the table below:

COMPONENT	GREY CAST IRON (KG)	STEEL (KG)	AL-SIC (KG)
Gear	4.08	4.51	1.61

Table 5 Mass comparison for different materials

4. CONCLUSION

After performing FEA and Experimental Stress Analysis following conclusions are drawn.

1. Stresses developed in case of drilling operations are much higher as compared with other two operations.
2. Also in case of drilling operation as the diameter of tool decreases the stresses induced also goes decreasing.
3. In case of turning operation, the bending stresses developed are very less.
4. Gears made up from steel material high bending stresses are induced and Al- Sic material bending stress induced are less.
5. The stresses in the Al-Sic material gear are nearly same as the other conventional materials of gear. So we can successfully replace the composite