Structural Analysis of Bevel Gear using ANSYS

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Abstract: As bevel gears are used to transmit high power therefore its essential to use materials having stiffness and lower weight. To suit this application, a new class of materials known as Metal Matrix composites (MMC) requires investigation. The current research investigates application of MMC (Material Matrix Composites) in Angular Miter Gears subjected to structural loads and vibration loads using Finite Element Method. The MMC material used for analysis are Al-MMC and Al-7075. The CAD model is developed in Creo design software and analysed using ANSYS FEA software. The equivalent stress generated using Al MMC material is 1.2% lower than structural steel material. The mass of Al MMC bevel gear is 64.2% lower than mass of structural steel bevel gear and mass of Al 7075 bevel gear is also 64.2% lower than mass of structural steel bevel gear.

Key Words: Bevel Gear, MMC, FEA

1. INTRODUCTION

A bevel gear is a type of gear which uses to transmit the power from one shaft to another shaft which is perpendicular to each other. In bevel gear the teeth are straight of straight bevel gear, which have a common apex point. Spiral bevel gears has curved teeth at an angle allowing tooth contact to be gradual and smooth.

Figure 1: Spiral bevel gear

Bevel gears are used for various applications like differential drives, hand drill and rotorcraft drive systems.

2. OBJECTIVE

As bevel gears are used to transmit high power therefore its essential to use materials having stiffness and lower weight. To suit this application, a new class of materials known as Metal Matrix composites (MMC) requires investigation. The current research investigates application of MMC (Material Matrix Composites) in Angular Miter Gears subjected to structural loads and vibration loads. The CAD model of bevel gear is developed using Creo parametric design software. The structural and modal analysis is conducted using ANSYS software.

3. METHODOLOGY

The FEA analysis involves 3 stages. The first stage is pre-processing which encompasses CAD modelling, meshing, applying loads and boundary conditions. The second stage involves solution and last stage involves postprocessing. The material properties of bevel gear used for analysis is shown in table 1 below which shown structural properties, physical properties.

Properties	Structural Steel	Al-MMC	Al-7075
Youngs Modulus (MPa)	206000	113000	71700
Density (Kg/m^3)	7850	2820	2810
Poisson's ratio	.34	.33	.33

Table 1: Bevel gear material properties [37]

CAD Modelling: The CAD modelling of bevel gear is done using Creo 2.0 software which is sketch based, parametric 3d modelling package. The tools used for modeling is revolve, sketch and pattern.

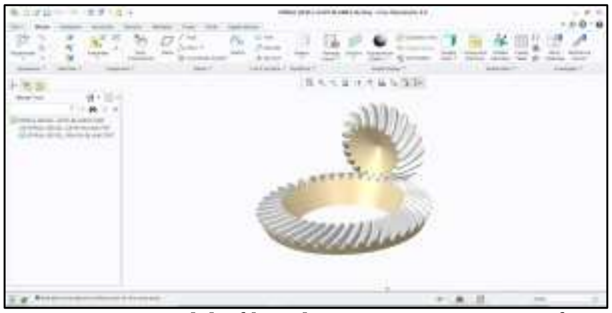

Figure 1: CAD model of bevel gear using Creo 2.0 software

The parameters are defined in Creo 2.0 software as shown in table 2 below.

Table 2: Design and dimensions of bevel gear [5]

VARIABLES	VALUE
Pitch Circle Diameter (Gear)	120
Pressure Angle	20^0
Pitch Circle Diameter (Pinion)	60
Tooth Angle	4.02
Pitch Circle Diameter (Inner)	84.22
Module	3

Relations

The parameters are defined in relation with each other. These relations are defined in creo 2.0 software for parametric modelling of bevel gear. The relations defined between parameters are discussed below.

```
TEETH=NOT_GEAR
PCD_IC=PCD_IC:FID_PCD_IC*2
PCD_INNER=PCD_INNER:FID_PCD_INNER*2
ANGLE=360/NOT_GEAR
OFFSET=ANGLE:FID_ANGLE
M=PCD_GEAR/NOT_GEAR
GEAR_ANGLE=ATAN(PCD_GEAR/PCD_PINION)
M_1=PCD_INNER/NOT_GEAR
PCD_GC=PCD_GEAR/COS(GEAR_ANGLE)
ROOT_RADIUS=M/3.3
BCD_IC=PCD_IC*COS(PRESSURE_ANGLE)
OFFSET_IC=OFFSET
ACD_GC=PCD_GC+2*M
RCD_IC=PCD_IC-2.5*M_1
ACD_IC=PCD_IC+2*M_1
NOT_IMAGINARY=PCD_GC/M
ROOT_RADIUS_1=M_1/3.3
BCD_GC=PCD_GC*COS(PRESSURE_ANGLE)
RCD_GC=PCD_GC-2.5*M
TOOTH_ANGLE=360/NOT_IMAGINARY
TOOTH_OFFSET=TOOTH_ANGLE/4
```

The static structural analysis is performed using ANSYS 18.1 software. The analysis comprises of 3 stages, namely pre-processing, solution and post-processing.

Pre-processing: In this stage the CAD model is developed using ANSYS software. ANSYS design modeler is specific tool used for designing and editing operation. The model is meshed using tetra elements of appropriate size and shape. After meshing appropriate loads and boundary conditions are assigned.

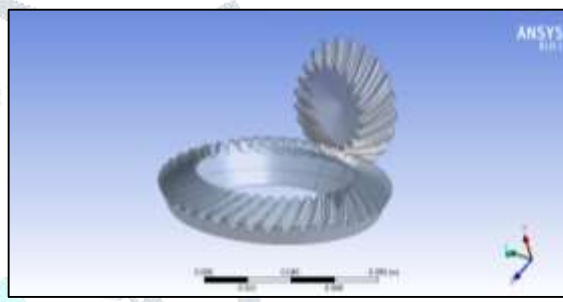

Figure 3: Imported CAD model of bevel gear in ANSYS software

The CAD model of bevel gear is imported in ANSYS design modeller as shown in figure 3 above. The model is checked for geometric errors, hard edges and other defects and corrected.

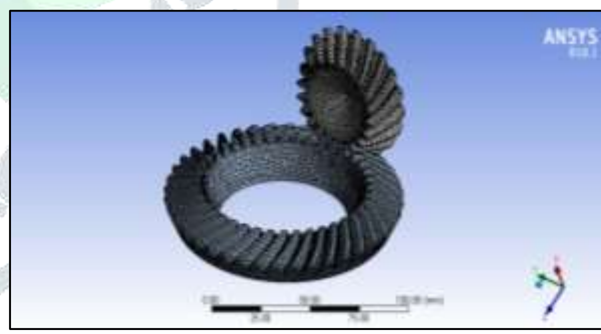

Fig 4: Meshing of bevel gear using ANSYS design modeler

The CAD model is meshed using tetrahedral elements and fine sizing with curvature effects on. The number of elements generated is 61363 and number of nodes generated is 102967 as shown in figure 4 above. The element shape of tetrahedral element is shown in figure 5 below. It consists of 4 nodes connected to each other by tetrahedral shape.

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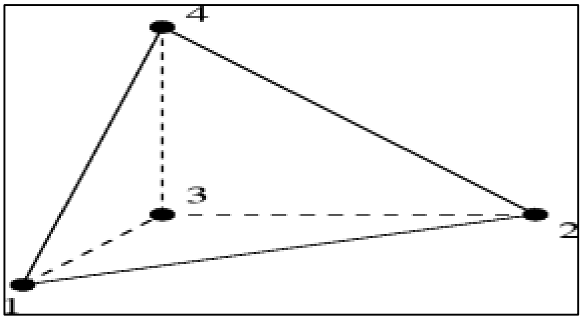

Fig 5: Element shape of tetrahedral element

CAD model of bevel gear is applied with structural loads as shown in figure below. The frictionless support is applied to gear and pinion on side surfaces as shown in figure 6 below. The moment is applied on gear inner surface as shown in figure 7.

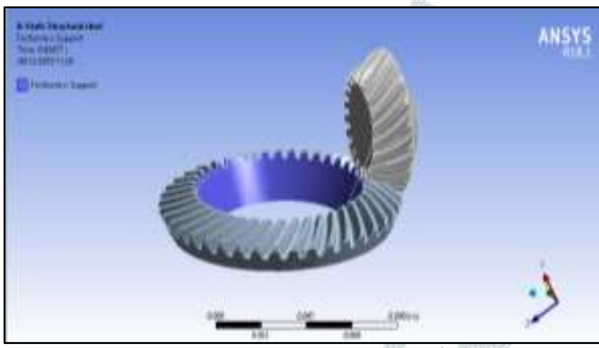

Fig 6: Frictionless support on inner surface of gear

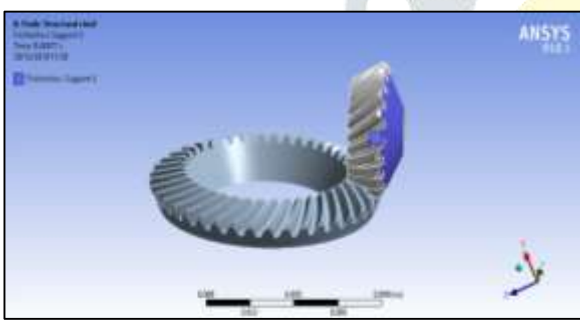

Fig 7: Frictionless support on pinion outer face

The pinion is applied with moment of 38 N-m on pinion outer flat face as taken from literature [6].

Type	Moment
Define By	Vector
Magnitude	38. N·m (ramped)
Direction	Click to Change
Suppressed	No
Behavior	Deformable

Fig 8: Moment applied on side face of pinion

Solution: In this stage software carries out matrix formulations, multiplications and inversions. Initially element stiffness matrix is formulated, the element stiffness matrix are assembled to form global stiffness matrix. When solver is set to run, the software calculates results at nodes and results are interpolated for entire element edge length.

Post-processing: This stage involves viewing of results like contour plots of stress, deformation, equivalent stress etc. At this stage, the optimization of input design variables like bevel gear diameter and mean diameter is envisaged. Accordingly, changes are made in initial design and previous steps are repeated.

Data Reduction

Surface fatigue failure in the gear tooth occurs due to many repetitive contact stress at the time of power transmission. If a pair of teeth in contact are subjected to cyclic type of loading, then contact stress are induced on the gear tooth surface, which are higher than the fatigue strength of the gear. This causes the failure of the gear teeth. In this research the maximum contact stress is calculated theoretically by using Hertz equation. The standard method for determining the bending stresses in bevel gears comes from the American Gear Manufacturers Association3and is based on the equation below

$$\sigma_b = \frac{2 \times T}{d} \times \frac{P_D}{b \times j} \times \frac{K_a \times K_m \times K_s}{K_v \times K_x}$$

(4.1)

Where σ_b = Maximum bending stress in tooth

Ka = Application factor

Kv = Dynamic factor

Pd = Diametrical pitch.

$P = \frac{Z}{D}$

b = Face width of the teeth.

T = Torque in N-m

K_m=Load distribution factor

J = Geometry factor

Hertz Equation

$$P_p = \left\{ \sqrt{\frac{F_t}{b \times d} \times \frac{U+1}{u}} \right\} \times Y_m \times Y_p$$

(4.2)

Where Pp = Contact stress in N/mm2

Y_m = material coefficient

Y_p = Pitch point coefficient

Ft = tangential force in N

b = Width of teeth in mm

d = Diameter of the gear in mm

4. RESULTS AND DISCUSSION

Contact Analysis Results using Structural Steel material. The contact stress analysis is conducted using ANSYS software. The results of structural steel material for deformation and equivalent stress generated are discussed in this section.

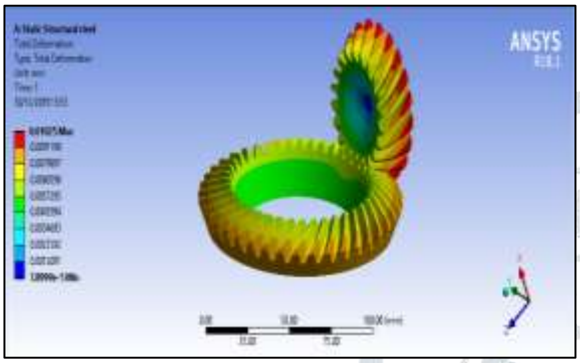

Figure 9: Deformation using structural steel material

The maximum deformation is observed on outer tooth of pinion with magnitude of .01025mm and lowest deformation is observed on inner surface of pinion. The other tooth surfaces experiences lower deformation. The gear experiences deformation of .0091mm as shown in figure 9 above.

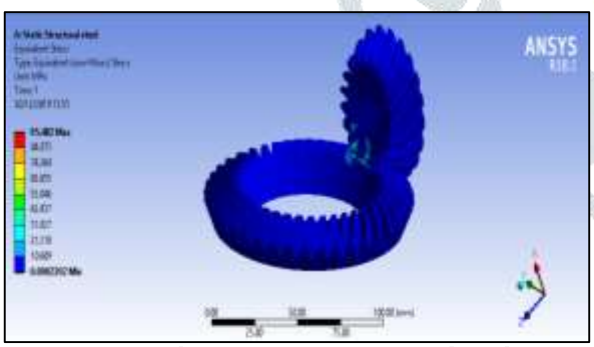

Figure 10: Equivalent stress using structural steel material

The maximum equivalent stress is observed on contact region between pinion and gear with magnitude of 95.48MPa as shown by red colour region while other regions experiences minimal contact stresses as shown by dark blue colour as shown in figure 10 above. The results of Al MMC material for deformation and equivalent stress generated are discussed in this section.

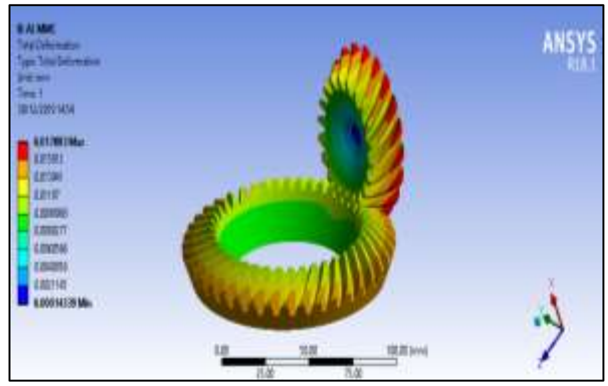

Figure 11: Deformation using Al MMC material

The maximum deformation is observed on outer tooth of pinion with magnitude of .0178mm and lowest deformation is observed on inner surface of pinion. The other tooth surfaces experiences lower deformation. The gear experiences deformation of .00159mm as shown in figure 11 above.

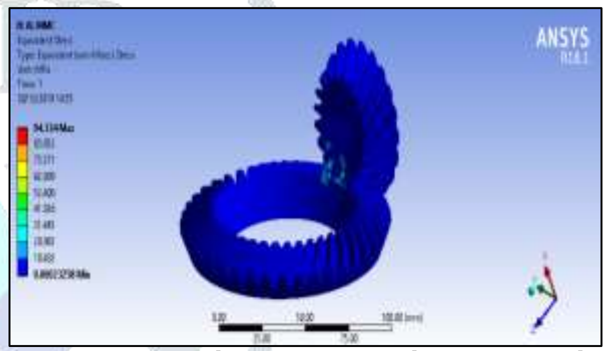

Figure 12: Equivalent stress using Al MMC material

The maximum equivalent stress is observed on contact region between pinion and gear with magnitude of 94.33MPa as shown by red color region while other regions experiences minimal contact stresses as shown by dark blue colour as shown in figure 12 above. The results of Al 7075 material for deformation and equivalent stress generated are discussed in this section.

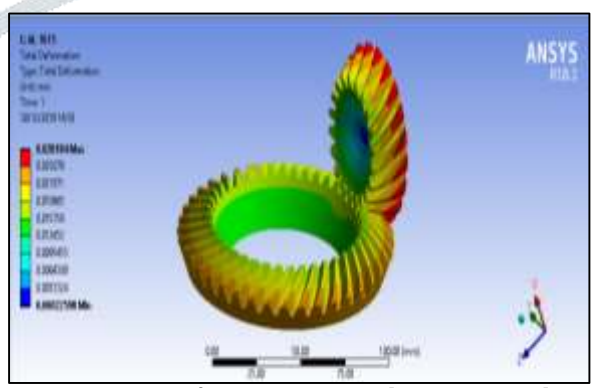

Figure 13: Deformation using Al 7075 material

The maximum deformation is observed on outer tooth of pinion with magnitude of .02818mm and lowest deformation is observed on inner surface of pinion. The other tooth surfaces experiences lower deformation. The gear experiences deformation of .021mm as shown in figure 13 above.

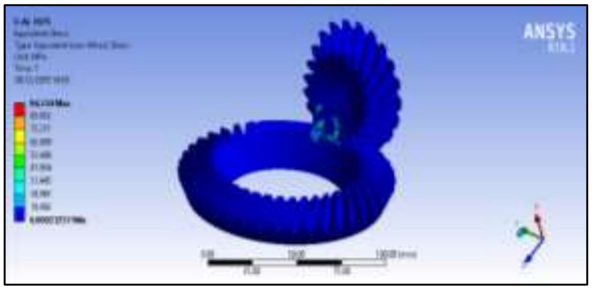

Figure 14: Equivalent stress using Al 7075 material

The maximum equivalent stress is observed on contact region between pinion and gear with magnitude of 94.334MPa as shown by red color region while other regions experiences minimal contact stresses as shown by dark blue color as shown in figure 14 above.

Table 3: Comparison of stresses and deformation

Material	Structural Steel	Al MMC	Al 7075
Deformation	0.01025	0.01788	0.02818
Stress	94.482	94.334	94.334

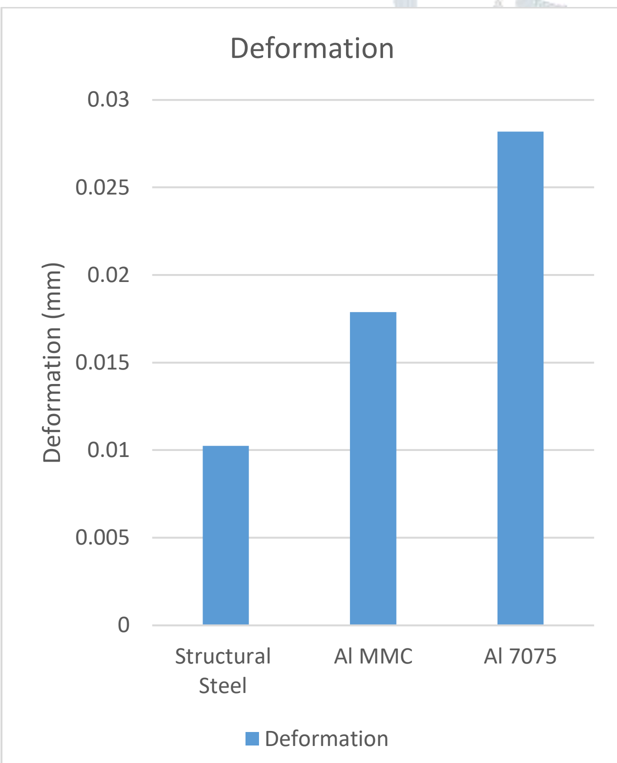

Figure 15: Deformation vs different materials

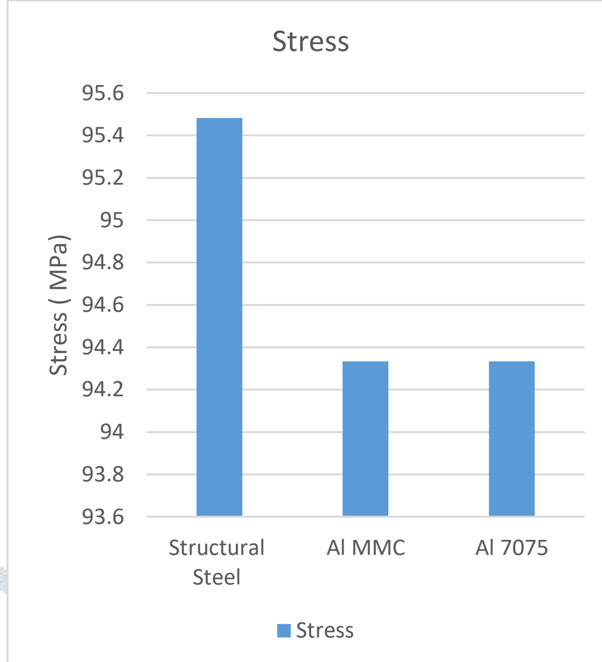

Figure 16: Stress vs different materials

5. CONCLUSION

The structural and modal analysis of spiral bevel gear is conducted using ANSYS software. The equivalent stress and natural frequencies are determined and corresponding mode shapes are generated. The detailed conclusion are as follows:

1. The equivalent stress generated using AL MMC and Al 7075 material are lower than spiral bevel gear made from structural steel.
2. The deformation observed in structural steel is comparatively lower than Al MMC material and Al 7075 alloy material.
3. The equivalent stress generated using Al MMC material is 1.2% lower than structural steel material.

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