# Analysis Of Spur Gear Using Boron Carbide Particulate Reinforced Lm6 Aluminium Metal Matrix Composite

[1]A.V.S.Gowtham, [2]T. Lakshmana Kishore, [3]M.Komaleswara Rao
[1]M.Tech student, [2]Assistant Professor, [3]Assistant professor
Mechanical Engineering (Machine Design) JNTUK-Ucev,Vizianagaram,India

**Abstract - In Present work fabrication and mechanical study of LM6 Aluminum and Boron Carbide ( 4C) composites containing weight ratios of 5%, 10%, and 15% of Boron Carbide is done by Stir-Casting method. Mechanical tests such as tensile test, hardness test, and compression tests are conducted. Modelling and analysis tools like CATIAV5 and ANSYS 15.0 Work bench are used to model the spur gears and to perform finite element analysis. The project aims at the minimization of both contact stress as well as deformation using the composite materials. The results of the FEM analysis from ANSYS are presented. These stresses will be compared with the theoretical Hertz's equation values. If both results agree well. This indicates that the FEM model is accurate. The contact stress and deformation of the gear teeth are the key parameters in designing the gear. When the working stress exceeds the maximum stress then the gears will be failed generally. The contact stress beyond the critical level causes pitting on the gear teeth. Gears undergo huge amount of compressive stresses in power transfer, so materials like LM6Al- 4C composites are used as the compressive strength of this composite very higher than Aluminum and alloy steel. Finally the spur gears with different module and pressure angle are modelled in CATIAV5 and analyzed in ANSYS workbench 15.0, it was noticed that increase in module and pressure angle decreases the contact stress among the mating gears.[1]**

**Keywords - LM6Al-B4C composite, Contact Stress, Finite element analysis, MMC's, Spur gear, Stir casting, compressive strength, tensile strength, module, pressure angle.**

## I.INTRODUCTION

In present situation the conventional materials are being replaced by Metal Matrix Composites due to their superior properties like high strength to weight ratio, low density etc.. Aluminum Boron carbide alloy composite materials are widely used for a many number of applications like nozzles in water jet cutting, ballistic armour, and in nuclear applications in conjunction with other materials. The LM6 aluminum alloy composition is (87.8 Al, **11.25 Si**, 0.1 Mg, 0.14 Mn, 0.46Fe,0.08Cu, 0.01 Ni, 0.01 Zn and 0.16 Ti).Here we can see the LM6 aluminium alloy contains nearly 11% of silicon and so it is used as a matrix due to following reasons.

### Al-Si Alloy as Matrix

**(Saheb et. al. 2001**)[2]:Al-Si alloy is considered as a framework material on account of its gigantic properties like high wear resistance, low warm extension coefficient, great consumption resistance, and enhanced mechanical properties at an extensive variety of temperatures (Saheb et. al. 2001). Aluminum – silicon composites are the most vital and generally utilized throwing combinations to cast parts with complex shapes in light of simple castability and great bargain between mechanical properties and gentility.

(**Merlin et al, 2009)[3]:**The use of aluminum compounds are likewise generally utilized as a part of car division which prompt financially supportable advancements). The aluminum – silicon alloy properties were impacted by theshape and conveyance of the eutectic silicon particles in the matrix, furthermore by the iron inter metallic and copper stages that happen upon solidification remarked by Mohamed et al (2009).

(**Anasyida et al., 2010).[4]**The part of Fe, Mn, Cu, and Mg substance was more touchy to varieties in microstructure and malleable properties of Al – Si close - eutectic compound.Aluminium – Silicon (Al–Si) alloys, they are used as engineering materials and are found widely application in the field of aerospace, automobile, and military applications Al – Si alloys having good castability, high wear resistance, low density and thermal expansion coefficient near – eutectic. These compounds are likewise impacted by their tribological properties, so they are utilized as a part of transportation vehicle segment. It is demonstrated that wear resistance of Al–Si compound is impacted by different variables like burden and Speed and additionally by microstructural parameters, for example, the morphology and volume division of the silicon stage. Al – Si alloy have enhanced the wear properties by fusing hard ceramic particles, for example, Al2O3, SiC and TiB2 to create composites (Daoud et al, 2004).[6], Due to magnificent castability, at some point Aluminum-silicon eutectic or close eutectic compounds are thrown to deliver 'Piston Alloy', which gives the best general equalization of properties (Day et.al., 1970)]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 [6] 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
[7] 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 [8] 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.

**Boron carbide as reinforcement:**Boron carbide has attractive properties like high strength, low density (2.52 g/cm3), extremely high hardness, good wear resistance and good chemical stability.Boron carbide(B4C) could be an alternative to Sic and Al2O3 due to its high hardness[9] (the third hardest material after diamond and boron nitride).The density of the composite is less than the aluminum base metal. Thereby reducing power consumption The hardness and compressive strength can be far increased by this reinforcement. The poisons ratio is also reduced than the base metal which reduces contact stress ,and increases the life of gears.

## II. METHOLOGY OF FABRICATION

### 2.1 Materials:

LM6Al was used as matrix material and Boron carbide particles were added as reinforcements to prepare composites in this study. The chemical composition of LM6Al is used as matrix material. The particle size of boron carbide ranges from 30 to 40 microns.

### 2.2 Preparation of composites:

Stir casting process is used to fabricate the LM6 Al-( 4C) composite. The surfaces of the Boron Carbide particles areoxidized by preheating the powder particles around 800 degrees centigrade for 2 hours. LM6 Al alloy ingots were taken into a graphite crucible and melted in an electrical furnace according to the required weights as shown in fig-1
The ingots were heated to a temperature until a slurry in semisolid state was obtained. Then the preheated boron carbide particulates were added and mixed to this slurry manually. Then composite slurry is reheated again to obtain a fully liquid state and the stirrer was rotated by means of a motor at an average speed of 200 rpm for nearly 2 hours time for the even distribution of boron carbide particles in LM6 Al-alloy[10]. The composite slurry was maintained to a final temperature of nearly 750 degrees centigrade. Then after finally the liquid metal was poured into a moulde of cylindrically shaped with a diameter of 15mm as shown in fig (2).Finally the castings were cooled to room temperature to relieve the residual stresses and then taken out from mould.

**Fig- 1 furnace**

**Fig2-Pouring Liquid metal into mold**

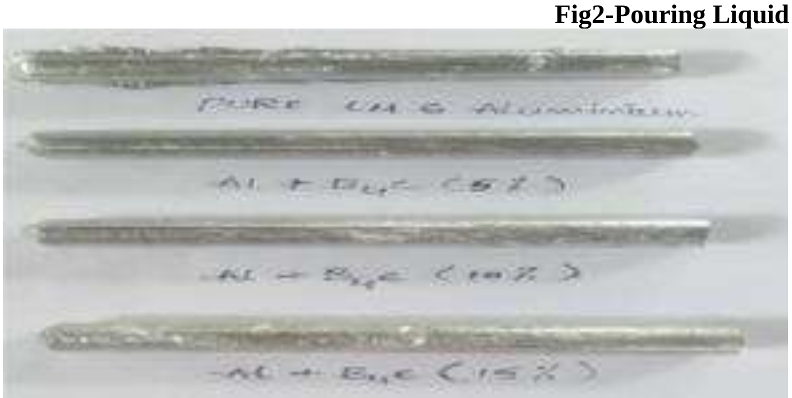



**Fig-3 composite specimens**

### 2.3 EXPERIMENTAL TESTING

#### 2.3.1. HARDNESS TEST

Vickers hardnes studies were carried out for the investigated materials using Vickers hardness tester with 1 Kg load. The time of indentation for hardness is taken as 15 seconds. Three readings were taken for each hardness value for the purpose of accuracy. Vickers hardness tester was shown in the figure. From the results we can say that the hardness value increases with the increase in % of boron carbide.

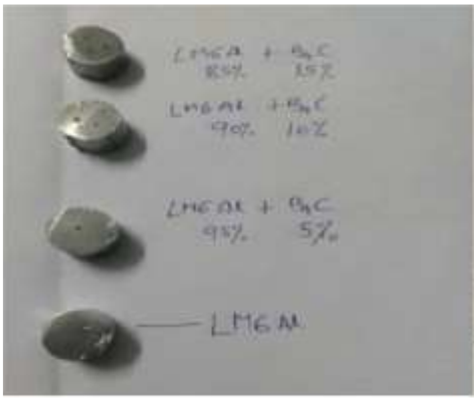


**Fig-4 Hardness of composite samples**

**Fig-5 hardness tester(Vickers)**

**Table-1 Hardness values of composite samples**

| S.No | Specimen | Hardness (VHN) |
|---|---|---|
| 1 | Aluminium | 59 |
| 2 | Aluminium -5% composite | 68 |
| 3 | Aluminium-10% composite | 74.4 |
| | Aluminium-15% composite | 92 |

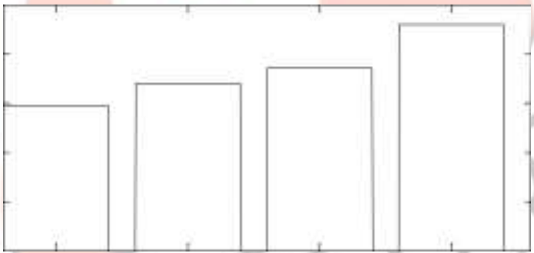


**Fig-6 Hardness vaariations of composites**

**2.3.2Tensile test:**

The composite specimens after removing from the mould is machined on lathe according to ASTME8 standards as shown in figures 7,8 respectively. The drawing of the specimen is shown in the figure -8. The specimens undergo tensile test by using an universal testing machine. The testing process involves fixing the specimen in jaws of the UTM carefully and load is given gradually until the specimen fails. From the final gauge length elongation is calculated which gives the strain and young's modulus values of the specimens. The same procedure is repeated for all specimens of different compositions. The results were tabulated as shown in the table-2. Interfacial bonds are the key parameters that effects the tensile strength of the composite[11]. From the graph(fig-11) we can see that ultimate tensile strength is increased with increase in % of boron carbide which denotes that interfacial bonding strength is increased due to stirring action and due to preheating of the boron carbide particles. Here from the graph(fig-12) we can see that there is no recognizable change in modulus of elasticity as compared with the ultimate tensile strength.

| % Reinforcement | Young's Modulus, GPa | Ultimate Tensile Strength (UTS), MPa | % of Elongation |
|---|---|---|---|
| LM6Aluminium | 71 | 170 | 21.2 |
| LM6 Al-5% B4C | 71.2 | 189 | 15.3 |
| LM6 Al-10% B4C | 71.8 | 242 | 13.01 |
| LM6 Al-15% B4C | 72.6 | 259 | 10.35 |

**Table 2 Comparison of tensile behaviour of the alloy and composites**

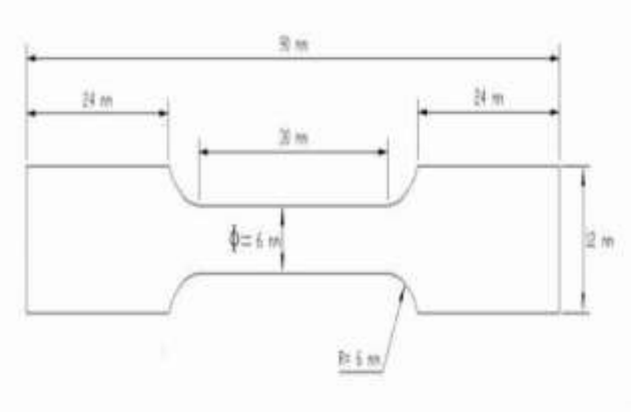


Fig-7 Machining on Lathe

Fig-8 Dimensions of specimens as per ASTM standards

**Fig-9 Machined specimens on Lathe**

**Fig-10Fractured specimens after tensile test**

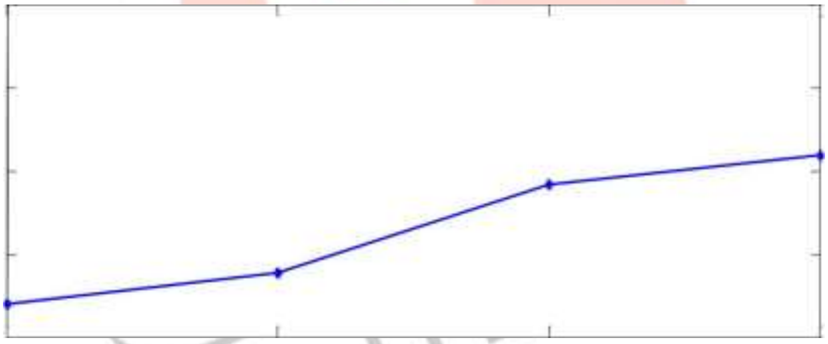


**Fig 11 Variation of ultimate tensile strength with the % of reinforcement**

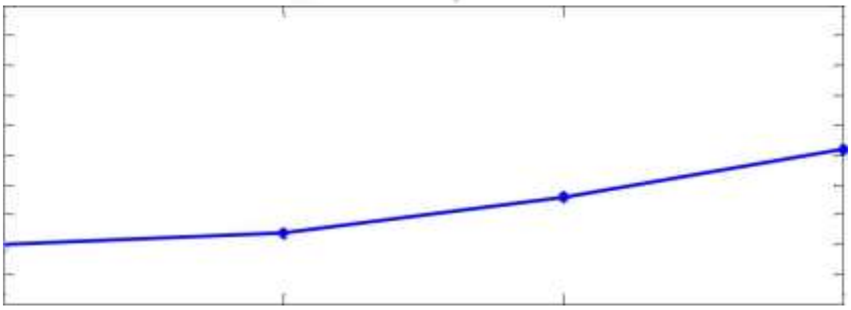


**Fig 12 Variation of youngs modulus of composite with the % of reinforcement**

### 2.2.3 Density

Density is the key effecting parameter in material selection for particular application, which increases the demand for the low density composites. The density of the composite is measured by using Archimedes equation. The average theoretical and measured density values of the Aluminium and its respective composites were given in table-3 . It was observed that the addition of Boron Carbide particles into the Aluminium alloy matrix significantly decreases the density of the resultant composites in compare to the base metal.

The density of the composites decreases with increasing the percentages of boron carbide as shown in fig-13. With 15% Boron Carbide, the density of composite decreased from 2.65to 2.63 gm/cm3

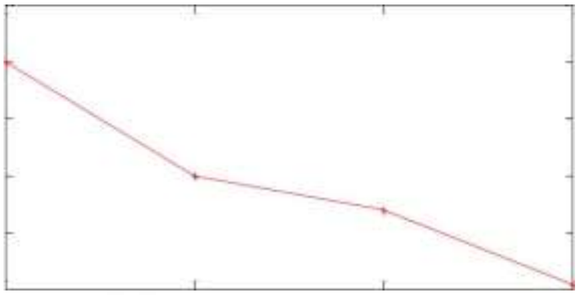
MMC=m/(m-m1)*H2O

Where MMC - the density of LM6 Al-B4C composite

Mass of the composite specimen in air------------------------------------------------------------------------ m

Mass of the composite specimen in distilledwater---------------------------------------------------------- m1

H2O - density of distilled water-998 kg/$m^3$



**2.3.4 POISSON'S RATIO:**

The ratio of lateral strain to linear strain is known as poison's ratio. The poisons ratio of the composite can be calculated by rule of mixtures.

Poisson's ratio (μ) = (μm×Vm + μf ×Vf) ...............................2.

Where, μ, μm, μf– Poisson's ratio of the composite, matrix and dispersed phase respectively; Vm,Vf– volume fraction of the matrix and dispersed phase respectively.

The poisons ratio of the aluminium is 0.33.

The poisons ratio of the Boron carbide 0.195.The poisons ratio of the composites were tabulated as show in the table-4

| S.No | Specimen | Poisson's ratio |
|---|---|---|
| 1. | Aluminium | 0.3300 |
| 2. | LM6 Aluminium –B4C5% composite | 0.32325 |
| 3. | LM6Aluminium-B4C 10%composite | 0.3165 |
| 4. | LM6 Aluminium-15% composite | 0.30975 |

**Table-4 poisons ratio of the composites**

**Fig-14 variations of poisons ratio with change in % of reinforcement**

**2.3.5COMPRESSION TEST:**

A compression test can be performed on UTM by keeping the test-piece on base block and moving down the central grip to apply load. It can also be performed on a compression testing machine. A compression testing machine show has two compression plates/heads. The upper head moveable while the lower head is stationary. One of the two heads is equipped with a hemispherical bearing to obtain Uniform distribution of load over the test- piece ends. In cylindrical specimen, it is essential to keep h/d < 2 to avoid lateral instability due to buckling action. Specimen size = h < 2d. Compression test is just opposite in nature to tensile test. Nature of deformation and fracture is quite different from that in tensile test. Compressive load tends to squeeze the specimen. Brittle materials are generally weak in tension but strong in compression. Hence this test is normally performed on cast iron, cement concrete and ceramic reinforced composites. Here in this compression test loads of 40kN,50KN, 60KN are imposed on the 20 mm length specimens of LM6-Al,5,10, and15% B4C composites of LM6 Aluminium. Finally after measuring the length of the specimens after compression, the % of compression is calculated for each specimen and it has been observed that the composite with 15% reinforcement has the least compression percentageof 15%,which shows that the compressive strength of the specimen increases with increase in the amount of reinforcement(boron carbide).

| S. | %of | Initial length | Final | Final | Final | % of |
|---|---|---|---|---|---|---|

| no | boron carbide | of specimen(mm) | length of specimen after 40 KN | length of specimen after 50 KN | length of specimen After 60 KN | compression |
|---|---|---|---|---|---|---|
| 1 | 0 | 20 | 17.5 | 15.5 | 14.25 | 28.75 |
| 2 | 5 | 20 | 18.3 | 17 | 15 | 22.5 |
| 3 | 10 | 20 | 19 | 18 | 16 | 20 |
| 4 | 15 | 20 | 19.6 | 14 | 17 | 15 |

**Table -5 % of compression with respect to loads applied**

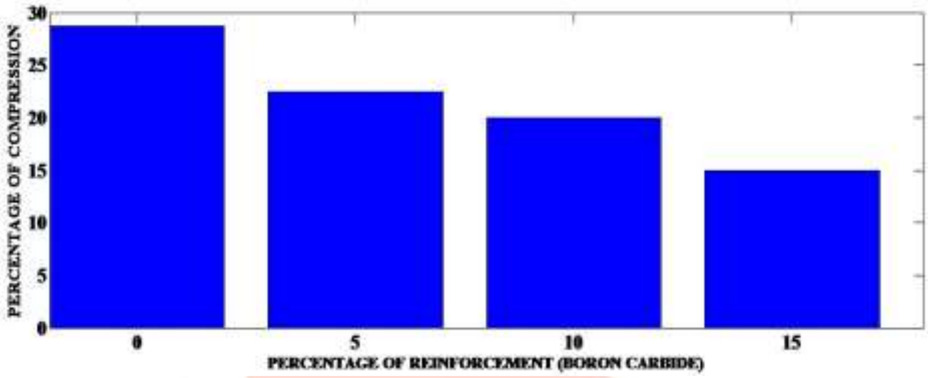



**Fig-15 Variation of % of compression with respect to change in % of reinforcement**

**III. Theoretical Analysis of Contact Stress of Spur gear using Hertz Equation**

$$\sigma_C = \sqrt{\frac{W(1+Rp_1/Rp_2)}{Rp_1 B\pi\left(\frac{1-\mu_1^2}{E_1}+\frac{1-\mu_2^2}{E_2}\right)\sin\emptyset}} \quad \text{-----------------------3}$$

σ=

maximum value of contact stress (N/mm2)

W= force pressing the two cylinders together (N)

B = Face width (mm)

*h*

E1, E2 = modulii of elasticity of two cylinder materials (N/mm2) µ1, µ2= Poisson's ratio of the two cylinder materials (Unit less) Ø= pressure angle

**INPUT DATAGEAR DIMENSIONS CALCULATION:**

Torque=1694.7725 N-mModule (m) =6.35 mm
Pressure angle (Ø) =20No. of teeth (N)=20
No of teeth on pinion (N) =20Pitch circle radius ( )=m*N/2=63.5mm
No of teeth on gear (N) =20 Addendum radius (Ra)= +m=69.85 mm
Face width=101.6mmDedendum radius (Rd)= -1.25*m=55.5625mm
Shaft radius=31.75 mm.
Torque = Force (W) * Shaft Radius (Rs)
1694.7725e3 (N-mm) = W * 31.75 (mm)
W = 53378.6614 N

**IV.MODELLING OF SPURGEAR IN CATIA:**

In this context spur gears are modeled in Catiav5 with different specifications like change in module and pressure angle. These designs are converted into IGES format and static analysis is done in Ansys work bench 15.0.In this analysis same moment (torque) of 1694.8N-m is given as input to all three pairs of gears and it was noticed that with increase in module and pressure angle the contact stress is decreased. The contact stress was also calculated by theoretical hertz equation and both theoretical and ansys results are compared.

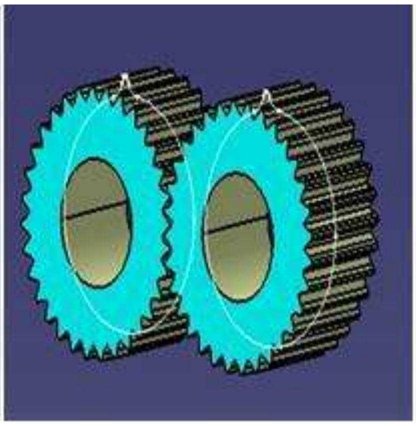
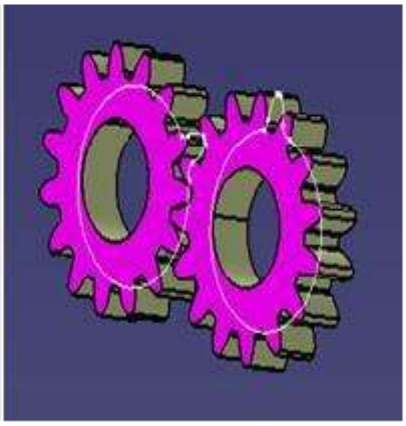
  

**Fig-16 Model of spur gear in CATIA Design-I**
**Fig-17 Model of spur gear in CATIA Design-II**
**Fig-18 Model of spur gear in CATIA Design-III**

**SPECIFICATIONS OF SPURGEAR PAIRS**

| S.No | Design-I | | Design-II | Design-III |
|---|---|---|---|---|
| **1.** | **MODULE** | **6.35 mm** | **3.96 mm** | **8.466 mm** |
| **2.** | Number Of Teeth | 20 | 32 | 15 |
| **3.** | Pitch Circle Diameter | 127 mm | 127mm | 127 mm |
| **4.** | **Pressure Angle** | **20 deg** | **15 deg** | **25 deg** |
| **5.** | Adendum Radius | 69.85 mm | 67.468mm | 71.965 mm |
| **6.** | Dedendum Radius | 55.88 mm | 58.698mm | 52.916 mm |
| **7.** | Face Width | 101.6 mm | 101.6 mm | 101.66 mm |
| **8.** | SHAFT RADIUS | 31.75 mm | 31.75 mm | 31.75 mm |

## V. FINITE ELEMENT ANALYSIS OF SPUR GEARS

After modelling spur gear pairs in catiav5 as per the above specifications, those designs were converted into IGS format and will be imported into Ansys workbench to calculate stresses and deformations. The static structural analysis has been done in ansys work bench. The material properties like youngs modulus for composites is evaluated through tensile test, and poisons ratio is obtained through rule of mixtures. Poisons ratio and density of a composite material is isotropic and can be estimated using the rule-of-mixtures. The material properties for structural steel is taken from design data book. The boundary conditions like fixed support and frictionless support were used in evaluation of contact stresses.

**Material properties of gear materials:**

| **Material property** | **Alloy steel** | **LM6Aluminium Alloy** | **Al-B4C composite** |
|---|---|---|---|
| Young's modulus (Gpa) | 210 | 71 | 72.6 |
| Density ( gm\cm$^3$) | 7.870 | 2.65 | 2.6305 |
| Poisons ratio (µ) | 0.3 | 0.33 | 0.30975 |
| Ultimate tensile strength (N/mm$^2$) | 200 | 156 | 259 |

**Table-7 material properties of gear materials 5.1**

**Automatic Mesh Generation**

In engineering simulation mesh generation is treated as the most important aspect.In present work fine mesh of gear pairs is done to obtain more accurate results.

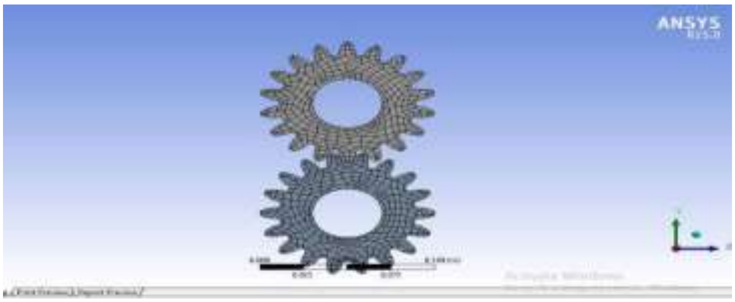


**Fig 19 Meshing of Spur gear assembly in ansys work bench.**

**5.2 Stress Analysis in ANSYS Mechanical**

In present work boundary conditions like fixed and frictionless supports were applied on the inner rims of left and right gears respectively .These conditions were applied to allow tangential rotation and restrict radial translation. Moment of 1694.8 N-mm is applied on the two faces of the rim in anticlockwise 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 centre distance of the two mating gears.

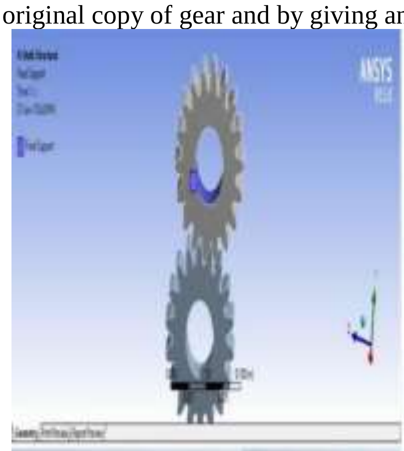


Fig-20 Fixed support on left gear Fig-21 Frictionless support on right spur gear Fig-22 Moment applied on right spur gear

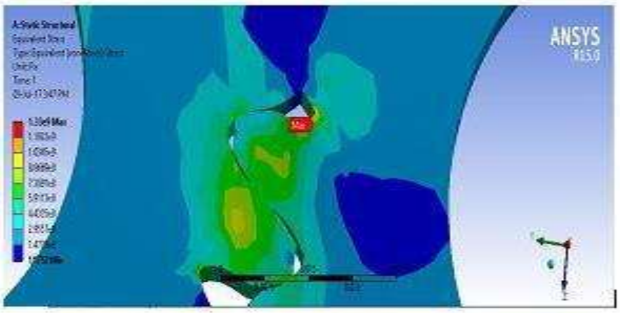


**Fig-23: Vonmoises stress of alloy steel spur gear**

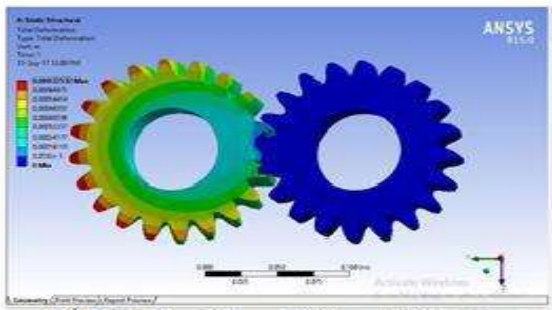


**Fig 24 Deformation of alloy steel spur gear**

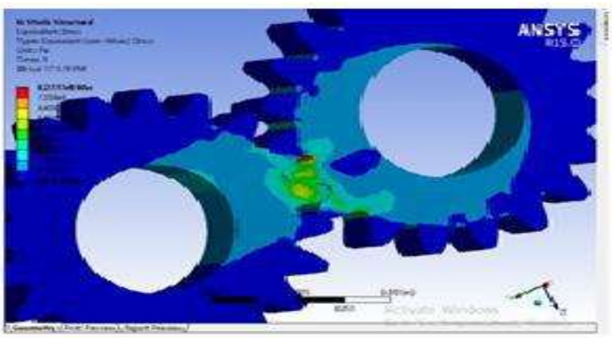


**Fig 25:Vonmoises stress of LM6 Aluminium Spur gear**

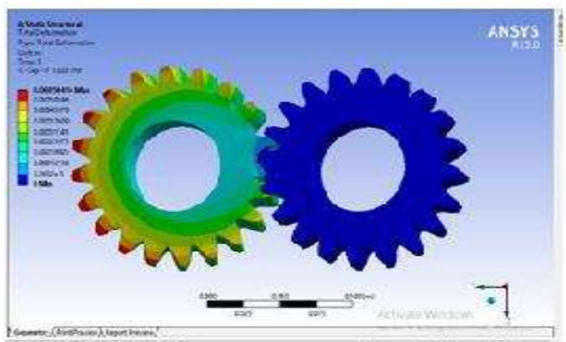


**Fig 26Deformation of LM6 Aluminium Spur gear**

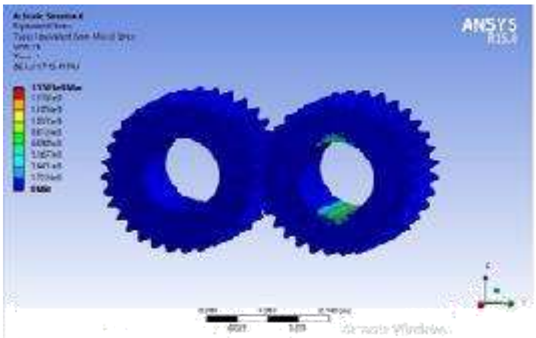



Fig-27: Vonmoises stress of spur gear design-II

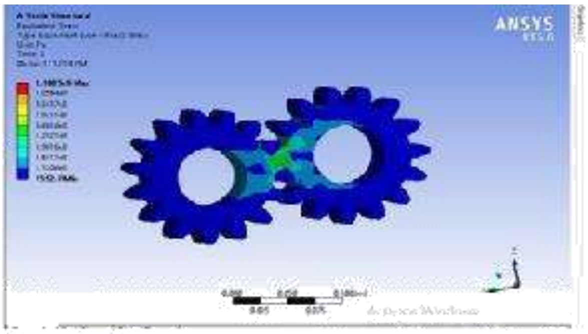



Fig-27: Vonmoises stress of spur gear design-III

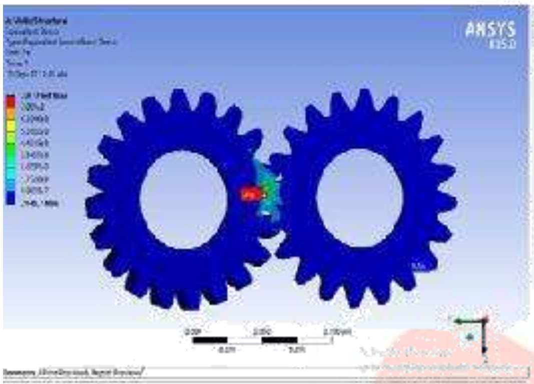



Fig 29 Von moises stress of Al-15%B4C Spur gear

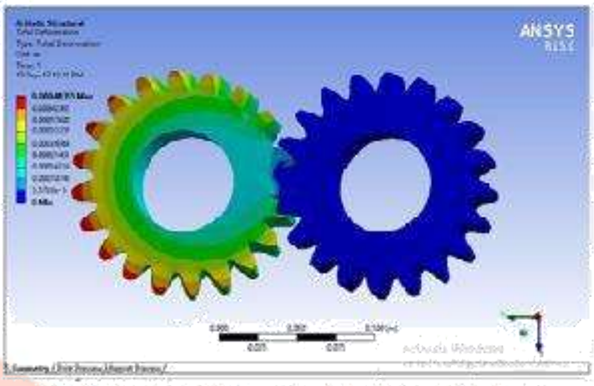



Fig-30: Deformation of Lm6 Al-B4C Spur gear.

## VI.RESULTS

From the theoretical and finite element analysis results we have noticed that the contact stress and deformations of the 15% reinforced composite is less than the pure LM6Al-alloy and structural steel which proves that the composite material is better than the conventional materials which improves the life of the gear pairs. The Hertz equation contact stress values are compared with ansys stress results and an an accepatable difference of nearly maximum 5% is obtained, which proves our assumption was correct.

| Materials | Contact Stress (Mpa) | | |
|---|---|---|---|
| | HERTZ THEORY | ANSYS | Error |
| Alloy Steel | 1300.89 | 1330 | 2.23% |
| LM6Aluminium | 790.79 | 827.77 | 4.6% |
| LM6 Al-15% B4C composite | 783.2 | 797.7 | 1.9% |

**Table -10The Contact stresses from ANSYS and Hertz equation.**

| Materials | Deformation(mm) |
|---|---|
| Alloy Steel | 0.725 |
| Aluminium | 0.564 |
| Al-15%B4C composite | 0.483 |

**Table -11Deformation from Ansys results**

| MODULE | PRESSURE ANGLE | HERTZ | ANSYS | ERROR |
|---|---|---|---|---|
| 3.965mm | 15 deg | 1495.89M Pa | 1550.3M Pa | 3.62% |
| 6.35 mm | 20 deg | 1300 MPa | 1330 MPa | 2.23% |
| 8.466mm | 25 deg | 1170.67 M Pa | 1188.5M Pa | 1.56% |

**Table -12 Variations in contact stress with respect to change in module and pressure –angle**

**VII.CONCLUSION**

LM6 Al-B4C composites of weight ratios 5%,10%,15% were fabricated through stir casting technique.Mechanical properties like tensile strength, youngs modulus, poisons ratio and hardness are evaluated. spur gears with different specifications are modelled in CatiaV5 and analyzed through Ansys workbench 15.0 which were compared with Hertz equation contact stress values. From all the procedure the following conclusions were drawn.

1. With the increase in % of reinforcement(boron carbide) the hardness of the composite increase from 59(VHN) for pure LM6-Al to 92(VHN) for 15 % reinforced composite.
2. With the increase in % of reinforcement (boron carbide) the tensile strength of the composite increased from 170 MPa for pure alloy to 259 MPa for 15% reinforced composite.
3. It was also observed that modulus of elasticity of the composite also increases with increase in % of reinforcement from 71GPa for pure alloy to 72.6 GPa for 15% reinforcement composite.
4. The density of the composite decrease from 2.65gm/cc for pure LM6Al-alloy to 2.6305 gm/cc for LM6 Al-B4C 15% composite, which shows that the strength to weight ratio increases with increase in % of reinforcement for composite.
5. The compression strength of the composite also increases with the increase in % Of reinforcement which is the most desired property for the gears to withstand high compressive stresses. The % of compression varies from 28.75% for pure LM6-Al alloy to 15% for 15% reinforced LM6-Al-B4C composite.
6. The poisons ratio of the composite also decreases from 0.33 for pure LM6-Al alloy to 0.30975 for 15% reinforced LM6Al-B4Creinforced composite, which indicates that the contact stress decreases with decrease in the poisons ratio by Hertz equation. Thus the composite can be chosen for gears .
7. It was noticed that the contact stress was decreased with increase in module and pressure angle,which can be considered in designing the gear.
8. For composite material the contact stresses and deformations are less when compared with alloy steel and pure LM6Al-alloy.
9. The contact stress values from both hertz theory and Ansys results are agreed.

**VII .FUTURE SCOPE**

This work can be extended by

1. The contact stress analysis for new composite material.

2.The analysis can be done for another type of gear helical, worm, bevel gear etc.

3.The contact stress can be varied by changing the tooth profile of the spur gear design.

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