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DESIGN ANALYSIS AND IMPLEMENTATION OF ALUMINIUM – SILICON CARBIDE – ZIRCONIA COMPOSITE SPUR GEAR FOR AUTOMOTIVE APPLICATIONS

[1] K.Nageswara Rao [2] V. Gopinath ,[3]V Srinivasa Reddy
[1] PGstudent , [2, 3] Associate Professor
Department of Mechanical Engineering,
QIS College of Engineering and Technology, Ongole. Andhra Pradesh.

ABSTRACT

Spur gear is the simplest and widely used in power transmission system for various industrial and automobile applications. A spur Gear is generally subjected to bending stress which causes teeth failure. However, it is observed that performance of the spur gear is not satisfactory in certain applications and therefore it is required to explore some alternate materials to improve the performance of the spur gears. Composite materials provide optimum strength with weight reduction and they are emerging as a better alternative for replacing conventional metallic gears. In this work, a conventional metallic gear of Alloy Steel is replaced by the composite gear of aluminum with Silicon Carbide and Zirconia materials. Such Composites material provides much improved mechanical properties such as better strength to weight ratio, more hardness, and hence less chances of failure. In this work, an analysis is made with replacing metallic gear with composite material such as Aluminum with Silicon Carbide and Zirconia so as to increase the working life of the gears to improve overall performance of machine. Finally, the Modeling of spur gear is carried out using Catia software and structural analysis of spur gear is carried out using ANSYS software with different composition of the materials. From the optimized materials identified the suitable composition and further will be carried out the casting of the prototype of spur gear. The results will compare with that of existing materials.

Key words :- conventional metallic gear , optimum strength, Zirconi, salt spray test

1. INTRODUCTION

Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure. The upcoming requirement of power saving and efficiency of mechanical parts during the past few years increased the use of composite materials. Composite materials are preferred in place where lighter materials are desired or required without sacrificing strength. nowadays, composite materials are used in large volume in various engineering structures including space crafts, airplanes, automobiles, boats, sports' equipment's, bridges and buildings. Widespread use of composite materials in industry is due to the good characteristics of its strength to density and hardness to density.

The spur gear transmits mechanical energy from a prime mover to an output device. The spur gears are used in heavy and low duty mechanical devices. But in this study we have emphasized on the low duty application like Textile machines, Printing press machines, Robotic mechanism etc. The major problem observed with existing metallic Spur gear are ¬ Existing gear is made of metal component provides poor weight to strength ratio. ¬ Metallic parts lead to corrosion so need to properly shielded. ¬ More wear in between the gears so required proper lubrication. ¬ Gears are getting costly due to increasing metal prices. ¬ Due to poor weight to strength ratio power losses in gear are higher. Thus gear needs to be redesigned providing energy saving by weight reduction,

providing internal damping, reducing lubrication requirements without increasing cost. Such a scope is provided by application of composite material providing solution to other existing problems in current gears available. Therefore, this work is concerned with the replacement of existing metallic gear with composite material gear in order to make it lighter and increasing the efficiency of mechanical machines

2.LITERATURE REVIEW

S. Mahendran et al (2014), To design the spur gear to study the weight reduction and stress distribution for cast steel and composite materials. Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. It is possible that gears will predominate as the most effective means of transmitting power in future machines due to their high degree of reliability and compactness. In addition, the rapid shift in the industry from heavy industries such as shipbuilding to industries such as automobile manufacture and office automation tools will necessitate a refined application of gear technology. To design the spur gear model using designs software. To study the impact analysis for cast steel and composite materials. To study the torque loading for cast steel and composite materials. Finally, comparing and analyzing of the composite gear with existing cast steel gear is to be done. Malkanagouda patil et al (2014), The possibility of using composite spur gear for power transmission from a Static strength point of view has been proved by the several authors in their previous study. In addition to static analysis, the dynamic response of composite gear using finite element method is studied. The objective of this paper is to study the free vibration behavior of composite spur gear using finite element method. The finite element theory is based on Mindlin's hypothesis which is also known as first order shear deformation plate theory (FSDT). The finite element analysis has been carried out for a composite gear as a four/eight nodded quadrilateral element and five degree of freedom (DOF). In this research, the natural frequencies and mode shapes of the composite gear are obtained after performing modal analysis.
D. Dighe et al (2014), Polymer& polymer composite gears find increasing application because of the low material manufacturing cost, lightweight& quiet operation compared with metal gears. Generally thermoplastic polymers like acetyl polymer & nylon polymer are used for gear applications. But acetyl and nylon gears have low load carrying capacity. To improve the performance of gears, geometry modification had been done like tooth width modification & cooling holes on tooth surface. But, for high power applications, these materials show poor performance. Therefore, it is necessary to select the polymer which has good mechanical properties & good thermal stability. Poly-Ether-Ether-Ketone (PEEK) has high strength & stiffness, low coefficient of thermal expansion which is required for gears. The comparative performance spur gears of 30% glass filled PA66 and 30% glass filled PEEK was investigated in this study. The results show that 30% glass filled PEEK gears have high wear resistance and high torque transmission capacity as compare with 30% glass filled PA66 gears.

Composite is an optimized and required properties that is applied to an object. The aim of applying composite materials is to improve surface properties of a bulk material usually referred to as a substrate. One can improve appearance, adhesion, wettability, corrosion resistance, wear resistance, scratch resistance, etc. Also improve the hardening properties.

The material properties of this experiment is consists of three materials. Mainly here we are taking for this experiment is three elements. Those are aluminum, zirconium oxide, silicon carbide. Here Aluminum takes 90% and zirconium takes 5% and finally Silicon carbide consists of 5%. Here we are taking for because of can improve appearance, adhesion, wettability, corrosion resistance, wear resistance, scratch resistance, etc. Also improve the hardening properties.

CONVENTIONAL MATERIALS: AN OVERVIEW

Cast iron is iron or a ferrous alloy which has been heated until it liquefies, and is then poured into a mould to solidify. It is usually made from pig iron. The alloy constituents affect its color when fractured: white cast iron has carbide impurities which allow cracks to pass straight through. Grey cast iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks.
Carbon (C) and silicon (Si) are the main alloying elements, with the amount ranging from 2.1–4 wt.% and 1–3 wt.%, respectively. Iron alloys with less carbon content are known as steel. While this technically makes these base alloys ternary Fe–C–Si alloys, the principle of cast iron solidification is understood from the binary iron–carbon phase diagram. Since the compositions of most cast irons are around the eutectic point of the iron–carbon system, the melting temperatures closely correlate, usually ranging from 1,150 to 1,200 °C (2,100 to 2,190 °F), which is about 300 °C (572 °F) lower than the melting point of pure iron.

3. EXPERIMENTAL METHODOLOGY

The methodology includes the process sequentially which carried out, this project includes the process of modeling and analysis of both existing materials and composite material in spur gear by FEA Software's. Both the results will compare.

3.1 SAND CASTING

Sand casting, also known as sand molded casting, is a metal casting process characterized by using sand as the mold material. The term "sand casting" can also refer to an object produced via the sand-casting process. Sand castings are produced in specialized factories called foundries. Over 70% of all metal castings are produced via a sand-casting process. Sand casting is relatively cheap and sufficiently refractory even for steel foundry use. In addition to the sand, a suitable bonding agent (usually clay) is mixed or occurs with the sand. The mixture is moistened, typically with water, but sometimes with other substances, to develop strength and plasticity of the clay and to make the aggregate suitable for molding. The sand is typically contained in a system of

frames or boxesknown as a flask. The mold cavities and gate system are created by compacting the sand around models, or patterns, or carved directly into the sand.

Fig 1. Casting images

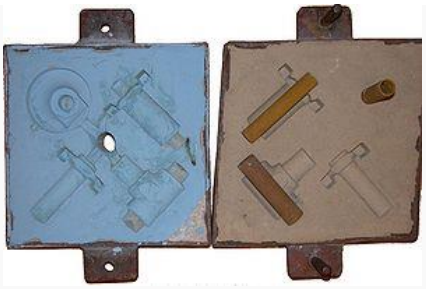


Fig.2 Cope and Drag patterns

Cope & drag (top and bottom halves of a sand mold), with cores in place on the drag

From the design, provided by an engineer or designer, a skilled *pattern maker* builds a *pattern* of the object to be produced, using wood, metal, or a plastic such as expanded polystyrene. Sand can be ground, swept or strickled into shape. The metal to be cast will contract during solidification, and this may be non-uniform due to uneven cooling. Therefore, the pattern must be slightly larger than the finished product, a difference known as *contraction allowance*. Pattern-makers are able to produce suitable patterns using "Contraction rules" (these are sometimes called "shrink allowance rulers" where the ruled markings are deliberately made to a larger spacing according to the percentage of extra length needed). Different scaled rules are used for different metals, because each metal and alloy contracts by an amount distinct from all others. Patterns also have core prints that create registers within the molds into which are placed sand cores. Such cores, sometimes reinforced by wires, are used to create under-cut profiles and cavities which cannot be molded with the cope and drag, such as the interior passages of valves or cooling passages in engine blocks.

Fig.3 Fabricated Spicemen

3.2 TENSILETESTINGOF SPICEMEN

The tension test is the most commonly used method to evaluate the mechanical properties ofmetals. Its main objective is the determination of properties related to the elastic design ofmachines and structures. Since the test is fully standardized and well established, one maystatethat it isa rapidwayofobtainingthedesiredmechanicalcharacteristics of materials.

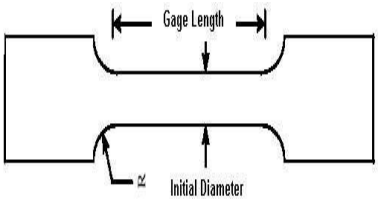


Fig 4. Typical tensile Test Spicemen

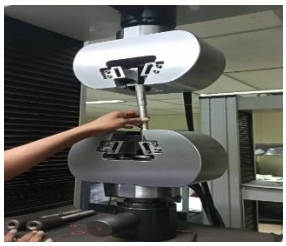


Fig 5 . Tensile test with specimen

Fig .6 Fractured Spicemen after Tensile Test

Table1.ElasticModuliofsomecommonEngineeringMaterials

Material	**ElasticModulus,E(GPa)**
Al-alloys	72.4
Copper	110
Nickel	207
low-CSteel	200
StainlessSteel(18Cr-8Ni)	193
Titanium	117

As one loads the specimen beyond the yield point and then relaxes the load to zero, thematerial does not recover its initial dimensions completely, instead a permanent strain isobserved. This property characterizes the induced deformation as “plastic “and the portion ofthe stress-strain curve beyond the yield point is defined as the plastic “range”.Beyond theyield point, Hooke’s Law is not applicable any more, since the stress needed to producecontinued plastic deformation increases with increasing strain in the plastic region. Thisphenomenon is defined as “strain-hardening”. The maximum point in the engineering stress-strain curve corresponds to the “ultimate tensile strength, UTS” of the material, which is at thesame time the minimum necessary stress to cause the phenomenon known as “necking”.Necking is defined as a localized decrease in the cross-sectional area of the specimen, whichresultsduetotheimperfectionswhichactaslocalstressraisersinthematerial.

3.3 VICKERS HARDNESS TEST

Hardness is a characteristic of a material, not a fundamental physical property. It is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation.

The **Vikersl hardness test method** as used to determine Vikers hardness, is defined in ASTM E10. Most commonly it is used to test materials that have a structure that is too coarse or that have a surface that is too rough to be tested using another test method, e.g., castings and forgings. Vikers testing often use a very high test load (3000 kgf) and a 10mm diameter indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies. The Vikers method applies a predetermined test load (F) to a carbide ball of fixed diameter (D) which is held for a predetermined time period and then removed. The resulting impression is measured with a specially designed Brinell microscope or optical system across at least two diameters – usually at right angles to each other and these results are averaged (d). Although the calculation below can be used to generate the Brinell number, most often a chart is then used to convert the averaged diameter measurement to a Brinell hardness number. Common test forces range from 500kgf often used for non-ferrous materials to 3000kgf usually used for steels and cast iron. There are other Vikers scales with load as low as 1kgf and 1mm diameter indenters but these are infrequently used.

Fig 7. Spicemen for Hardness Test

Fig 8. Vikers Hardness test

Typically, the greatest source of error in Brinell testing is the measurement of the indentation. Due to disparities in operators making the measurements, the results will vary even under perfect conditions. Less than perfect conditions can cause the variation to increase greatly. Frequently the test surface is prepared with a grinder to remove surface conditions. The jagged edge makes interpretation of the indentation difficult. Furthermore, when operators know the specifications limits for rejects, they may often be influenced to see the measurements in a way that increases the percentage of "good" tests and less re-testing.

Two types of technological remedies for countering Brinell measurement error problems have been developed over the years. Automatic optical Brinell scopes, such as the B.O.S.S. system, use computers and image analysis to read the indentations in a consistent manner. This standardization helps eliminate operator subjectivity so operators are less-prone to automatically view in-tolerance results when the sample's result may be out-of-tolerance.

Brinell units, which measure according to ASTM E103, measure the samples using Brinell hardness parameters together with a Rockwell hardness method. This method provides the most repeatable results (and greater speed) since the vagaries of optical interpretations are removed through the use of an automatic mechanical depth measurement. Using this method, however, results may not be strictly consistent with Brinell results due to the different test methods – an offset to the results may be required for some materials. It is easy to establish the correct values in those cases where this may be a problem.

3.4 SALT SPRAY TEST

The salt spray test is a standardized test method used to check corrosion resistance of coated samples. Coatings provide corrosion resistance to metallic parts made of steel, zinc or brass. Since coatings can provide a high corrosion resistance through the intended life of the part in use, it is necessary to check corrosion resistance by other means. Salt spray test is an accelerated corrosion test that produces a corrosive attack to the coated samples in order to predict its suitability in use as a protective finish. The appearance of corrosion products (oxides) is evaluated aftera period of time. Test duration depends on the corrosion resistance of the coating; the more corrosion resistant the coating is, the longer the period in testing without showing signs of corrosion.

Salt spray testing is popular because it is cheap, quick, well standardized and reasonably repeatable. There is, however, only a weak correlation between the duration in salt spray test and the expected life of a coating (especially on hot dip galvanized steel where drying cycles are important for durability), since corrosion is a very complicated process and can be influenced by many external factors. Nevertheless, salt spray test is widely used in the industrial sector for the evaluation of corrosion resistance of finished surfaces or parts.

The salt spray test is a standardized and popular corrosion test method, used to check corrosion resistance of materials and surface coatings. Usually, the materials to be tested are metallic and finished with a surface coating which is intended to provide a degree of corrosion protection to the underlying metal.

Salt spray testing is an accelerated corrosion test that produces a corrosive attack to coated samples in order to evaluate (mostly comparatively) the suitability of the coating for use as a protective finish. The appearance of corrosion products (rust) is evaluated after a pre-determined period of time. Test duration depends on the corrosion resistance of the coating; generally, the more corrosion resistant the coating is, the longer the period of testing before the appearance of corrosion/ rust. The salt spray test is one of the most widespread and long established corrosion tests. ASTM B117 was the first internationally recognized salt spray standard, originally published in 1939. Other important relevant standards are ISO9227, JIS Z 2371 and ASTM G85

Testing equipment

Fig 9.Salt spray cabinet

Salt spray cabinet

The apparatus for testing consists of a closed testing chamber, where a salted solution (mainly, a solution of 5% sodium chloride) is atomized by means of a nozzle. This produces a corrosive environment of dense saline fog in the chamber so that parts exposed in it are subjected to severely corrosive conditions. Typical volumes of these chambers are of 15 cubic feet (420 L) because of the smallest volume accepted by International Standards on Salt Spray Tests - ASTM-B-117, ISO 9227 and now discontinued DIN 50021 (400 liters). It has been found very difficult to attain constancy of corrosivity in different exposure regions within the test chambers, for sizes below 400 liters. Chambers are available from sizes as small as 4.3 cu ft. (120 L) up to 2,058 cubic feet (58,300 L). Most common machines range from 15 to 160 cubic feet (420–4,530 L).

The optical microscope, often referred to as the "light microscope", is a type of microscope which uses visible light and a system of lenses to magnify images of small samples. Optical microscopes are the oldest design of microscope and were possibly invented in their present compound form in the 17th century. Basic optical microscopes can be very simple, although there are many complex designs which aim to improve resolution and sample contrast.

The image from an optical microscope can be captured by normal light-sensitive cameras to generate a micrograph. Originally images were captured by photographic film but modern developments in CMOS and charge-coupled device (CCD) cameras allow the capture of digital images. Purely digital sample, showing the resulting image directly on a computer screen..

4. RESULTS

4.1.Tensile Test

Table 2. Tensile test results

Test Parameters	**Observed Values**	
Sample Id	**T1**	**T2**
Ultimate Tensile Strength(N/mm2/MPA)	94	92
Yield Strength(Mpa)	52	52
Elongation(50 mm GL)	5.0	5.0

4.2.Vikers Hardness Test

Table 3.Vikers Hardness test results

Test Parameter	**Observed Values**
Observed Values in (HV5 kg)	40.6, 41.2, 41.8

4.3.Salt Spray Test

Test Parameters:

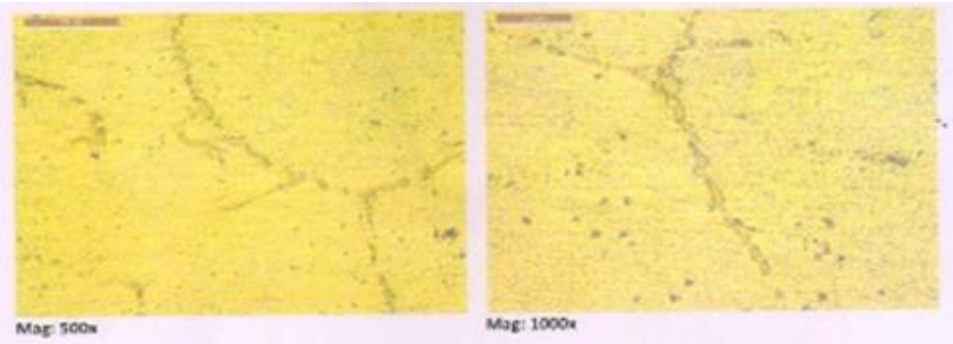
Chamber Temperature:34.5-35.5 Deg Centigrade
pH Value: 6.65-6.85
Value of Salt Solution Collected:1.00- 1.50 ml/hr
Concentration of Solution :4.80 - 5.30% of Nacl
Air Pressure : 14-18 Psi, Components Loading in the Chamber Position : 30 Degree Angle.

Observation:

No White Rust Formation noticed at Up to 18 Hrs

MICROSTRUCTURE STUDY

Microstructural images of Aluminium-SiC - Zirconia composite is shown in fig . The study of microstructure is very useful for the analysis of properties & proportion of reinforcement particulates mixing with the matrix. Microstructure studies of composite worn surfaces were examined in light optical Microscope. The light optical microscope is a type of optical microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties. The microstructures of Al+SiC with Zirconia (with percentage of 5%) composite is shown in the figure 1 and 2 where Zirconia particulates were dispersed uniformly with the Aluminium matrix. Good retention of particles was clearly seen in the microstructures of aluminium with zirconia composites in the figure 2. Micro structure discussion shows the uniform distribution of Silicon Carbide and Zirconia particulates with the Aluminum. The microstructure also revealed good interfacial bonding between Aluminium and reinforcement particulates like Zirconia percentage of 5% with Aluminium alloy. Therefore, when Zirconia is increasing the bonding and adhesion strength also increased.



5.ANALYSIS OF COMPOSITE MATERIAL:

1. Total Deformation:

Deformation analysis is concerned with determining if a measured displacement is significant enough to warrant a response. Deformation data must be checked for statistical significance, and then checked against specified limits, and reviewed to see if movements below specified limits imply potential risks.

a. Structural Steel

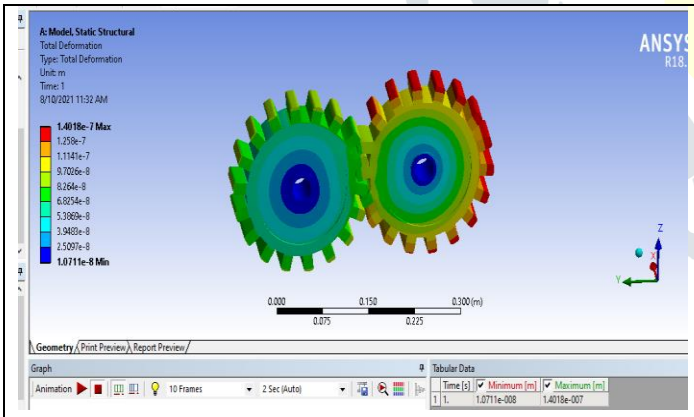


Fig 11. a. Structural Steel of total deformaion
b.90% Al + 5 % ZrO + 5 % SiC

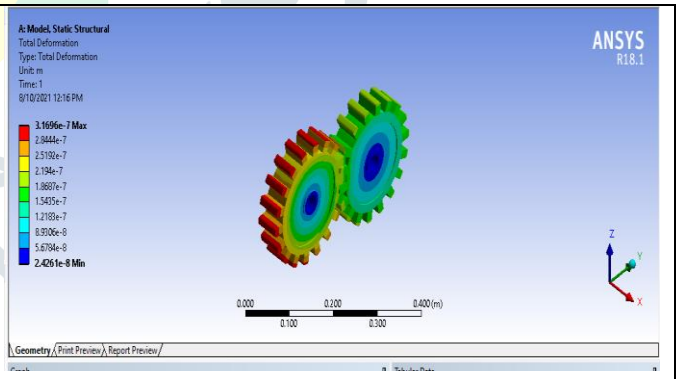


Fig 11.b. Alloyng of 90% Al + 5 % ZrO + 5 % SiC
c.92% Al + 4 % ZrO + 4 % SiC

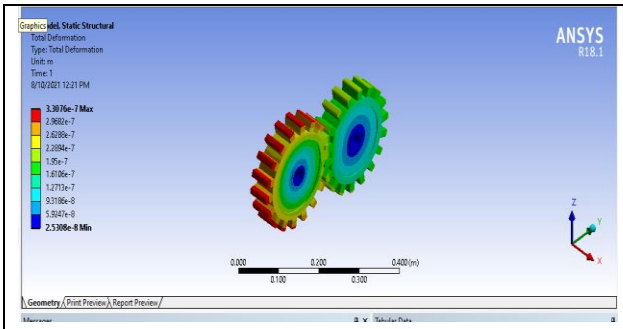


Fig 11.c. alloying of 92% Al + 4 % ZrO + 4 % SiC
d.96% Al + 2%Zr + 2% SiC

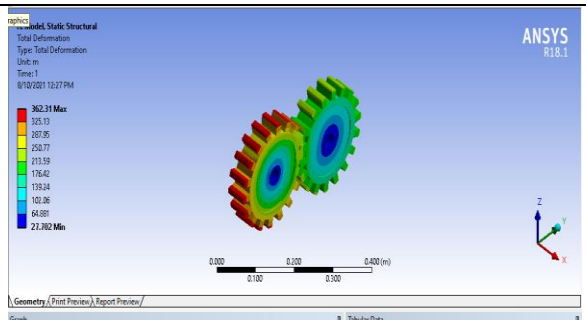


Fig 11.d. alloying of 96% Al + 2%Zr + 2% SiC

2. Equivalent Stress (von – Mises):

The von Mises yield criterion states that if the von Mises stress of a material under load is equal or greater than the yield limit of the same material under simple tension then the material will yield.

a. Structural Steel

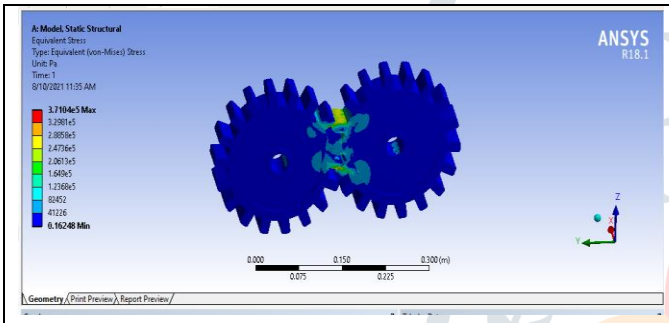


Fig 12.a.Structural Steel of Equivalent Stress (von – Mises
b.90% Al + 5 % ZrO + 5 % SiC

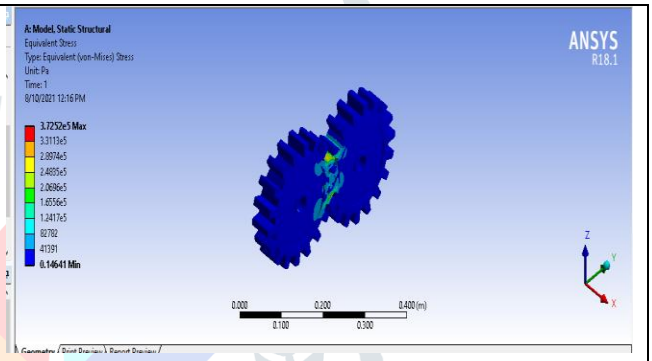


Fig 12.b. alloying of .90% Al + 5 % ZrO + 5 % SiC
c.92% Al + 4 % ZrO + 4 % SiC

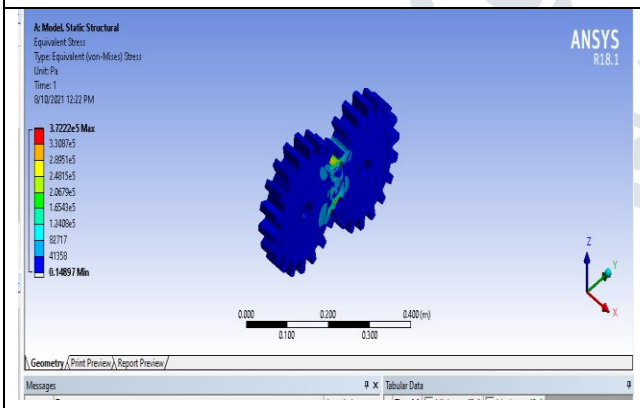


Fig 12.c. alloying of 92% Al + 4 % ZrO + 4 % SiC
d.96% Al + 2%Zr + 2% SiC

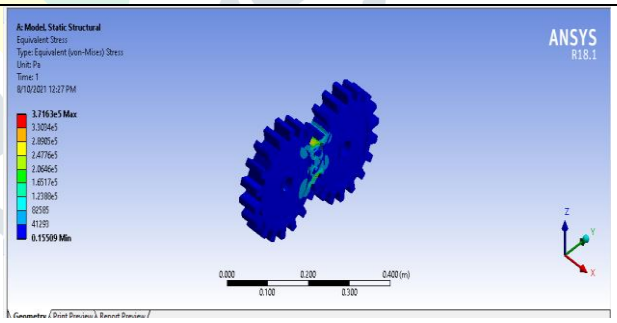


Fig 12.d.alloying of 96% Al + 2%Zr + 2% SiC

c. Contact Stress:

Hertzian contact stress refers to the localized stresses that develop as two curved surfaces come in contact and deform slightly under the imposed loads. This amount of deformation is dependent on the modulus of elasticity of the material in contact.

a. Structural Steel

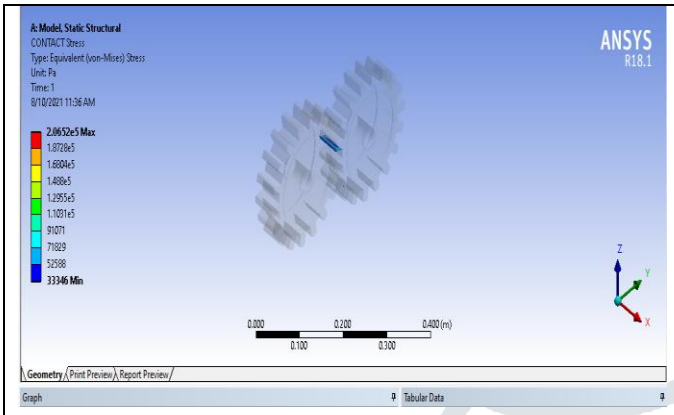


Fig 13.a.a. Structural Steel of contact stress

b.90% Al + 5 % ZrO + 5 % SiC

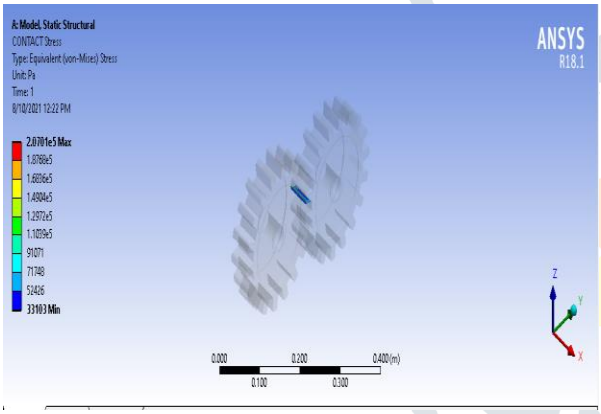


Fig 13.c. alloying of 92% Al + 4 % ZrO + 4 % SiC

d.96% Al + 2%Zr + 2% SiC

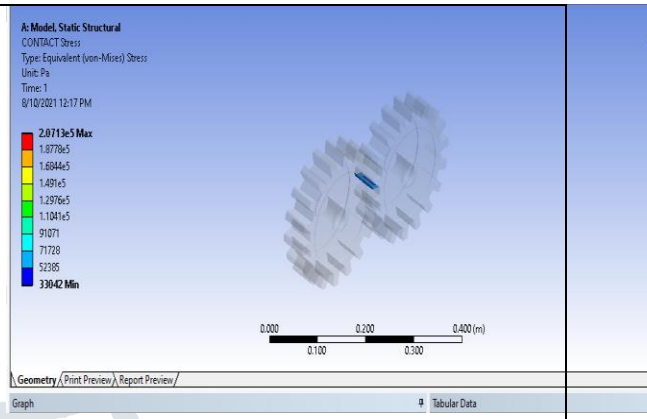


Fig 13.b. alloying of 90% Al + 5 % ZrO + 5 % SiC

c.92% Al + 4 % ZrO + 4 % SiC

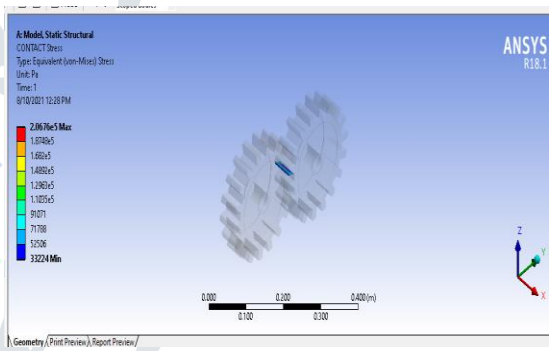


Fig 13.d. alloying of 96% Al + 2%Zr + 2% SiC

4. Pressure:

The pressure angle of a gear is defined as the angle formed by the radial line and the line tangent to the profile at the pitch point. The pressure angle of a gear is also the angle between the line of action and the line tangent to the pitch circles of mating gears.

a. Structural Steel

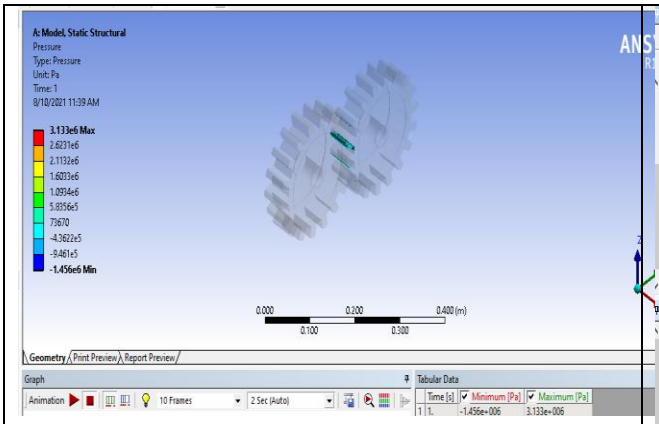


Fig 14.a.Structural Steel of Pressure
b.90% Al + 5 % ZrO + 5 % SiC

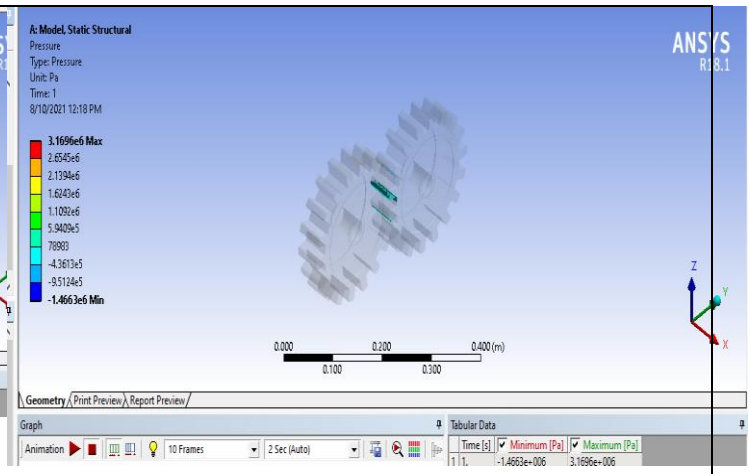


Fig 14.b. alloying of 90% Al + 5 % ZrO + 5 % SiC
c.92% Al + 4 % ZrO + 4 % SiC

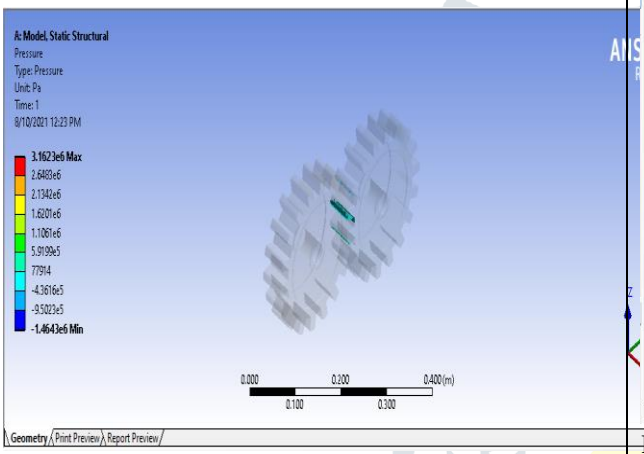


Fig 14.c.alloying of 92% Al + 4 % ZrO + 4 % SiC
d.96% Al + 2%Zr + 2% SiC

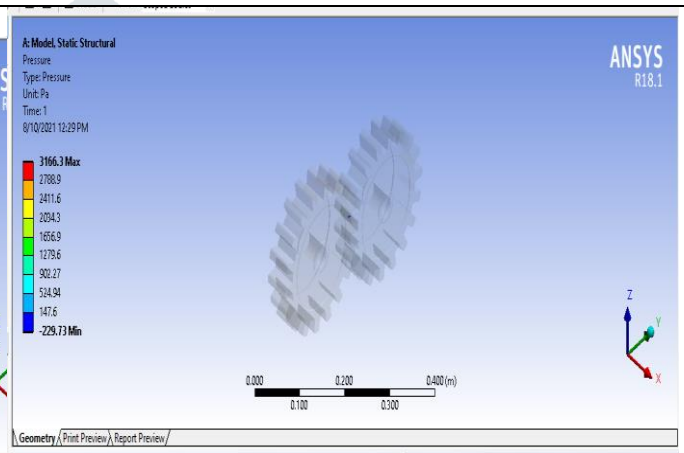


Fig 14.d.alloying of 96% Al + 2%Zr + 2% SiC

5. Penetration

a. Structural Steel

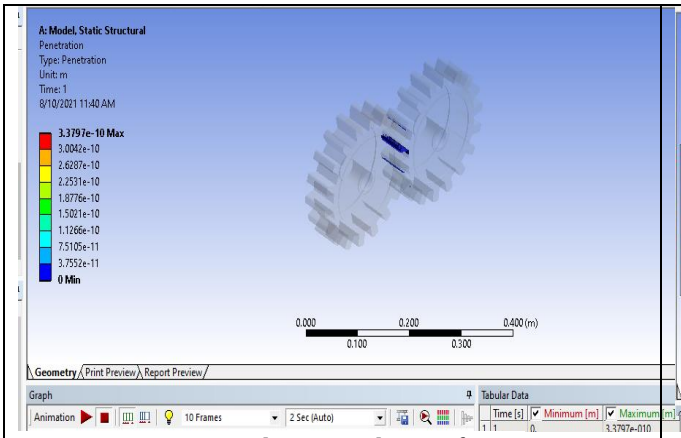


Fig 15.a.Structural Steel of Penetration
b.90% Al + 5 % ZrO + 5 % SiC

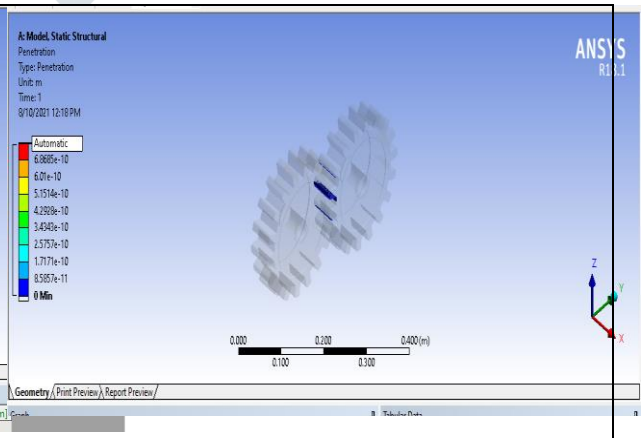
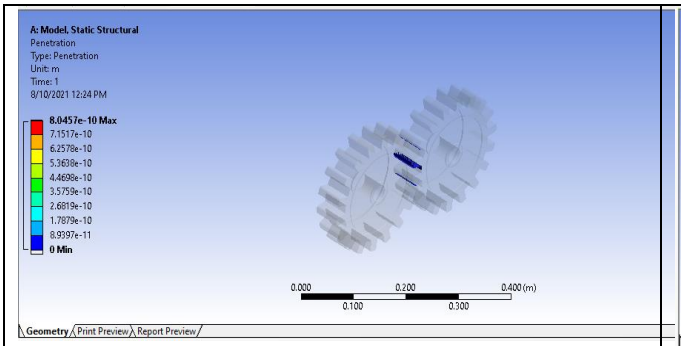
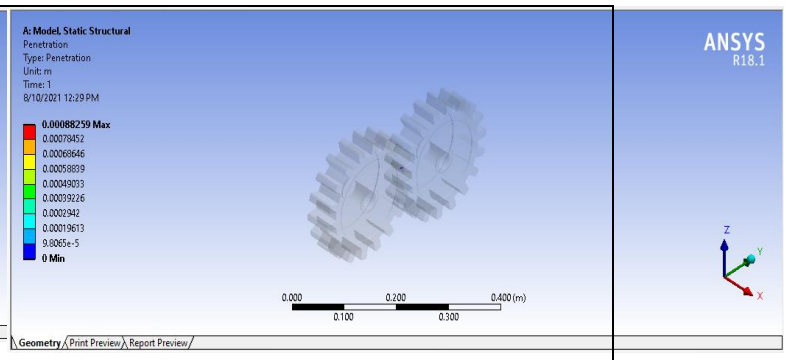


Fig 15.b. alloying of 90% Al + 5 % ZrO + 5 % SiC



15 c.92% Al + 4 % ZrO + 4 % SiC



15 d.96% Al + 2%Zr + 2% SiC

6. Sliding Distance

a. Structural Steel

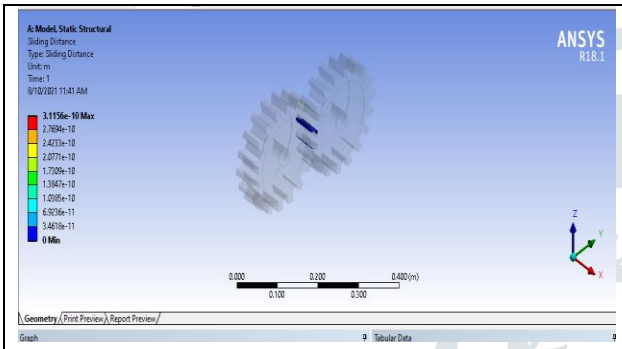


Fig 16.a. Structural Steel of . Sliding Distance

b.90% Al + 5 % ZrO + 5 % SiC

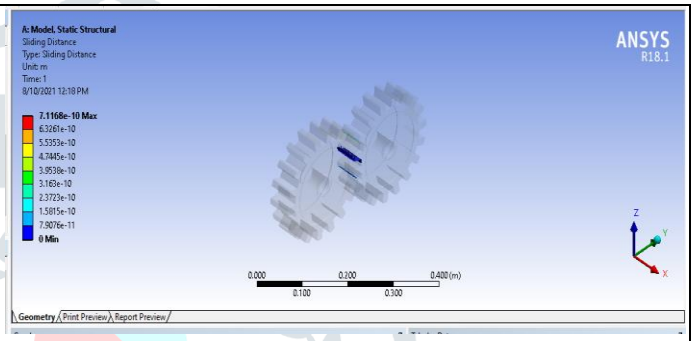


Fig 16.b. alloying of 90% Al + 5 % ZrO + 5 % SiC

c.92% Al + 4 % ZrO + 4 % SiC

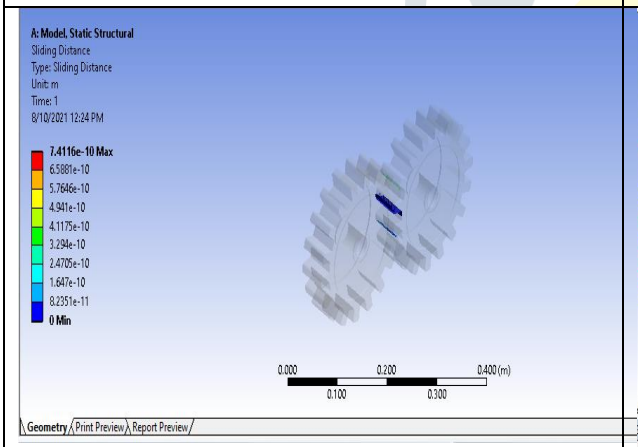


Fig 16.c. alloying of 92% Al + 4 % ZrO + 4 % SiC

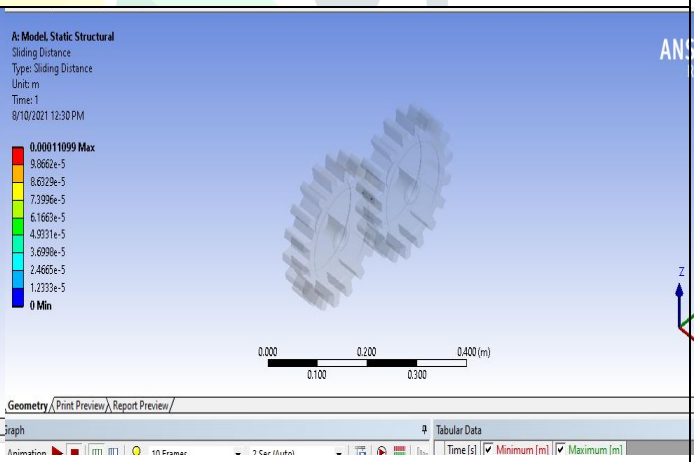


Fig 16.d. alloying of 96% Al + 2%Zr + 2% SiC

5.1. COMPARISON OF RESULTS

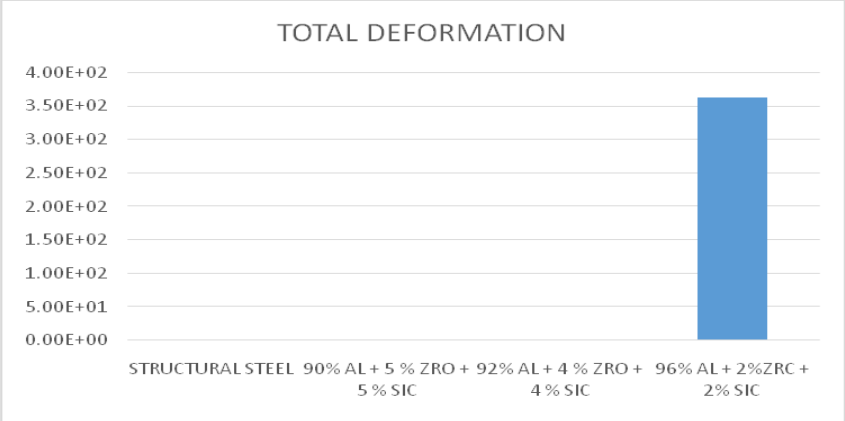


Figure 17 .Total deformation

In materials science, deformation refers to modifications of the shape or size of an object due to applied forces or a change in temperature. Deformation is usually caused by forces such as: Tensile (pulling) Compressive (pushing) and Shear.Total deformation is the vectors sum all directional displacements of the systems. So from the comparison graph it can be interpreted that when the spur gear is casted with 96%Al+2%ZRC+2%SIC it is highly deformable.

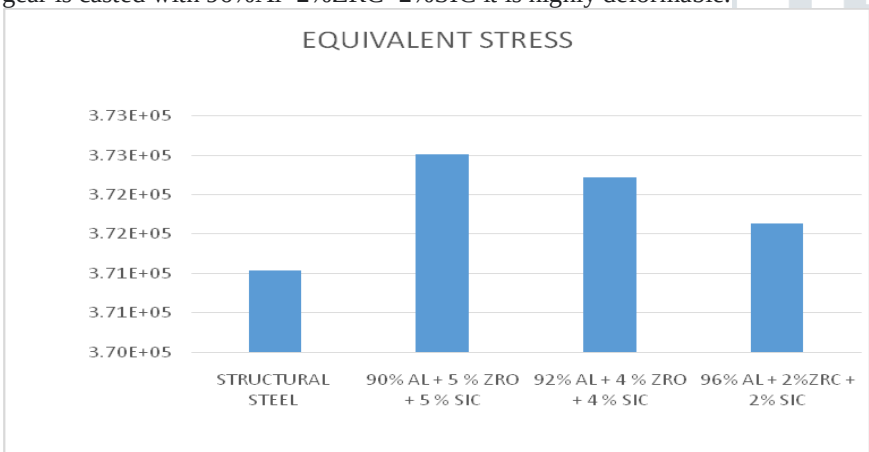


Figure 18.Equivalent stress

Equivalent stress is widely used to represent a material's status for ductile material. Equivalent (Von Mises) stress is a value used to determine if a given material will yield or fracture. It is mostly used for ductile materials, such as metals. The von Mises yield criterion states that if the von Mises stress of a material under load is equal or greater than the yield limit of the same material under simple tension then the material will yield. Thus it was observed that when the spur gear when casted with 96%Al+2%ZRC+2%SIC had yielded better than the other compositions.

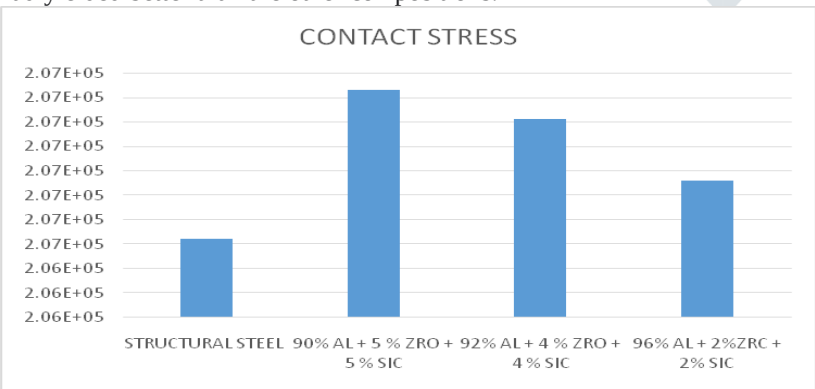


Figure 19. Contact stress

Contact stress analysis for spur gears is performed between two gear teeth at different contact positions during rotation. In machine design, problems frequently occurs when two members with curved surfaces are deformed when pressed against one another giving

rise to an area of contact under compressive stresses. Thus it was observed that the gear when casted with 96%Al+2%ZRC+2%SIC optimum contact stress is attained.

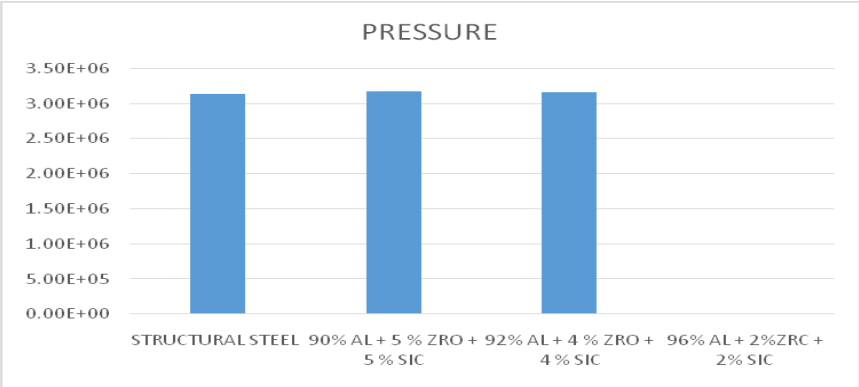


Figure 20. Pressure

Pressure angle (also referred to as tooth shape) is the angle at which the pressure from the tooth of one gear is passed onto the tooth of another gear. And hence from the comparison graph it can be correlated that the gear had shown less pressure angle compared to other materials.

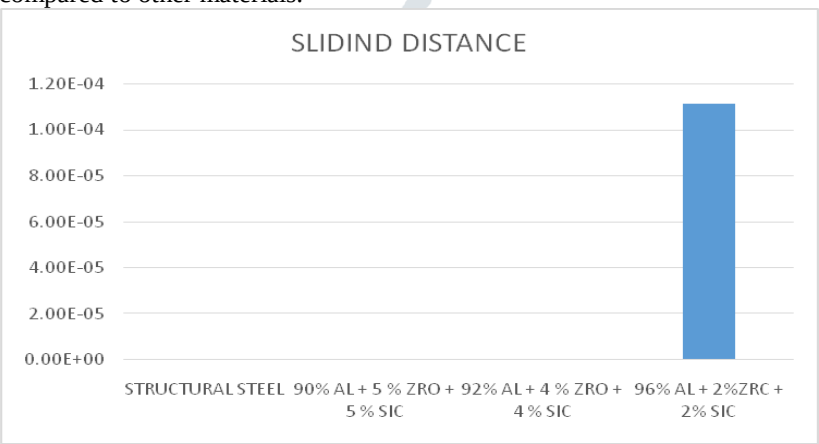


Figure 21. Sliding distance

Sliding velocity is the relative velocity in a transverse plane of a common contact point between mating gear teeth, it is the vectorial difference between the two rolling velocities that are tangential to the tooth profiles and perpendicular to the line of action.

6. CONCLUSION

From the obtained numerical results, it was found that the best composition of aluminium-SiC-Zirconia for spurs gear. In this work the experimental and analysis on the fabricated composite material has been done successfully. The results of the composite material which is fabricated by using casting technique and to determine stress , strain and displacements analysis has been taken to find out the optimum composition of above said materials. Also found from the obtained experimental investigation, the Tensile and hardness was improved with 90%aluminium – 5%Silicon Carbide-5%Zirconia.

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