



## **The Structural and Thermal Analysis of Two Different Composition Piston Geometry using Finite Element Method**

**I.J.Isaac Premkumar\*, K.Santhosh<sup>1</sup>, R.Loganathan<sup>2</sup>,  
K.R.Motilal<sup>3</sup> and P.Jayaraman<sup>4</sup>**

<sup>1,2</sup>Department of Mechanical Engineering, V.S.B College of Engineering Technical Campus, Coimbatore – 642109, Tamilnadu, India.

<sup>3,4</sup>, Department of Mechanical Engineering, V.S.B College of Engineering Technical Campus, Coimbatore – 642109, Tamilnadu, India.

**Abstract :** In this study, static structural analysis and thermal analysis were investigated on a conventional diesel piston, made of aluminum silicon alloy. The usage of Al-SiC Metal Matrix Composites was constantly increasing in the last years due to their unique properties such as light weight, high strength, high specific modulus, high fatigue strength, high hardness and low density. Al-SiC composites of various carbide compositions were produced using a centrifugal casting machine and stir casting machine. The mechanical properties, hardness, tensile strength, yield stress and elongation were studied in order to determine the optimum strength of the metal matrix composites. Scanning electron microscopy was used to study the microstructure-property correlation. It was observed that the tensile and hardness of the composites increased as the proportion of silicon carbide became higher in the composites. Also with increasing proportion of silicon carbide in the composite, the material became harder and appeared to have smaller values for total displacement and total energy during impact testing.

**Key words :** Diesel piston, Carbide compositions, Microstructure-property, Silicon carbide, Impact testing.

### **1. Introduction:**

Metal composite materials have found application in many areas of day to day life for quite some time. In traffic engineering, especially in the automotive industry, MMCs have been used commercially in fiber reinforced pistons and aluminum crank cases with strengthened cylinder surfaces as well as particle strengthened brake disks. Aluminum was a chemical element in the boron group with symbol Al and atomic number was 13. It was silvery white, and it was insoluble in water under normal circumstances. Aluminum alloys were alloys in which aluminium (Al) was the strongest metal. The typical alloying elements were silicon and zinc. There were two divisions, namely casting alloys and wrought alloys. Silicon carbide (SiC)<sub>[1]</sub>, was a compound of silicon and carbon with chemical formula SiC. It occurs in nature as the extremely rare mineral

**I.J.Isaac Premkumar *et al* / International Journal of ChemTech Research, 2019,12(2): 152-161.**

DOI= <http://dx.doi.org/10.20902/IJCTR.2019.120219>

moissanite. Silicon carbide powder had been mass-produced since 1893 for use as an abrasive. Grains of silicon carbide can be bonded together by sintering to form very hard ceramics that were widely used in applications requiring high endurance, such as car brakes, car clutches and ceramic plates in bulletproof vests. Electronic applications of silicon carbide such as light-emitting diodes (LEDs) and detectors in early radios were first demonstrated around 1907. SiC was used in semiconductor electronics devices that operate at high temperatures or high voltages, or both. Large single crystals of silicon carbide can be grown by the Lely method; they can be cut into gems known as synthetic moissanite. Silicon carbide with high surface area can be produced from SiO<sub>2</sub> contained in plant material.

Composites reinforced with particulate (discontinuous types of reinforcement) can have costs comparable to unreinforced metals, with significantly better hardness, and somewhat better stiffness and strength. Continuous reinforcement (long fiber or wire reinforcement) can result in dramatic improvements in MMC properties, but costs remain high. Continuously and discontinuously reinforced MMCs have very different applications, and will be treated separately throughout this chapter.

Tailor ability was a key advantage of all types of composites, but was particularly so in the case of MMCs. MMCs can be designed to fulfill requirements that no other materials, including other advanced materials, can achieve. There were a number of niche applications in aerospace structures and electronics that capitalize on this advantage.

Metal matrix composites (MMCs)<sup>[1]</sup> usually consist of a low-density metal, such as aluminium (properties of Aluminium, table.1) or magnesium, reinforced with particulate or fibers of a ceramic material, such as silicon carbide (properties of silicon carbide, table.1) or graphite. Compared with unreinforced metals, MMCs offer higher specific strength and stiffness, higher operating temperature, and greater wear resistance, as well as the opportunity to tailor these properties for a particular application.

## 2. Materials and Methods:

### 2.1 Al-SiC preparation and properties:

Al-SiC composites of various carbide compositions were produced using a centrifugal casting machine and stir casting machines as shown in Figure.1. In a stir casting process as shown in Figure.3, the reinforcing phases were distributed into molten matrix by mechanical stirring. Stir casting<sup>[2]</sup> of metal matrix composites was initiated in 1968, when S. Ray introduced alumina particles into aluminum melt by stirring molten aluminum alloys containing the ceramic powders. Mechanical stirring in the furnace was a key element of this process. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting was suitable for manufacturing composites with up to 30% volume fractions of reinforcement.

The cast composites were sometimes further extruded to reduce porosity, refine the microstructure, and homogenize the distribution of the reinforcement. A major concern associated with the stir casting process was the segregation of reinforcing particles which was caused by the surfacing or settling of the reinforcement particles during the melting and casting processes. The final distribution of the particles in the solid depends on material properties and process parameters such as the wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification. The distribution of the particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added.

An interesting recent development in stir casting was a two-step mixing process. In this process, the matrix material was heated to above its liquidus temperature so that the metal was totally melted. The melt was then cooled down to a temperature between the liquidus and solidus points and kept in a semi-solid state. At this stage, the preheated particles were added and mixed. The slurry was again heated to a fully liquid state and mixed thoroughly. This two-step mixing process had been used in the fabrication of aluminum. Among all the well-established metal matrix composite fabrication methods, stir casting was the most economical. For that reason, stir casting was currently the most popular commercial method of producing aluminum based composites.



Figure.1 Stir casting Equipment

## 2.2 Weight Fractions of mixture:

Assuming that the composite material consists of fibers and matrix material, the weight of the composite material was equal to the sum of the weight of the fibers and the weight of the matrix.

Therefore,  $W_c = w_f + w_m$  where,

Al 6061 90% SiC 10% as shown in Figure.2

$$500 \text{ g} = 500(.90) + 500(.1) \text{g}$$

$$= 450 + 50$$

$$= 500 \text{ g}$$

$w_c$  - weight of composite material

$w_f$  - weight of fiber

$w_m$  - weight of matrix

## 2.3 Density of mixture:

$$\rho_c = \rho_f V_f + \rho_m V_m$$

$$= \text{density of Al6061} (0.90) + \text{density of SiC} (0.1)$$

$$= 2700 (0.90) + 3100 (0.1)$$

$$= 2430 + 310 = 2740 \text{ Kg/mm}^3$$

## 2.4 Weight ratio



Figure.2 450 gms of aluminium with 50 gms of SiC



**Figure.3 Stir casting and mixing**

**Table.1 Properties of Al-SiC:**

Properties	Al 6061	SiC
Density (Kg/mm <sup>3</sup> )	2700	3100
Young's modulus (Gpa)	75	410
Poisson's Ratio	0.33	0.14
Tensile Strength (Mpa)	115	390

### 3. Result and Discussion:

#### 3.1 Test performances:

##### 3.1.1 Measurement of Hardness:

Hardness was not an intrinsic material property dictated by precise definitions in terms of fundamental units of mass, length and time. A hardness property value was the result of a defined measurement procedure. The Rockwell hardness test method as shown in Figure.5 consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter was forced into the test material as shown in Figure.4 under a preliminary minor load  $F_0$  usually 10 kgf. When equilibrium had been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, was set to a datum position. While the preliminary minor load was still applied an additional major load was applied with resulting increase in penetration. When equilibrium had again been reached, the additional major load was removed but the preliminary minor load was still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load was used to calculate the Rockwell hardness number.

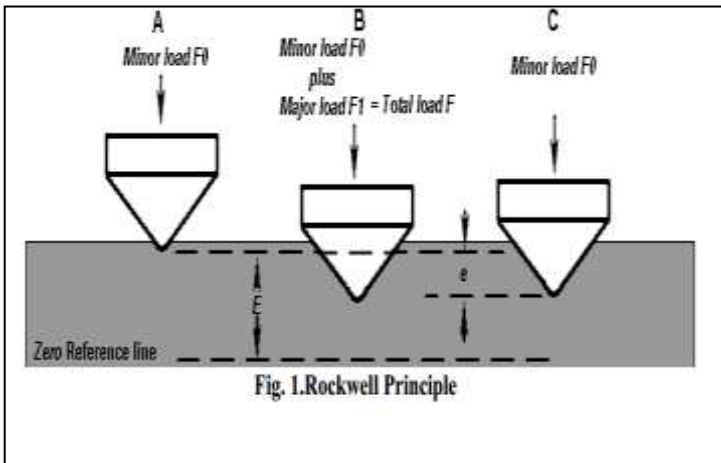


Figure.4 Rockwell Hardness

Figure.5 Rockwell Hardness Test

$$HR = E - e$$

F0 = preliminary minor load in kgf

F1 = additional major load in kgf

F = total load in kgf

e = permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm

E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter

HR = Rockwell hardness number

D = diameter of steel ball

Advantages of the Rockwell hardness method include the direct Rockwell hardness number readout and rapid testing time. Disadvantages include many arbitrary non-related scales and possible effects from the specimen support anvil (try putting a cigarette paper under a test block and take note of the effect on the hardness reading Table.2 Vickers and Brinell methods don't suffer from this effect).

### 3.1.2 Rockwell Hardness Testing Results

Table.2 Test results

S. No	Sample Id	Observed values, HRB			Average, HRB
		1	2	3	
1	Al-SiC10%	70	71	70	70

## 3.2 Tensile Test

### 3.2.1 Testing with UTM

Mechanical testing plays an important role in evaluating fundamental properties of engineering materials as well as in developing new materials and in controlling the quality of materials for use in design and construction. If a material was to be used as part of an engineering structure that will be subjected to a load, it was important to know that the material was strong enough and rigid enough to withstand the loads that it will experience in service. As a result engineers have developed a number of experimental techniques for mechanical testing of engineering materials subjected to tension, compression, bending or torsion loading. The most common type of test used to measure the mechanical properties of a material was the Tension Test as shown in Figure.6. Tension test was widely used to provide basic design information on the strength of materials and was an acceptance test for the specification of materials. The major parameters that describe the stress-strain curve obtained during the tension test were the tensile strength (UTS), yield strength or yield point ( $\sigma_y$ ), elastic modulus (E), percent elongation ( $\Delta L\%$ ) and the reduction in area (RA%). Toughness, Resilience, Poisson's ratio ( $\nu$ ) can also be found by the use of this testing technique.

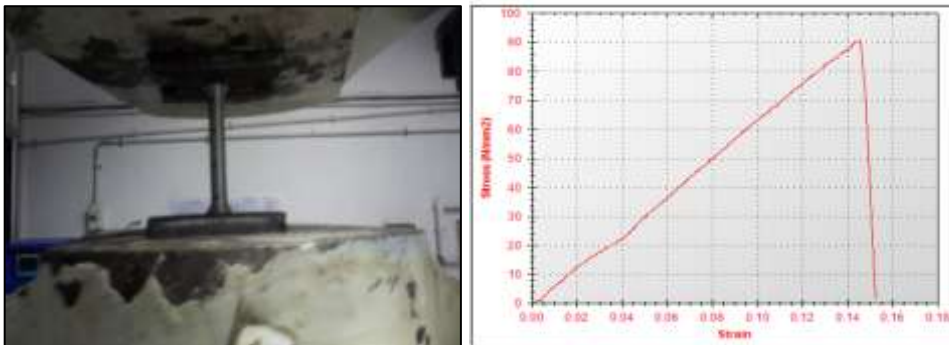
### 3.2.2 Yield Strength

Yield strength was the stress level at which plastic deformation starts. The beginning of first plastic deformation was called yielding. It was an important parameter in design. The stress at which plastic deformation or yielding was observed to begin depends on the sensitivity of the strain measurements. With most materials there was a gradual transition from elastic to plastic behavior, and the point at which plastic deformation begins was hard to define with precision. Various criteria for the initiation of yielding were used depending on the sensitivity of the strain measurements and the intended use of the data. 0.2% off-set method was a commonly used method to determine the yield strength.  $\Sigma_y$  (0.2%) was found by drawing a parallel line to the elastic region and the point at which this line intersects with the stress-strain curve was set as the yielding point. An illustration of 0.2% off-set method was shown in the appendix part.

### 3.2.3 Ductility:

Ductility was the degree of plastic deformation that a material can withstand before fracture. A material that experiences very little or no plastic deformation upon fracture was termed brittle. In general, measurements of ductility were of interest in three ways:

- To indicate the extent to which a metal can be deformed without fracture in metalworking operations such as rolling and extrusion.
- To indicate to the designer, in a general way, the ability of the metal to flow plastically before fracture.
- To serve as an indicator of changes in impurity level or processing conditions. Ductility measurements may be specified to assess material quality even though no direct relationship exists between the ductility measurement and performance in service.



**Figure.6 Tensile test and Stress strain diagram Al-SiC**

### 3.2.4 TENSILE TEST REPORT

Yield Stress	: 72.177 N/mm <sup>2</sup>
Tensile Strength	: 90.667 N/mm <sup>2</sup>
Elongation	: 2.12 %

## 3.3 Micro Analysis

### 3.3.1 Microstructure analysis:

Microstructure was defined as the structure of a prepared surface or thin foil of material as revealed by a microscope above 25 $\times$  magnification. The microstructure of a material can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behavior, wear resistance, and so on, which in turn govern the application of these materials in industrial practice. Microstructure at scales smaller than can be viewed with optical microscopes was often called ultra-structure or nanostructure. While the structure in which individual atoms were arranged was known as crystal structure. The nanostructure of biological specimens was referred to as ultrastructure. A microstructure's influence on the mechanical and physical properties of a material was primarily governed by the different defects present or absent of the structure. These defects can take many forms but the primary ones were the pores. Even if those

pores play a very important role in the definition of the characteristics of a material, so does its composition. In fact, for many materials, different phases can exist at the same time. These phases have different properties and if managed correctly, can prevent the fracture of the material.

### 3.3.2 Method:

The concept of microstructure was perhaps more accessible to the casual observer through macro structural features in commonplace objects. If one ever comes across a piece of galvanized steel, such as the casing of a lamp post or road divider, one observes that the surface was not uniformly colored, but was covered with a patchwork of interlocking polygons of different shades of grey or silver. Each polygon (the most frequently occurring would be hexagons) was a single crystal of zinc adhering to the surface of the steel beneath. Zinc and lead were two common metals which form large crystals visible to the naked eye. The metallic atoms in each crystal were well-organized into one of seven crystal lattice systems possible for metals (cubic, tetrahedral, hexagonal, monoclinic, triclinic, rhombohedral, and orthorhombic); these systems dictate that the atoms were all lined up like points in a 3-D matrix. However, the direction of alignment of the matrices differ from crystal to adjacent crystal, leading to variance in the reflectivity of each presented face of the interlocked crystals on the galvanized surface. Symmetrical crystals were generally unstressed, unworked. They grow in all directions equally and were not subjected to deforming stresses either during or after. For large crystals, the ratio of crystal bulk to inter-crystal boundary (more properly, intergranular boundary) was high. This indicates high ductility but correspondingly, lower strength but a true study would take into quantitative account the relative strengths of the crystal and that of inter-crystal bonding. Microstructure analysis was performed on the cross section perpendicular to the welding direction. Keller's reagent can refer to either of two different mixtures of acids. In metallurgy, Keller's reagent was a mixture of nitric acid, hydrochloric acid, and hydrofluoric acid, used to etch aluminum alloys to reveal their grain boundaries and orientations. It was also sometimes called Dix-Keller reagent. Microstructure of the weld was observed by optical microscope and scanning electron microscope equipped with an EDX system.

### 3.3.3 Test Results

Micro Test

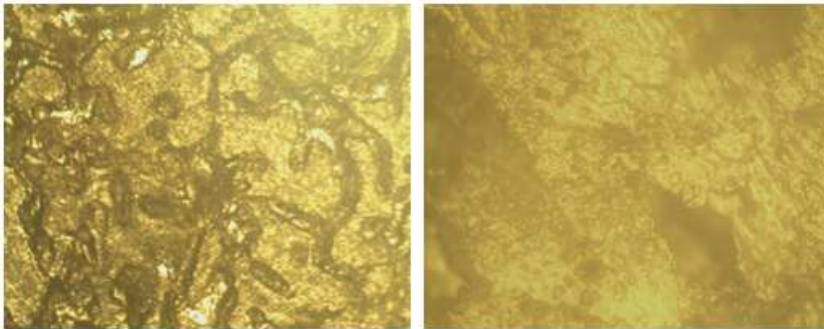


Figure.7 Mag 100X

Figure.8 Mag 400X

### 3.4 Static structural analysis:

A static structural analysis<sub>[10]</sub> determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions were assumed; that was, the loads and the structure's response were assumed to vary slowly with respect to time. A static structural load can be performed using the ANSYS as shown in Figure.9,10,11 and 12.

3.4.1 Ansys result for Aluminium:

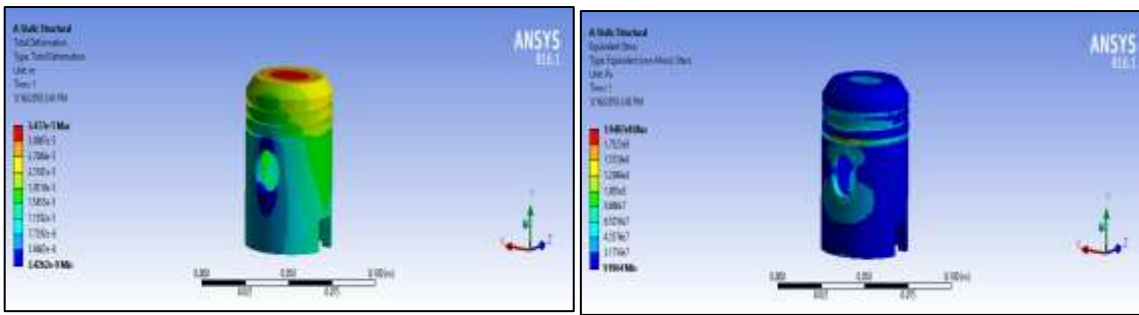


Figure.9 Total deformation and Equivalent stress of Aluminium

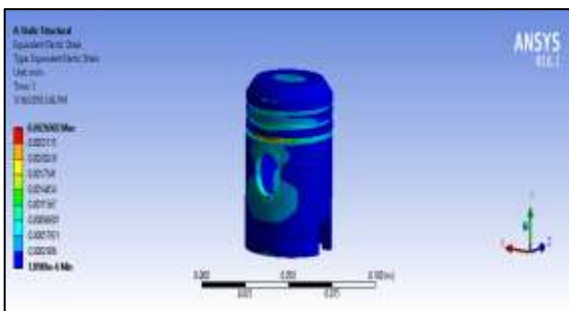


Figure.10 Equivalent elastic strain Aluminium

3.4.2 Ansys result for Al-SiC:

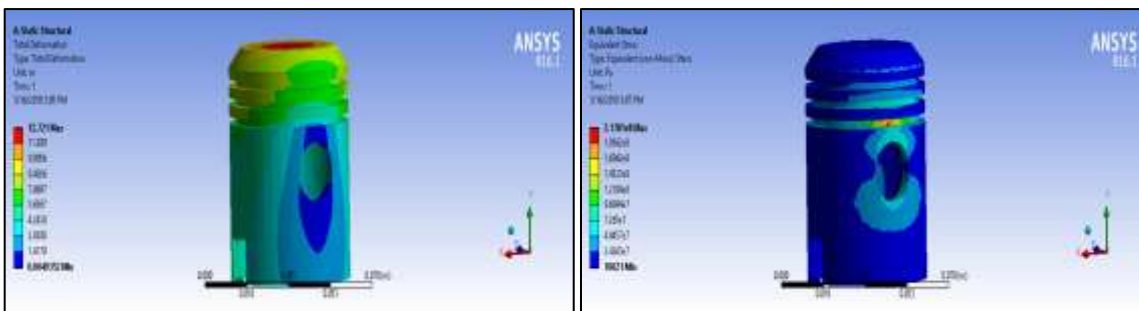


Figure.11 Total deformation and Equivalent stress of Al-SiC

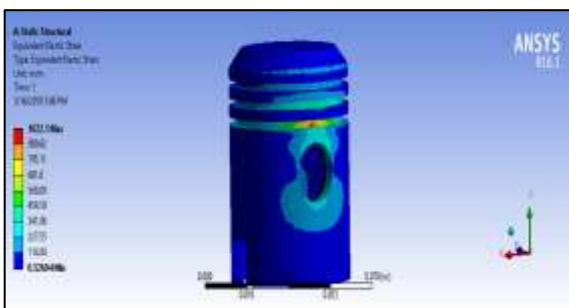


Figure.12 Equivalent elastic strain Al-SiC

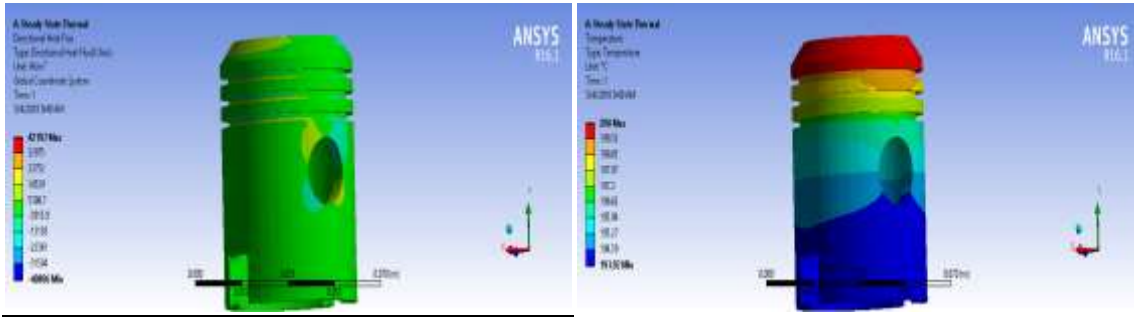
3.5 Thermal analysis:

The effects of heat and thermal management of structures was more and more critical as performance limits were pushed further by the need to have lighter, smaller and more efficient designs. Convection, radiation

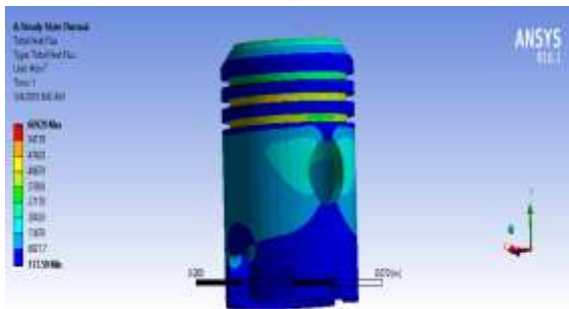


and conduction loads were obvious, but the need to include the effect of power losses and thermal energy from friction and external sources such as pipe flows means that analysts need to have more tools at their disposal to simulate thermal models accurately<sub>[11]</sub>. Thermal analyses<sub>[7]</sub> as shown in Figure.13,14,15 and 16 were used to determine the temperature distribution, thermal gradient, heat flow, and other such thermal quantities in a structure.

**3.5.1 Temperature analysis of Al:**

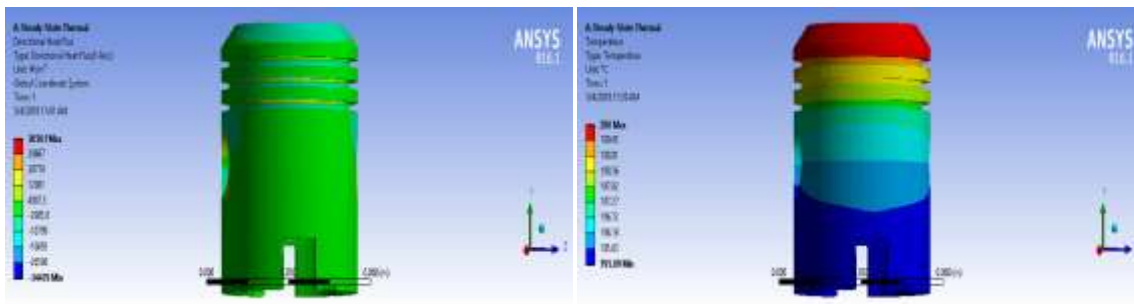


**Figure.13 Directional heat flux and Temperature deformation of Aluminium<sub>[7]</sub>**

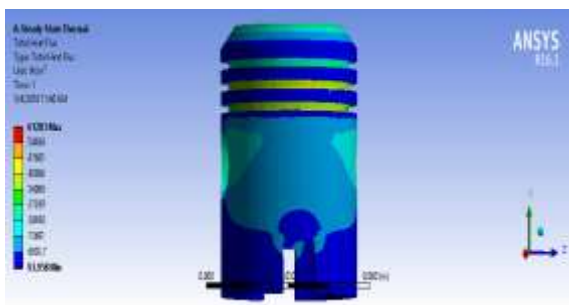


**Figure.14 Total heat flux<sub>[8]</sub>**

**3.5.2 Temperature analysis of Al-SiC:**



**Figure.15 Directional heat flux and Temperature deformation of Al-SiC<sub>[7]</sub>**



**Figure.16 Total heat flux<sub>[8]</sub>**

#### 4. Conclusion:

This investigation and analysis of the piston made up of aluminium and silicon carbide were very much useful in internal combustion engine. Silicon carbide plays a key role in enhancing the mechanical property. This analysis exhibits the advantages of Al-SiC over aluminium based on the hardness, tensile strength, stress and thermal stability. The result depicts that the hardness and tensile strength of Al-SiC<sub>[1]</sub> is higher compared to aluminium. Hence Al-SiC is optimum material for piston than aluminium. Thermal stability of Al-SiC which was analyzed by using ANSYS is more efficient than aluminium piston. Al-SiC possess low thermal conductivity. Factor of safety is improved in this composite Al-SiC piston with the low deformation rates. By this analysis, the results conclude that Al-SiC is better than aluminium.

#### 5. References:

1. H.C.Anilkumar, H.S.Hebbar and K.S.Ravishankar, "Mechanical properties Of SiC Reinforced Aluminium Alloy Composites", IJMME, 2011, Vol.6, Issue.1, pp. 41-45.
2. Vivekanandan.P, Arunachalam.V.P, "The Experimental Analysis of Stir Casting Method on Aluminium-Tib2 Composites", IJCET, 2013, Vol.3.
3. Sandeep Kumar Ravesh, Dr. T. K. Garg, "Preparation & Analysis for Some Mechanical Property of Aluminium Based Metal Matrix Composite Reinforced with Sic", IJERA, 2012, vol.2, issue6, pp.727-731.
4. B.S.Motgi, R Patil, "A Study on Mechanical Properties of SiCand Tib2 Reinforced Aluminium Alloy Composites", IOSR,Vol. 7, Issue 6, 2013, pp.41-46.
5. Arun Kumar M. B. and R. P.Swamy, "Evaluation of Mechanical Properties of al6061, SiCand e-glass Fibre Reinforced Hybrid Metal Matrix Composites", ARPN, 2011, Vol.6, Issue.5
6. IJRST –International Journal for Innovative Research in Science & Technology| Volume 1 | Issue 12 | May 2015.
7. Ekrem Buyukkaya and Muhammet Cerit, "Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method",Surface & Coatings Technology 202 (2007) 398–402
8. S. SrikanthReddy , Dr. B. Sudheer Prem Kumar, "Thermal Analysis and Optimization of I.C. Engine Piston Using Finite Element Method", IJRSET, Vol. 2, Issue 12, December 2013, PP.7834-7843.
9. K.Satyanarayana1, S.V.Uma MaheswaraRao2 , Viswanath.A.K3 , T.V.Hanumanta Rao1, "Quasi-dynamic and thermal analysis of a diesel engine piston under variable compression", Materials Today: Proceedings 5 (2018) 5103–5109.
10. Gadde Anil Kumar, Chandolu Nehemya Raj, "Design and Analysis of an IC engine piston and piston rings by using three different materials", International Journal of Advances in Mechanical and Civil Engineering, ISSN: 2394-2827.
11. A. R. Bhagat , Y. M. Jibhakate , "Thermal Analysis And Optimization Of I.C. Engine Piston Using finite Element Method", International Journal of Modern Engineering Research (IJMER) Vol.2, Issue.4, July-Aug 2012 pp-2919-2921.

\*\*\*\*\*