Design, Static Structural and a Steady State Thermal Analysis of Aluminum Composite Piston

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Abstract - The aim of this project is to increase the life and to analyze the various characteristics of composite piston that is strength, weight, thermal conductivity, density, thermal stress and specific heat. Piston is the basic component of the automobile engine. The modified design of the composite piston in this project is compared with existing piston to analyze the Mean Time Between Maintenance. Now-a-days the pistons are made up of aluminium silicon alloy which expands enormously due to generation of heat in the piston. This will affect clearance volume and insufficient clearance can cause the piston to seize in the cylinder. Hence an alternative composite material (Al) which will reduce the expansion. These composite piston are mainly applicable in receprocating engines, pumps and marine ships. The temperature distribution of the piston will be analyzed with the help of ANSYS software. In this analysis, the rate of heat transfer and thermal stress are evaluated for different composition materials.

Key Words:

composite piston, aluminum silicon alloy, thermal stress, thermal distribution

1.INTRODUCTION

1.1 I.C ENGINE

The internal combustion engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber. In an internal combustion engine the expansion of the high-temperature and -pressure gases produced by combustion applies direct force to some component of the engine, such as pistons, turbine blades, or a nozzle. This force moves the component over a distance, generating useful mechanical energy. The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines, along with variants, such as the Wankel rotary engine. A second class of internal combustion engines use continuous combustion: gas turbines, jet engines and most rocket engines, each of which are internal combustion engines on the same principle as previously described.

1.2 APPLICATIONS

Internal combustion engines are most commonly used for mobile propulsion in vehicles and portable machinery. In mobile equipment, internal combustion is advantageous since it can provide high power-to-weight ratios together with excellent fuel energy density. Generally using fossil fuel (mainly petroleum), these engines have appeared in transport in almost all vehicles (automobiles, trucks, motorcycles, boats, and in a wide variety of aircraft and locomotives).

Where very high power-to-weight ratios are required, internal combustion engines appear in the form of gas turbines. These applications include jet aircraft, helicopters, large ships and electric generators.

1.3 PISTON

ROLE OF PISTON IN AN IC ENGINE

A four-stroke engine is the most common type used in automobiles. The four strokes are intake, compression, power, and exhaust. Each stroke requires approximately 180 degrees of crankshaft (or flywheel) rotation, so the complete so the complete cycle would take 720 degrees. Each stroke plays a very important role in the combustion process, and each has a different pressure surrounding it.

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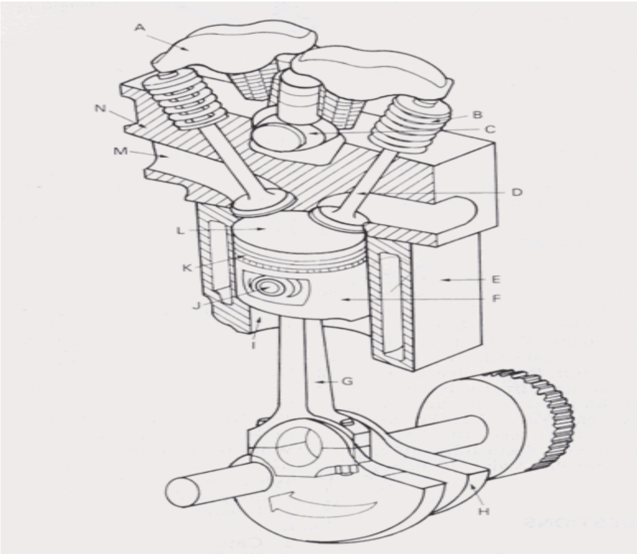


COMPOSITE PISTON

Aluminium silicon carbide alloy

Aluminium-silicon-silicon carbide composite was prepared by mechanical mixing of silicon carbide powder (220 mesh) in solidifying solid-liquid slurry of hypoeutectic, eutectic and hypereutectic compositions of aluminium-silicon alloy. Requisite amount of silicon carbide powder was charged into agitating metallic melt of aluminium-silicon matrix alloy and mixing continued while dropping the temperature of the system. The mixing period was 3-4 min during which temperature of the system dropped to 15±5°C below the liquids. On completion of mixing, plumbago crucible containing the composite slurry was taken out from the furnace and finally solidified composite was removed from the crucible for the further study. Scanning Electron Microscope test (SEM) indicates the presence of silicon carbide in the composite. Silicon carbide occurred in the grain boundary regions associated with silicon and fragmented dendrites together with eutectic mixture. Strength, hardness and wear resistance of composite is studied increase of silicon carbide content. Various Al-Si-SiC composites were prepared by melting the constituent metals and master alloy in a furnace and incorporating the silicon carbide in the solidifying metallic slurry of aluminium-silicon matrix alloy. Aluminium of respective pure quality was selected and silicon carbide powder was dispersed. A weighed amount (1000 g) of charge consisting of commercially pure Aluminium and Silicon Carbide powder of a weighed amount (40g & 60g) was added respectively.

Structural	
Young's Modulus	2.3e+011 Pa
Poisson's Ratio	0.24
Density	2937. kg/m³
Thermal Expansion	9.5e-006 1/°C
BHN	1. 81(60gm SiC sample) 2. 74(40gm SiC sample)
VHN	1. 87@500gm load(60gmSiC sample) 2. 76@500gm load(40gm Sic sample)
Thermal	
Thermal Conductivity	197. W/m·°C
Specific Heat	894. J/kg·°C

Ak12+ 20% al2o3

A composite is a material made with several different constituents intimately bonded.Aluminum is the most popular matrix for the metal matrix composites The Al alloys are attractivedue to their low density, their capability to be strengthened by precipitation, their good corrosionresistance, high thermal and electrical conductivity, and their high damping capacity. Al alloysoffer a large variety of mechanical properties depending on the chemical composition of the Almatrix. They are usually reinforced by Al2O3, SiC, C, SiO2, B, BN, B4C, AlN. The aluminummatrices are in general Al-Si, Al-Cu. Metal composite materials have found application in manyareas of daily life for quite some time. Often it is not realized that the application makes use ofcomposite materials. These materials are produced *in situ* from the conventional production andprocessing of metals. Materials like cast iron with graphite or steel with high carbide content, as well as tungsten carbides, consisting of carbides and metallic binders, also belong to this group ofcomposite materials. Substantial progress in the development of light metal matrix composites hasbeen achieved in recent decades, so that they could be introduced into the most importantapplications. From this potential, metal matrix composites fulfil all the desired conceptions of thedesigner. This material group becomes interesting for use as constructional and functionalmaterials, if the property profile of conventional materials either does not reach the increasedstandards of specific demands, or is the solution of the problem. However, the technology ofMMCs is in competition with other modern material technologies, for example powder metallurgy.The characteristics of metal matrix composite materials are determined by their microstructure

Parameter	Composite AK12/22% Al_2O_3
Density, g/cm^3	2.711
Electric conductivity, MS/m	11.5-11.8
Thermal conductivity, W/m·K	90.5
Thermal expansion coefficient, x10^{-6}/K	18.51
Young modulus, GPa	90-94
Tensile strength, MPa	330-345
Hardness, HB	175-190
Yield point [N/m^2]·10^8	2.89
Specific heat [J/kg·K]	1010
Poisson number [-]	0.22

Aluminium eutectic alloy

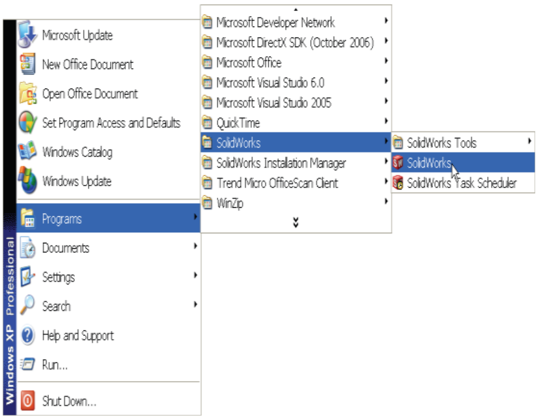
Composite pistons are most often obtained through squeeze casting. They are made from aluminium alloys reinforced with ceramic particles throughout the product's volume or locally. In case of local reinforcement, ceramic inserts or premoulds made of whiskers or short fibres are used. For the manufacture of locally reinforced pistons, metal pressure infiltration of a preheated pre mould is applied. **Composition and properties of piston skirt and crown materials**

The material for conventional piston has been chosen as Eutectic Al Alloy. It is also material for skirt when the piston arranged by ceramic crown. Generally in this material aluminium is the main component with range from 74.4-79.6.in addition to main component aluminium it consists of copper 4.5%, ferrous 1.5%, silicon 12%, Magnesium 0.5 % and remaining consists of other impurities.

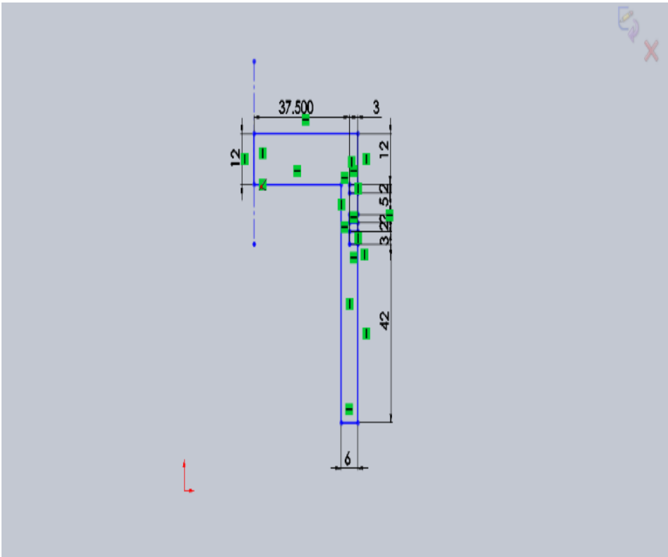
Poisson Ratio	0.33
Modulus of Elasticity /GPa	81.2
Density at 20°C / (kg/m3)	2730
Thermal Conductivity at 25°C /(W/m K)	136.5
Thermal Expansion Coefficient (100-300°C)/(1/°C)	18.0E-06 - 22.5E-06
Specific Heat Capacity at 100°C /(J/kg K)	963
Ultimate Tensile Strength at 25°C /MPa	280
Yield Tensile Strength at 25°C /MPa	240
Fatigue Tensile Strength (5e8 cycles R.R Moore Test) /MPa	110

Piston modeling in Solid Works

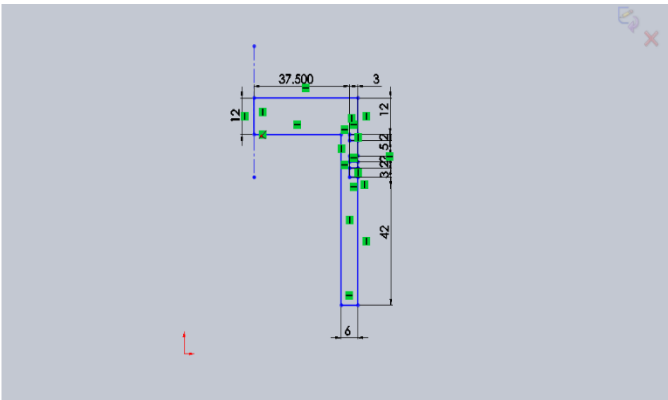
Start ….programs…..Solid Works ……select



And select the xy-plane and draw the below 2d- digram



By revolve definition with respect to vertical axis :



Dimensions of the Piston :

Bore diameter : 75mm

Top land : 12mm

Piston skirt :26mm

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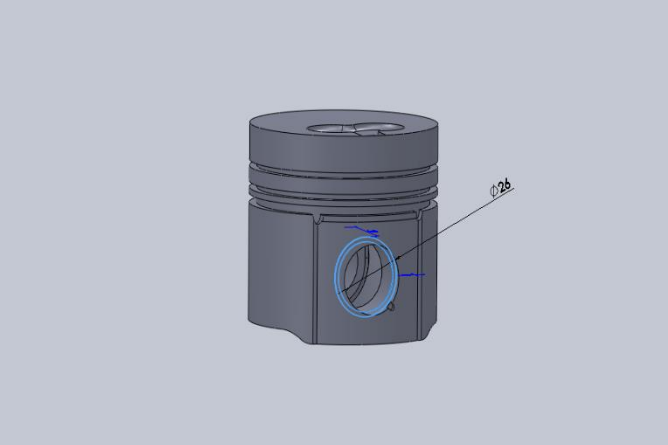
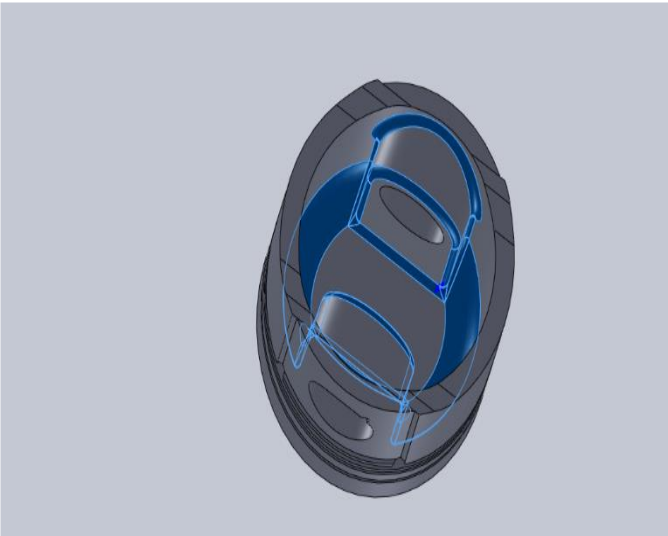
Piston barrel :**42mm**

Piston thickness :**6mm**

Length of piston : **68mm**

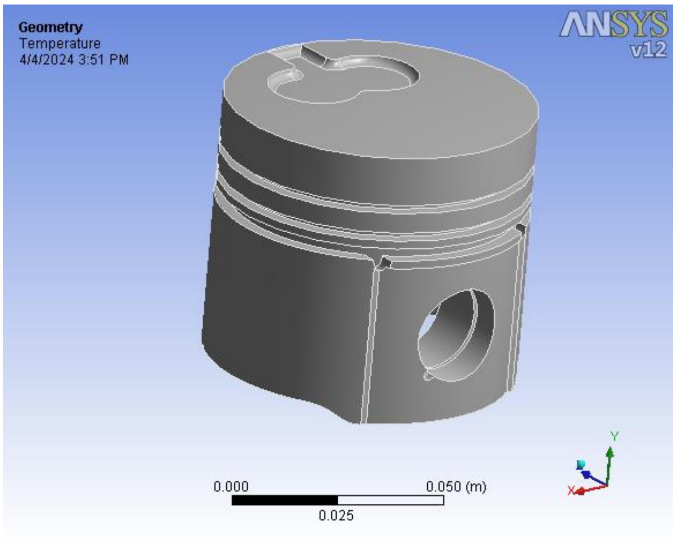




Different views of modelled piston in solid works

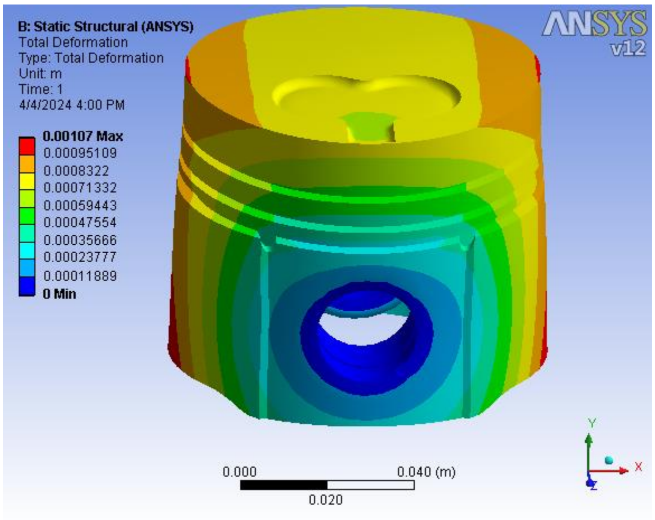
ANALYZING THE COMPOSITE PISTON IN ANSYS WORKBENCH

Geometry

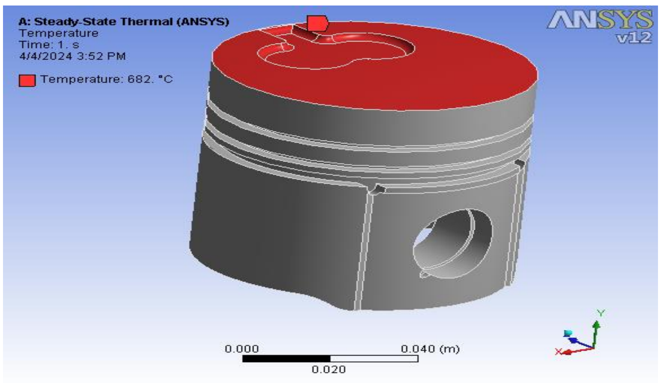


For The Material-1 (Aluminum – Silicon alloy) :

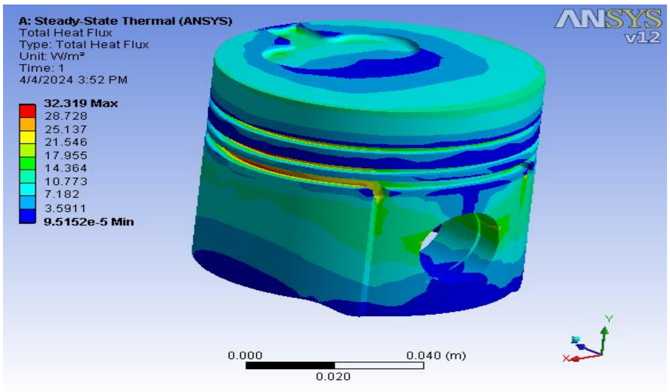
Total Deformation



Thermal analysis of the Composite piston

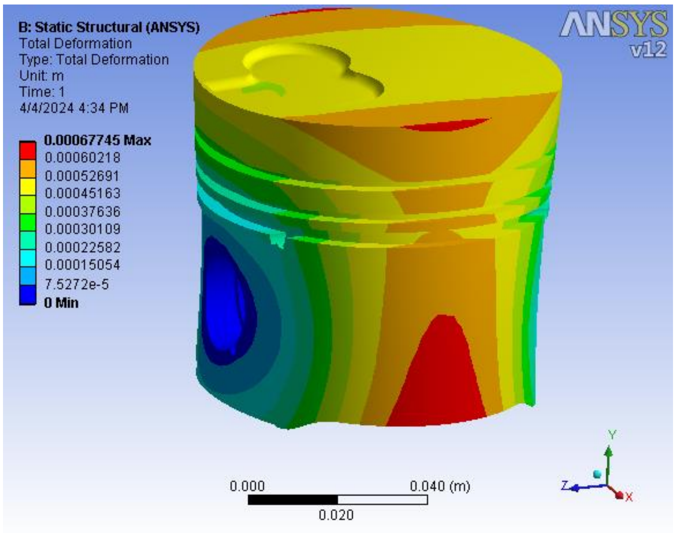


Total Heat Flux:



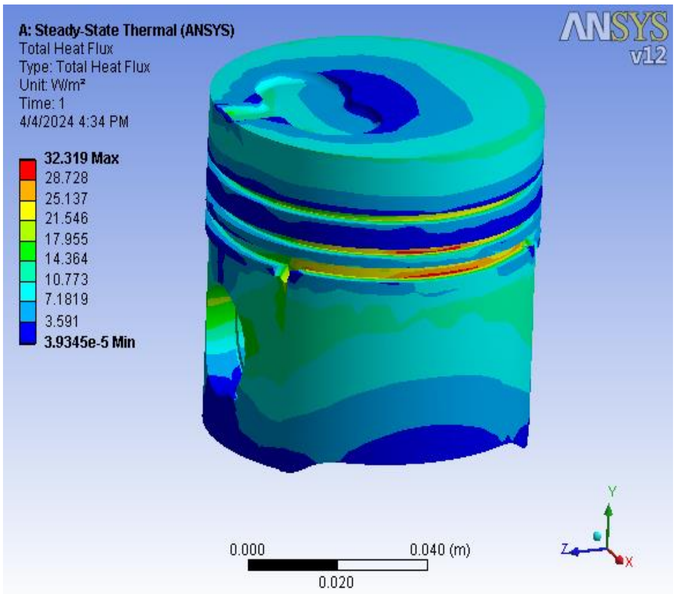
For Material-2 (Ak12+ 20% al2o3) :

Total Deformation



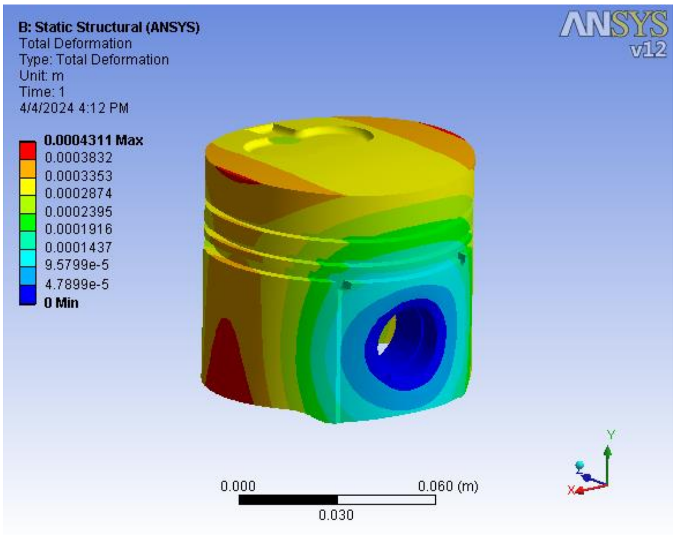
Thermal analysis of the piston for material-2

Total Heat Flux



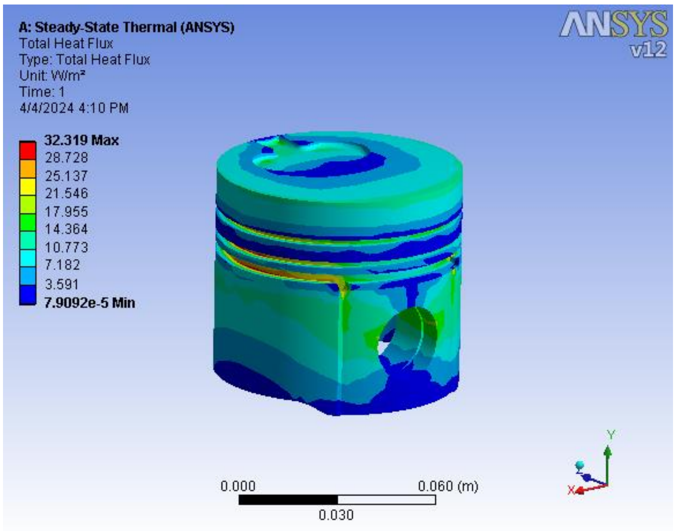
FOR MATERIAL-3 (aluminium-Silicon Carbide alloy)

Total Deformation



Steady-State Thermal

Total Heat Flux



RESULTS

Table 1 Static analysis for piston material (aluminum-silicon alloy) developed by the pressure of 5 Mpa

s.no	Stress	Values in pascals
1	Equivalent (von-mises) stress	4.5172e9
2	Maximum shear stress	2.607e9
3	Maximum principal stress	2.1128e9
4	Medium principal stress	2.5396e8
5	Minimum principal stress	1.215e8
7	Maximum principal elastic strain	0.03786 (in m)

Table 3 Static analysis for piston material 1 (Ak12+ 20% al2o3) stress developed by the pressure of 5 Mpa

s.no	Stress	Values in pascals
1	Equivalent (von-mises) stress	3.753e9
2	Maximum shear stress	2.1586e9
3	Maximum principal stress	1.8284e9
4	Medium principal stress	1.9514e8
5	Minimum principal stress	5.1483e7
6	Maximum principal elastic strain	0.022082 (in mt)

Static analysis for piston material 3 (aluminium SILICON CARBIDALLOY) stress developed by the pressure of 5 Mpa

s.no	Stress	Values in pascals
1	Equivalent (von-mises) stress	5.6275e9
2	Maximum shear stress	3.2408e9
3	Maximum principal stress	2.7419e9
4	Medium principal stress	2.9478e8
5	Minimum principal stress	8.8439e7
6	Maximum principal elastic strain	0.014251 in mt

Thermal heat distribution and pressure acting at 5 Mpa

Sl.no	Material	temperature in c
1	Aluminium-silicon alloy	682
2	Ak12+ 20% al2o3	682
3	Aluminium eutectic alloy	682
4	Aluminium silicon carbide alloy	682

Thermal heat distribution and pressure acting at 5 Mpa

Sl.no	Material	Total Heat flux in w/m2
1	Aluminium-silicon alloy	32.319
2	Ak12+ 20% al2o3	32.319
3	Aluminium eutectic alloy	32.318
4	Aluminium silicon carbide alloy	32.318

CONCLUSION

Background : Physically, chemically and mechanically aluminium is a metal like steel, brass, copper, zinc, lead or titanium. It can be melted, cast, formed and machined much like these metals and it conducts electric current. In fact often the same equipment and fabrication methods are used as for steel.

Light Weight : Aluminium is a very light metal with a specific weight of 2.7 g/cm3, about a third that of steel. For example, the use of aluminium in vehicles reduces dead-weight and energy consumption while increasing load capacity. Its strength can be adapted to the application required by modifying the composition of its alloys.

Corrosion Resistance : Aluminium naturally generates a protective oxide coating and is highly corrosion resistant. Different types of surface treatment such as anodising, painting or lacquering can further improve this property. It is particularly useful for applications where protection and conservation are required.

Electrical and Thermal Conductivity : Aluminium is an excellent heat and electricity conductor and in relation to its weight is almost twice as good a conductor as copper. This has made aluminium the most commonly used material in major power transmission lines.

Ductility : Aluminium is ductile and has a low melting point and density. In a molten condition it can be processed in a number of ways. Its ductility allows products of aluminium to be basically formed close to the end of the product's design.

The electrical and thermal conductivity of aluminum can be improved by the addition of trace amounts of boron to eliminate the undesirable effects of chromium, titanium, vanadium, and zirconium. Aluminium Boron master alloys provide a convenient mechanism for making the desired boron addition. Boron has also been acknowledged as an effective grain refiner for silicon aluminum alloys .

Hence from the above advantages and this project , we have found out that the Aluminium-Boron Alloy is much preferable in the manufacturing of the piston , when compared to the conventional Aluminium 5045 Alloy that is currently being used in the production of the piston

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