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Steady State Thermal and Structural Analysis of Piston Using Finite Element Simulation

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ABSTRACT

Composite materials are gaining importance because of their advantages including low cost, ease, and simplicity of operation. Composites containing hard oxides (like SiC) are preferred for high wear resistance along with increased hardness, improved corrosion resistance and high-temperature oxidation resistance as compared to alloy and pure metal. Composite coating is used for the purpose of wear resistance. In this work, material composition test, hardness test, of such composite coatings are carried out. The effect of particle size and number of particles suspended is reported. SiC Composites allowed depositing on Aluminium using casting process. Computer aided engineering (CAD) tools allow engineers to design product and to simulate these designs for residual stress, structural response, thermal effects, pre-processing and post processing fatigue on the components of the I C Engine. In this project the piston is modeled using CATIA V5, meshing and analysis is done in ANSYS 16.0 software and the thermal and static behavior is studied and the results are tabulated. The study of various stresses acting on the piston under been carried out. This work has been taken upon the following aspects to cover the research gaps and to present the results based on the systematic studies. For improving the efficiency of the engine there is a need to study more about the behavior of piston. Pistons are generally made up of alloy steels that show the great resistant property against thermal and structural loads. By going through the structural and thermal analysis, we decide whether our material selection for design piston is safe or not under applied load conditions. At the end the results are compared. This work will help persons working in the field of steady state thermal analysis of piston.
Keywords: Internal Combustion (IC) Engines, Performance, Heat transfer, Temperature piston.

I. INTRODUCTION

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 six-stroke piston engine and 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.

Firearms are also a form of internal combustion engine.

The components of a reciprocating IC engine, block, piston, piston skirt, valves, crankshaft and connecting rod have remained basically unchanged since the late 1800s. The main differences between a new engine and one built 100 years ago are the thermal efficiency and the emission level. For many years, IC engine research was aimed at improving thermal efficiency and reducing noise and vibration. As a consequence, the thermal efficiency has increased from about 10% to values as high as 50%.

Working of Petrol Engine

In the most general form, an internal combustion engine is a device that converts chemical energy in fuels into useful mechanical energy, through a combustion process. Combustion is the process of converting chemical energy into thermal energy, using fuel and an oxidizer Internal refers to the combustion process taking place inside the engine, in a combustion chamber. There are many internal combustion engine concepts, but the most common is the reciprocating engine. The reciprocating engine concept uses pistons that move up and down, driven by the thermal energy from the combustion process.

The combustion process is a set of reactions which release energy or heat through oxidization.

A typical combustion reaction is the methane-oxygen reaction:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + energy \quad (1)$$

All combustion reaction are exothermic reactions, meaning that they release energy to the environment. This energy is what can be converted into useful mechanical energy in a reciprocating engine. The modern reciprocating engine is a four stroke engine. It is called a four stroke engine because the engine does four piston movements before it completes the combustion process. The four strokes make it possible to complete a thermodynamic cycle.

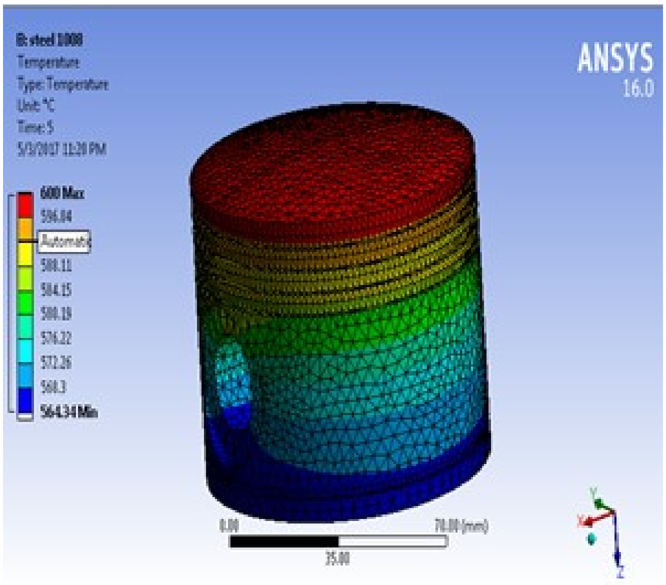
A four-stroke engine (also known as four cycle) is an internal combustion (IC) engine in which the piston completes four separate strokes while turning a crankshaft. A stroke refers to the full travel of the piston along the cylinder, in either direction. The four separate strokes are termed:

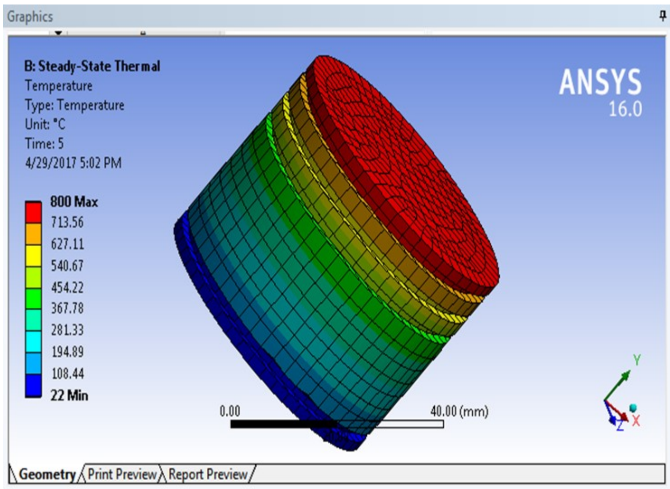
a) **Intake:** also known as induction or suction, this stroke of the piston begins at top dead center (T.D.C.) and ends at bottom dead center (B.D.C.). In this stroke the intake valve must be in the open position while the piston pulls an air-fuel mixture into the cylinder by producing vacuum pressure into the cylinder through its downward motion.

b) **Compression:** This stroke begins at B.D.C, or just at the end of the suction stroke, and ends at T.D.C. In this stroke the piston compresses the air-fuel mixture in preparation for ignition during the power stroke (below). Both the intake and exhaust valves are closed during this stage.

c) **Combustion:** also known as power or ignition. This is the start of the second revolution of the four stroke cycle. At this point the crankshaft has completed a full 360 degree revolution. While the piston is at T.D.C. (the end of the compression stroke) the compressed air-fuel mixture is ignited by a spark plug (in a gasoline engine) or by heat generated by high compression (diesel engines), forcefully returning the piston to B.D.C. This stroke produces mechanical work from the engine to turn the crankshaft.

Exhaust: also known as outlet. During the exhaust stroke, the piston once again returns from B.D.C. to T.D.C. while the exhaust valve is open. This action expels the spent air-fuel mixture through the exhaust valve.





Thermal analysis of Petrol Engine

The thermodynamic analysis of the actual four-stroke or two-stroke cycles is not a simple task. However, the analysis can be simplified significantly if air standard assumptions are utilized. The resulting cycle, which closely resembles the actual operating conditions, is the Otto cycle.

During the normal operation of the engine as the fuel mixture is being compressed an electric arc is created to ignite the fuel. At low rpm this occurs close to TDC (Top Dead Centre). As engine rpm raises the spark point is moved earlier in the cycle so that the fuel charge can be ignited while it is still being compressed. We can see this advantage reflected in the various Otto engines designs. The atmospheric (non-compression) engine operated at 14% efficiency. The compressed charge engine had an operating efficiency of 32%.

The heat flow through the piston ring to the cylinder liner is complex to model analytically due to a large number of circumstances that occurs under a four-stroke cycle which all can affect the heat flow.

A number of these circumstances are presented below.

- Varying oil film thickness affect the thermal conductivity of the oil and causes surface-to-surface contact between the piston rings and the cylinder liner.
- The rings may twist during a stroke and change the contact geometry.
- Piston ring manufacture tolerances can vary and affect the clearance between the ring and the liner.
- Surface-to-surface or hydrodynamic friction may arise in the ring-liner interaction and raise the oil and surface temperatures.
- Tilting of the piston varies the amount of contact between the piston rings circumferentially.
- Combustion gases may penetrate the top land crevice and locally increase the heat flux input to the piston top land.
- Thermal expansion of the piston and the piston rings changes the piston- and the piston ring geometry.
- Combustion gas blow-by will affect the heat transfer by adding convective heat transfer to both the piston and the cylinder liner.

Finite Element Method

Definition

The finite element method is a numerical technique which is commercially used for the finding of an approximate solution of partial differential equation as well as integral equation. In some solving partial differential equations the first problem is to create an equation that approximate the equation which is to be studied. It means that during calculations the error should not accumulate, thereby causing the output as to be meaningless.

Heat transfer analysis using the Finite Element Method

In order to perform a multidimensional heat transfer analysis the Finite Element Method can be utilized. This type of solution method is based on the use of elements which represents the body of the object. Each element expresses the physical, geometrical and material properties of the structure. The elements consist of nodes in which a shape function describes the node value changes along the elements. The number of nodes of an element can vary, but generally three- or four node elements are used in a 2D-analysis, while for 3D-analysis four- or eight node elements are commonly used. Depending on the type of analysis that is conducted, each node has a certain number of degrees of freedom.

The finite element analysis consists of a computer model of a material or designs that are stressed and analyzed for specific results. It is often used either for the refinement of existing product or for any new design. The modification of existing design or product or a structure is utilized to qualify the product for a new service condition. Sometimes in structural failure, FEA may help for the determination of design modification to meet the new conditions. Generally two types of analysis are used in manufacturing industry: 2D modeling and 3D modeling. In case of 2D modeling the analysis runs on a normal computer, it leads to lesser accurate results. On the other hand 3D modeling gives more accurate results by sacrificing the ability to run on all but the fastest computers effectively. The complex nature of linear systems is less as comparing with the non linear systems. Non linear systems accounts for plastic deformation and many are also capable of testing a material all the way to fracture of a material.

II. LITERATURE REVIEW

Shubham Shrivastava[1], Shikar Upadhyay[2], [2016] – In this present work, cylinder block was made in 3D software Solidworks in which perpendicular fins are mounted. After that modifications is done in engine cylinder block fins, thickness is reduced from 3 mm to 2 mm. so that weight will reduced, second thing to choose material which has to replace the existing materials, in this analysis aluminium alloy 1050 is chosen for thermal analysis to evaluate the better heat transfer rate. In first case due to modification weight of block reduced to **13.2 %,** in second case due to material change weight reduced to **2.1 %** without compromising with strength.

K. Venkatareddy, V. Chandrashekar Goud – In the project we design a piston by using solid works 2016 design software and we did the structural load analysis and thermal analysis by applying various materials such as composites on piston in ansys workbench software. Modeling and analysis of piston is done. Modeling of piston is done in solid works 2016 design software by using various commands. The solid works part file is converted into IGS file and imported to Ansys workbench. First Static structural analysis is carried out on piston at 1.5MPa pressure with four different materials, such as grey cast iron, aluminum alloy and al-sic graphite and aluminum oxide in ansys workbench. Maximum stress, deformation, maximum strain and maximum shear stress are noted and tabulated Then steady state thermal analysis is carried out at maximum temperature 400deg and minimum temperature 30deg for the above four various materials. Temperature distribution and heat flux are noted for four different materials and tabulated. From the tables it is concluded that the aluminum silicon carbide graphite (Al-SiC Graphite) is showing efficient results Hence Al-SiC-Graphite is preferable among the four applied materials.

K. Sundaram, N. Palanikumar – In this work, material composition test, hardness test, of such composite coatings are carried out. The effect of particle size and number of particles suspended is reported. SiC Composites have been deposited on Aluminium by casting process. The resulting castings are studied using scanning electron microscopy and hardness tests

The piston is modeling using Pro-E modeling and analyzing using ANSYS simulation software for Aluminium (Pure) and Aluminium-SiC and the results were discussed. In this project, 3D Model is prepared in CREO and then CAE analysis is performed by Ansys 14.5 and three different materials (Al with 10% SiC, AL with 20% SiC and AL With 30% SiC) for piston are taken into thermal analysis. From the result obtained from Ansys, It Seems that the Aluminium with 10% SiC material having better temperature distribution in both steady state thermal analysis as well as transient state thermal analysis hence aluminium with 10% SiC Material is better than Aluminium alloy Material therefore Aluminium with 10% SiC Material is most suitable for piston.

Abino John1, Jenson T Mathew2, [2015] - A piston made of composite material (aluminium silicon carbide) is designed and analyzed successfully. Composite piston made of metal matrix offers high strength retention on ageing even at severe environments. Compared to aluminium, the aluminium silicon carbide is found to have lesser deformation, lesser stress and good temperature distribution. Some of the limitations faced by aluminium piston are overcame by the aluminium silicon carbide piston. From this project we get the clear knowledge about the composite material AlSiC and its features.

S. Bhattacharya1, A. Basu2, S. Chowdhury3, Y.S. Upadhyaya4, [2014] - has presented a thermo-mechanical analysis of a natural gas, internal combustion engine cylinder head are presented in this paper. The results are pertinent to the evaluation of overheating damage in critical areas. The three-dimensional geometries of the cylinder head and the water jacket were modeled by means of a computer-aided engineering tool. Commercial finite element and computational fluid dynamics codes were used to compute details of mechanical stress in the head and flow details in the cylinder and cooling jacket, respectively. A six-cylinder, four-stroke diesel engine and a spark-ignition natural gas engine were modeled over a range of speeds at full load. Computed results, such as maximum allowable cylinder pressure, output power, BMEP and BSFC, were validated by experimented data in the diesel engine model. The results were in good agreement with experimental data. The results show high stresses at the valve bridge. Cylindehead temperatures and comparison of output power with high stress measurements, often exceeding the elastic limit, were found at the valve bridge.

III. METHODS AND MATERIAL

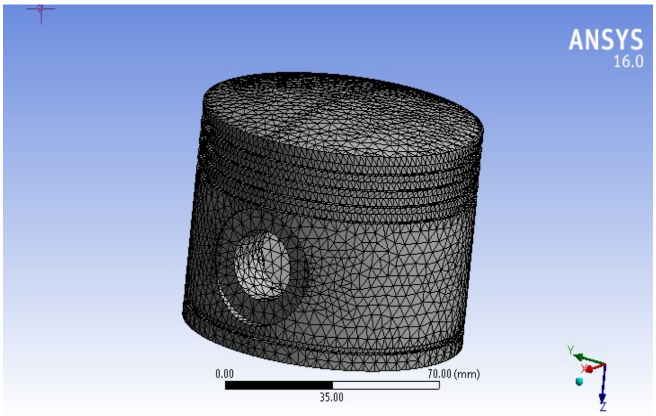
Model Specification

Parameter	Calculated values	Actual values	Difference
Piston length	36.16 mm	37 mm	0.84 mm
Piston diameter	50 mm	49.5mm	0.5mm
Pin hole external diameter	13mm	12.7mm	0.3 mm
Pin hole internal diameter	8mm	6.6 mm	1.4 mm
Piston ring axial thickness	1.05mm	0.8mm	0.205mm
Radial thickness of ring	1.62 mm	2mm	0.3mm
Depth of ring groove	2.02mm	2.01mm	0.01mm
Gap between the rings	2.75mm	2.6mm	0.15mm
Top land thickness	7.3mm	5.6mm	1.7mm
Thickness of piston at top	7.05mm	6.65mm	0.4mm
Thickness of piston at open end	1.76mm	1.64mm	.12mm

- **Meshing condition**

Nodes – 217999

Elements – 132921



Material Property

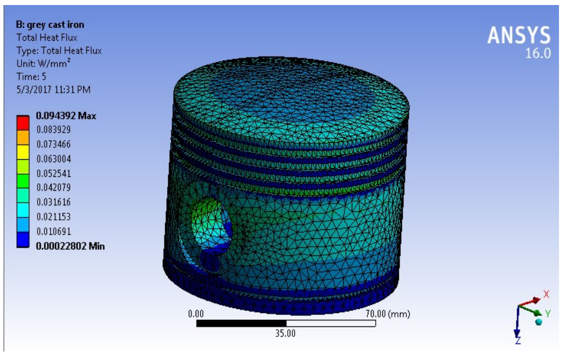
S. No.	Property	Materials					
		Grey Cast Iron	Al-alloy 6061	Steel 1008	Steel 1020	Pure Aluminium (Al)	Aluminium Al-Sic-Graphite (Sic 25%, Graphite 4%)
1	Density (kg/m³)	7060	2650	7950	7870	2680	2720
2	Poisson's ratio	0.26	0.34	0.3	0.29	0.34	0.34
3	Ultimate tensile strength(MPa)	235	220	340	394.72	165	260
4	Young's modulus(MPa)	12400	71000	210000	200000	71000	74000
5	Specific heat(J/kg°C)	460	897	450	486	910	850
6	Thermal conductivity(w/mm°K)	0.048	0.34	0.0652	0.0519	0.151	0.025

Parameters Taken For Result

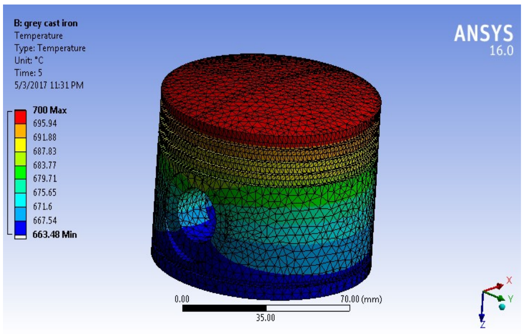
- **Temperature**: temperature distribution in 3D plane.
- **Heat flux**: 3D view of heat flux distribution.
- **Stress:** Resistive force applied per unit area by the material.
- **Strain**: It is the ratio of lateral strain to that of linear strain.

IV. RESULTS AND DISCUSSION

Steady State Thermal Analysis Grey Cast Iron

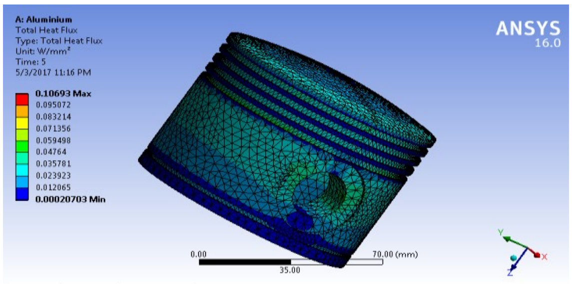


Total Heat Flux distribution on Grey cast iron

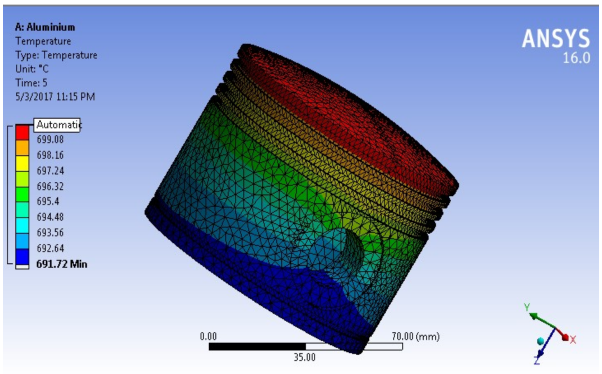


Temperature distribution on Grey cast iron

Pure Aluminium

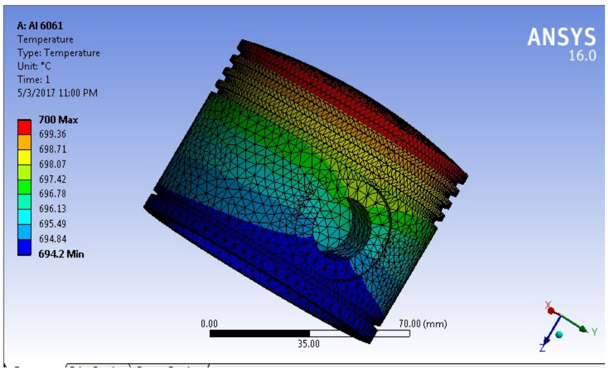


Total Heat Flux distribution on Pure Aluminium

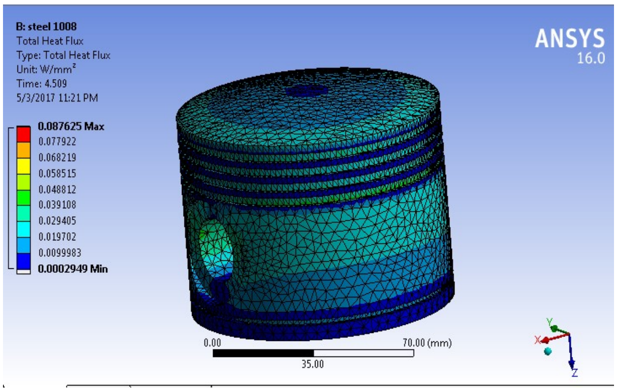


Temperature distribution on Pure Aluminium

Aluminium 6061

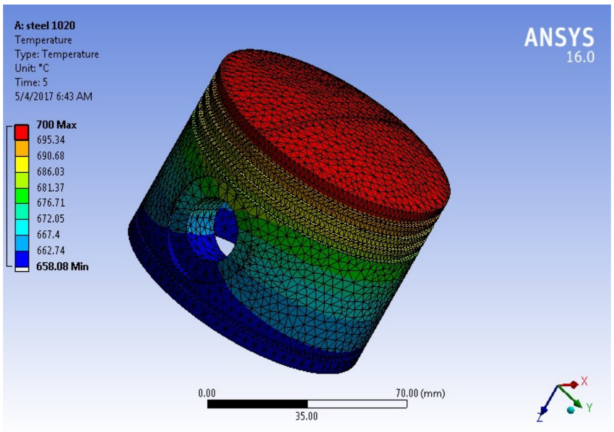


Temperature distribution on Aluminium 6061

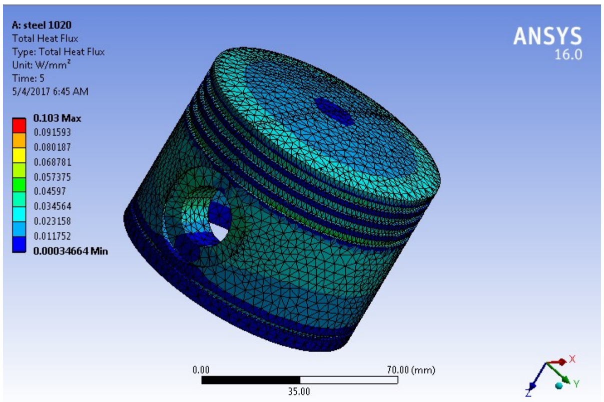


Total Heat Flux distribution on steel 1008

Steel 1020

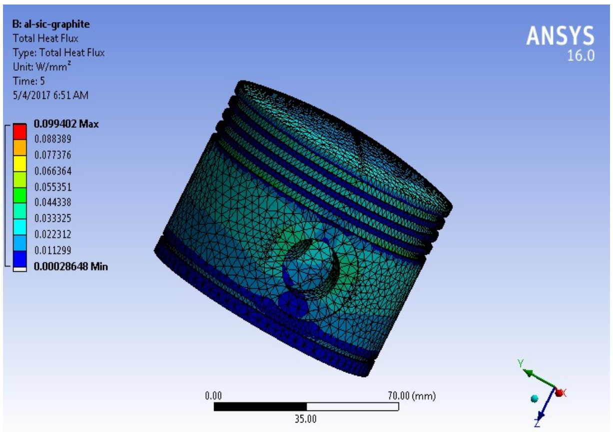


Temperature distribution on steel 1020

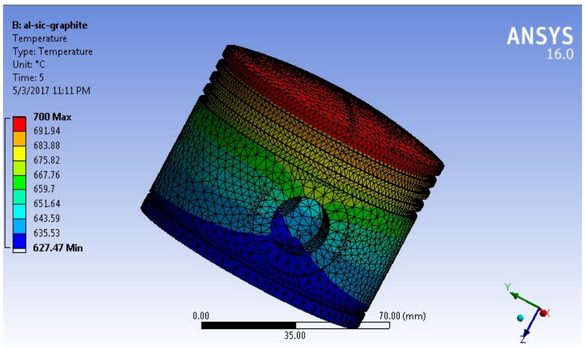


Total Heat Flux distribution on steel 1020

Al – Sic – Graphite



Total Heat Flux distribution on Al – SiC - Graphite



Temperature distribution on Al – SiC -Graphite

Data obtained during our analysis are shown below in tabular form

Material	Deformation	
	Maximum	Minimum
Cast Iron	0.11960	0.000012634
Pure Aluminium	0.03231	0.000006345
Steel 1008	5.72240	0.000335290
Steel 1020	10.1120	0.014647000
Steel 6061	0.022008	0.000000073
Al – SiC - Graphite	0.031026	0.000007699

Variation of deformation within different materials

Material	Deformation	
	Maximum	Minimum
Cast Iron	0.11960	0.000012634
Pure Aluminium	0.03231	0.000006345
Steel 1008	5.72240	0.000335290
Steel 1020	10.1120	0.014647000
Steel 6061	0.022008	0.000000073
Al – SiC - Graphite	0.031026	0.000007699

Variation of Von Mises stress within different materials

Material	Equivalent stress distribution	
	Maximum	Minimum
Cast Iron	0.0111230	0.0000278500
Pure Aluminium	0.0026916	0.0000045157
Steel 1008	0.6660600	0.0008524100
Steel 1020	0.8300300	0.0035302000
Steel 6061	0.0055491	0.0000027725
Al – SiC - Graphite	0.0025824	0.0000032410

Variation of elastic strain within different materials

Material	Elastic strain	
	Maximum	Minimum
Cast Iron	0.0111230	0.0000278500

Pure Aluminium	0.0026916	0.0000045157
Steel 1008	0.6660600	0.0008524100
Steel 1020	0.8300300	0.0035302000
Steel 6061	0.0055491	0.0000027725
Al – SiC - Graphite	0.0025824	0.0000032410

V. CONCLUSION

Thermal and structural analysis of piston is performed in ANSYS 16.0. For our analysis a 3 D model is designed in CATIA V5. And then it is imported in ANSYS. After applying the boundary conditions, the results were obtained and discussed.

The results obtained during thermal as well as structural analysis, it can be concluded that the steel 1020 has shown more variation which is not suited for the operation if I.C. Engine. Al – Si - Graphite material has shown average results which are best suited for I C Engine of a bike. So, the best material is Al – SiC – Graphite.

VI. FUTURE SCOPE

Various new materials are coming up Now A days and that too with a lot of new properties. In a future lot of new materials will be used in order to improve the I C Engine performance. Many defects related to the piston will be minimized. Also, this work will be helpful for the person doing work in this field.

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