

# Design and Analysis of Modular Piston by Using Couple Field Analysis

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## ABSTRACT

Piston is the one of the most important component of the engine. We should use light weight material like Aluminum, Titanium to design the piston so as to reduce the weight because improved engine designs require optimized engine components. Along with less weight of the piston, rejection of waste also has a great concern. If we could eliminate the excess heat before it heats up engine components, we can improve component life by eliminating thermal stress and cooling requirements, for this purpose ceramic pistons are developed, these pistons are very costly but they don't conduct heat and are prone to thermal stress

We all know that cost of high strength metals is very high so use of automobile components made with high strength alloys is limited to luxuries and sports cars, so, we need low cost designs. It is impossible to make a low cost design using high strength super alloy to meet the design requirements. So, we are proposing a tri metallic design to reduce the cost and improve life of the component

In this study we are developing a tri - metallic piston, the dimensions of the piston are taken by reverse engineering using a re-bored piston, models of a regular piston and bimetallic piston and tri metallic piston are prepared using Catia and are tested under same boundary conditions in Ansys. Several combinations of tri metals are used and design modifications are done to minimize the stress and deformations in the piston without effecting its purpose. This study is mainly concentrate on thermal deformations induced in the piston sub assembly.

**KEYWORDS:** Modular Piston, Couple Field Analysis, Piston crown, Piston Skirt, wrist pin.

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## I. INTRODUCTION

A piston is a cylindrical engine component that slides back and forth in the cylinder bore by forces produced during the combustion process. The piston acts as a movable end of the combustion chamber. The stationary end of the combustion chamber is the cylinder head. Pistons are commonly made of a cast aluminum alloy for lightweight and excellent thermal conductivity. Thermal conductivity is the ability of

a material to conduct and transfer heat. Aluminum expands when heated and proper clearance must be provided to maintain free piston movement in the cylinder bore. Insufficient clearance can cause the piston to seize in the cylinder. Excessive clearance can cause a loss of compression and an increase in piston noise.

Piston features include the piston head, piston pin, skirt, ring grooves, ring lands, and piston rings. The piston head is the top surface (closest to the cylinder head) of the piston which is subjected

to tremendous forces and heat during normal engine operation.

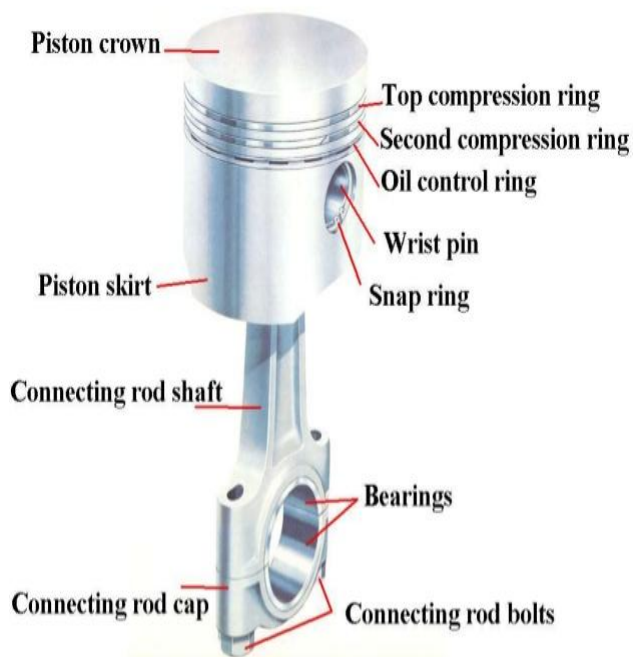


Fig: 1.1 Piston and connecting rod Assembly

A piston pin bore is a through hole in the side of the piston perpendicular to piston travel that receives the piston pin. A piston pin is a hollow shaft that connects the small end of the connecting rod to the piston. The skirt of a piston is the portion of the piston closest to the crankshaft that helps align the piston as it moves in the cylinder bore. Some skirts have profiles cut into them to reduce piston mass and to provide clearance for the rotating crankshaft counterweights.

The piston acts as the movable end of the combustion chamber and must withstand pressure fluctuations, thermal stress, and mechanical load. Piston material and design contribute to the overall durability and performance of an engine. Most pistons are made from die- or gravity-cast aluminium alloy. Cast aluminium alloy is lightweight and has good structural integrity and low manufacturing costs. Piston designs are based on benefits and compromises for optimum overall engine performance

## II. LITERATURE REVIEW

This topic shows review on design analysis of piston on the basis of improving strength according to the material properties.

Vibhandiket. al. (2014), studied that Design analysis and optimization of piston and

deformation of its thermal stresses using CAE tools, he had selected I.C. engine piston from TATA motors of diesel engine vehicle. He had performed thermal analysis on conventional diesel piston and secondly on optimized piston made of aluminium alloy and titanium alloy material. Conventional diesel piston made of structural steel. The main objective of this analysis is to reduce the stress concentration on the upper end of the piston so as to increase life of piston. After the analysis he conclude that titanium has better thermal property, it also help us to improve piston qualities but it is expensive for large scale applications, due to which it can be used in some special cases.

Ch. VenkataRajamet. al. (2013), focused on Design analysis and optimization of piston using CATIA and ANSYS. He had optimized with all parameters are within consideration. Target of optimization was to reach a mass reduction of piston. In this analysis a ceramic coating on crown is made. In an optimization of piston, the length is constant because heat flow is not affected the length, diameter is also made constant due to same reason. The volume varied after applying temperature and pressure loads over piston as volume is not only depending on length and diameter but also on thickness which is more affected. The material is removed to reduce the weight of the piston with reduced material. The results obtained by this analysis shows that, by reducing the volume of the piston, thickness of barrel and width of other ring lands, Von misses stress is increased by and Deflection is increased after optimization. But all the parameters are within design consideration.

V. V. Mukkawaret. al. (2015), describes the stress distribution of two different Al alloys by using CAE tools. The piston used for this analysis belongs to four stroke single cylinder engine of Bajaj Pulsar 220 cc motorcycle. He had concluded that deformation is low in AL-GHY 1250 piston as compare to conventional piston. Mass reduction is possible with this alloy. Factor of safety increased up to 27% at same working condition. He used Al-GHY 1250 and conventional material Al-2618 and results were compared, he found that Al-GHY 1250 is better than conventional alloy piston.

Manjunatha T. R. et. al.(2013), under look specification for both high pressure and low reassure stages and analysis is carried out during suction and compression stroke and identify area those are likely to fail due to maximum stress concentration. The material used foe the cylinder is cast-iron and for piston aluminiumalloy for both



low and high pressure. He concluded that the stress developed during suction and compression stroke is less than the allowable stress. So the design is safe.

Swati S. chouguleet. al. (2013), focused on the main objective of this paper is to investigate and analyse the stress distribution of piston at actual engine condition during combustion recess the parameters used for simulation is operating gas pressure and material properties of piston. She concluded that there is as cope for reduction in a scope for reduction in thickness of piston and therefore optimization of piston is done with mass reduction by 24.319% than non-optimized piston. The static and dynamic analysis is carried out which are well below the permissible stress value.

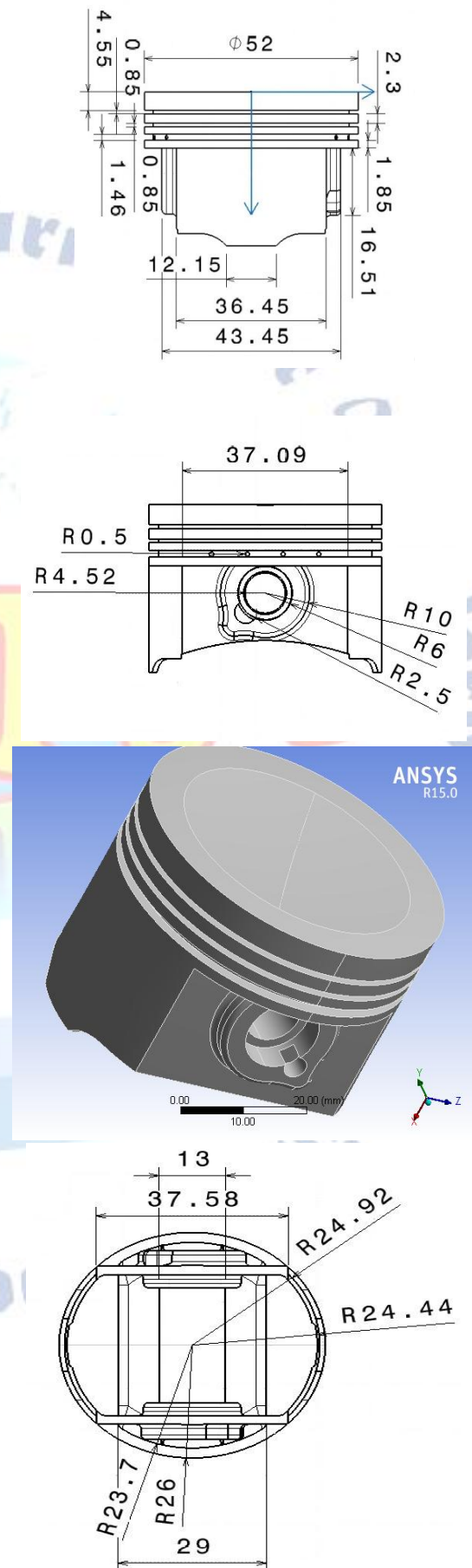
The study of Lokesh Singh et. al. (2015) is related to the material for the piston is aluminium silicon composites. The high temperature at piston head, due to direct contact with gas, thermal boundary conditions is applied and for maximum pressure mechanical boundary conditions are applied. After all these analysis all values obtained by the analysis is less than permissible value so the design is safe under applied loading condition.

The study of R. C. Singh et.al. (2014), discussed about failure of piston in I.C.engines, after all the review, it was found that the function coefficient increases with increasing surface roughness of liner surface and thermal performance of the piston increases. The stress values obtained from FEA during analysis is compared with material properties of the piston like aluminium alloy zirconium material. If those value obtained are less than allowable stress value of material then the design is safe.

### III. MODELING

CATIA which stands for Computer Aided Three Dimensional Interactive Application is CAD software CATIA has a unique ability of modelling a product in the context of its real life behavior. This design software became successful because of its technology which facilitates its customers to innovate a new robust, parametric, feature based model consistently. CATIA provides easy to use solution tailored to the needs of small medium sized enterprises as well as large industrial corporations in all industries, consumer goods, fabrications and assembly, electrical and electronics goods, automotive, aerospace, 24Shipbuilding and plant design. It is user friendly. Solid and surface modelling can be done easily.

### 3.1 Model view of tri metallic piston:



#### IV. ANALYSIS

##### 4.1 ANSYS

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behavior of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. This type of analysis is typically used for the design and optimization of a system far too complex to analyses by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

##### 4.2 Thermal stress analysis of tri metallic piston

Using reverse engineering technique a single piece piston model is created from an old IC engine piston. This particular piston is divided into three sub components which are piston crown, piston skirt and piston pin. By using stainless steel, cast-iron, aluminium alloy, aluminium oxide ( $\text{Al}_2\text{O}_3$ ) and silicon carbide (Sic). By taking 4 different cases with single material and 4 different cases with different material combinations by using ansys reports have been generated.

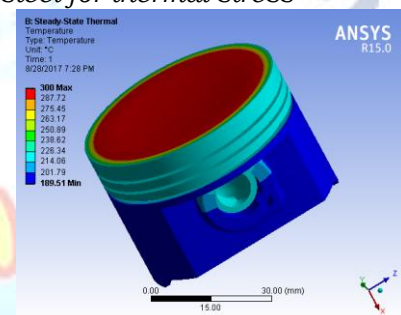
The material combinations are varied for all 8 cases the combinations of cases are taken as Case 1 with complete stainless steel material Case 2-with complete aluminium alloy Case 3- with complete aluminium oxide ( $\text{Al}_2\text{O}_3$ ) Case 4- with silicon carbide (sic) in all 1,2,3,4 cases piston crown, piston skirt and piston pin are taken as same materials. Case 5- with modular model aluminium oxide ( $\text{Al}_2\text{O}_3$ ) for piston crown/aluminium oxide ( $\text{Al}_2\text{O}_3$ ) for piston skirt /stainless steel for piston pin in Case 6- modular model aluminium oxide ( $\text{Al}_2\text{O}_3$ ) for piston crown/aluminium oxide ( $\text{Al}_2\text{O}_3$ ) for piston skirt /aluminium alloy for piston pin in Case 7- modular model silicon carbide (sic) for piston crown/silicon carbide (sic) for piston skirt /stainless steel for piston pin in Case 8- modular model silicon carbide (sic) for piston crown/silicon carbide (sic) for piston skirt /aluminium alloy for piston pin. In 5,6,7,8 cases for modular model material is varied for all the three parts.

Both single piece case (1, 2, 3, and 4) and moduler model case (5, 6, 7, and 8) are studied using Ansys. Thermal Stress behavior is studied under no mechanical load conditions. For this analysis coupled field system is used. This analysis

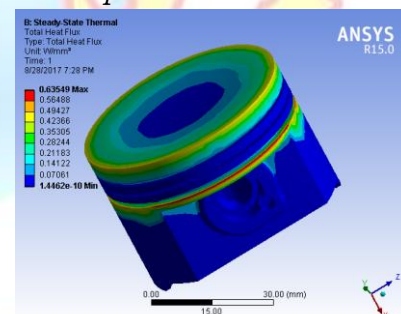
mainly focused on thermal stresses in modulermodels and cost optimization by reducing the use of high strength alloys and ceramics using moduler design.

By comparing all 8 cases of analytical reports the results for modular piston performs far better than single piece piston in all aspect, as modular piston reduces the cost of manufacturing piston with costly super alloys and composites. Replacing the piston crown material with composite reduces the net heat absorption by the piston. By introducing the composite crown we can reduce the thermal expansions in the piston. Deformations in the component are reduced in case of silicon carbide and aluminum oxide modular piston.

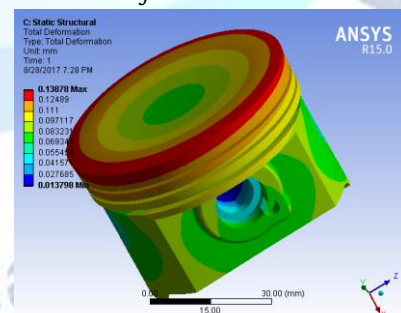
*Case 1 Analysis of regular piston made with stainless steel for thermal stress*



*Temperature distribution*



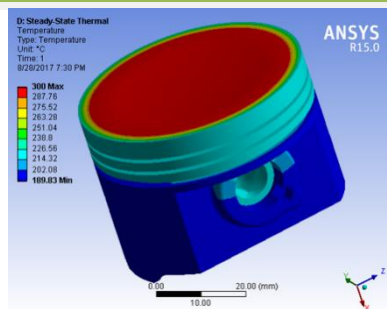
*Heat flux distribution*



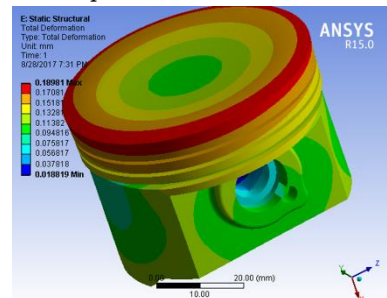
*total deformation distribution*

*Case 2 Analysis of regular piston made with aluminium alloy for thermal stress*

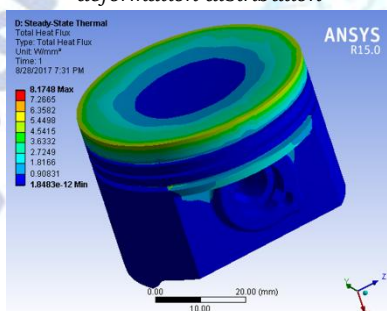




Temperature distributiontotal

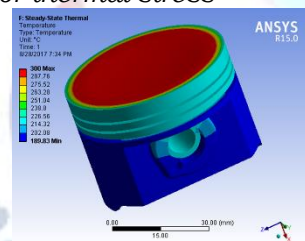


deformation distribution

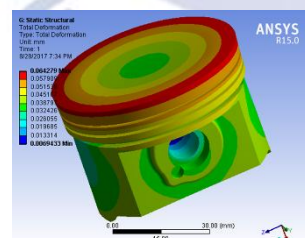


heat flux distribution

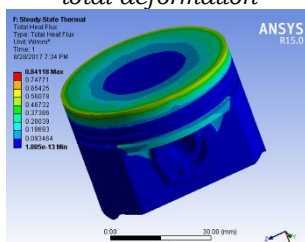
Case 3 Analysis of regular piston made with  $Al_2O_3/Al_2O_3$  for thermal stress



temperature distribution

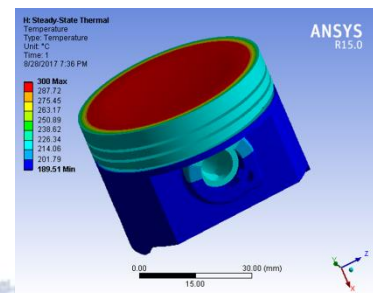


total deformation

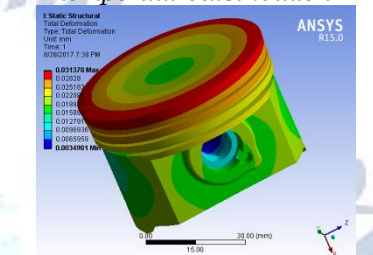


heat flux distribution

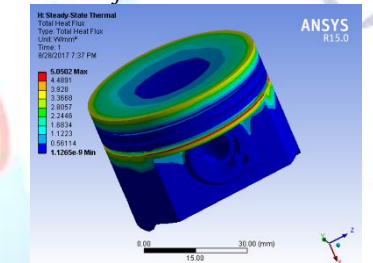
Case 4 Analysis of regular piston made with SiC/SiC for thermal stress



temperaturedistribution

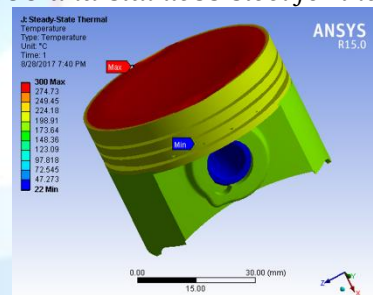


total deformation distribution

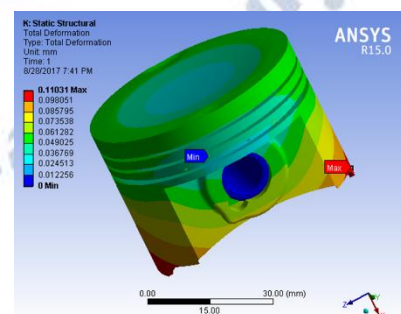


heat flux distribution

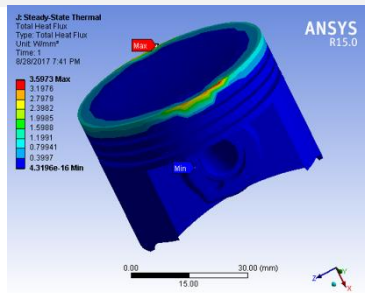
Case 5 Analysis of tri-metallic piston made with  $Al_2O_3/Al_2O_3$  and stainless steel for thermal stress



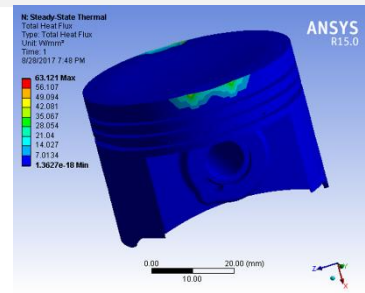
temperature distribution



total deformation distribution

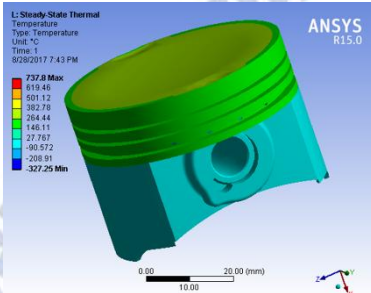


heat flux distribution

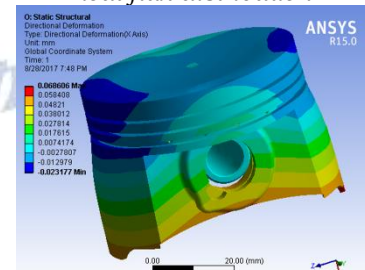


heat flux distribution

Case 6 Analysis of tri-metallic piston made with  $Al_2O_3/Al_2O_3$ , aluminium alloy and stainless steel for thermal stress

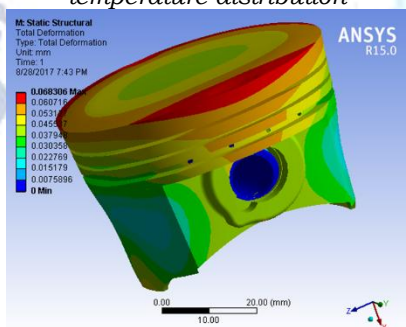


temperature distribution

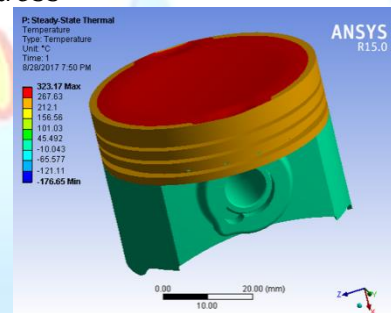


total deformation distribution

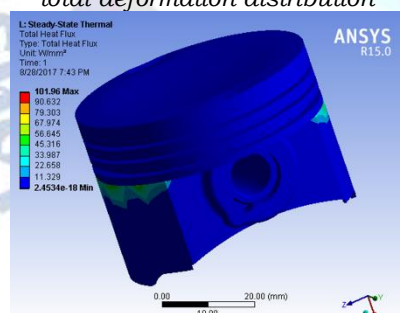
Case 8 Analysis of tri-metallic piston made with  $SiC/SiC$ , aluminium alloy and stainless steel for thermal stress



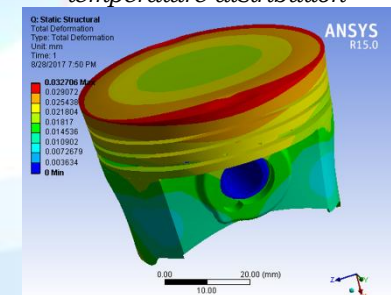
total deformation distribution



temperature distribution

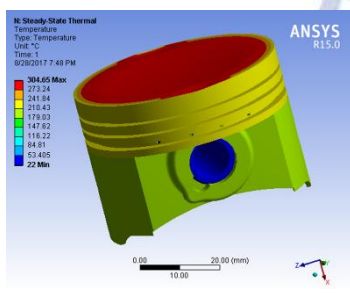


heat flux distribution

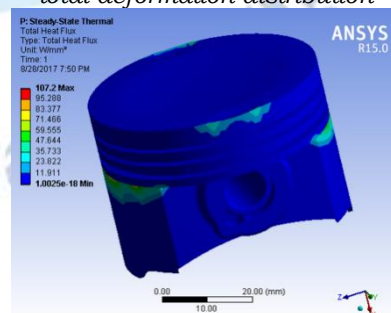


total deformation distribution

Case 7 Analysis of tri-metallic piston made with  $SiC/SiC$  and stainless steel for thermal stress



temperature distribution



heat flux distribution

- Case 1- model 1 stain less steel
- Case 2- model 1 aluminium alloy
- Case 3- model 1  $al_2o_3-al_2o_3$
- Case 4- model 1 sic-sic
- Case 5- modular model  $Al_2O_3-al_2O_3/stainlesssteel$

Case 6- modular model

Al<sub>2</sub>O<sub>3</sub>-al<sub>2</sub>o<sub>3</sub>/stainlesssteel/aluminium alloy

Case 7- modular model Sic-Sic/stainlesssteel

Case 8- modular model

Sic-Sic/stainlesssteel/aluminium alloy

**Thermal analysis of tri metallic piston using Sic/Sic, Al<sub>2</sub>O<sub>3</sub>/Al<sub>2</sub>O<sub>3</sub>, aluminium alloy**

case	Temperature°C		Total heat flux W/mm <sup>2</sup>		Total deformation mm		Elastic strain		Equivalent stress N/mm <sup>2</sup>	
	min	max	min	max	min	max	min	max	min	max
1	189.51	300	1.45E-10	0.63549	0.013798	0.13878	2.94E-09	0.00427	0.000472	741.91
2	189.83	300	1.85E-12	8.1748	0.018819	0.18981	2.75E-08	0.005782	0.001938	376.31
3	189.83	300	1.89E-13	0.84118	0.006943	0.064279	1.16E-08	0.002149	0.003327	590.04
4	189.51	300	1.13E-09	5.0502	0.003498	0.031378	5.32E-09	0.001075	0.001951	395.05
5	22	300	4.32E-16	3.5973	0	0.11031	0	0.005345	0	1022.4
6	-327.25	737	2.45E-18	101.96	0	0.068306	0	0.009519	0	630.4
7	22	304.65	1.36E-18	63.121	-0.02318	0.068606	0	0.010209	0	1851.2
8	-176.65	323.17	1.00E-18	107.2	0	0.032706	0	0.004493	0	291.18

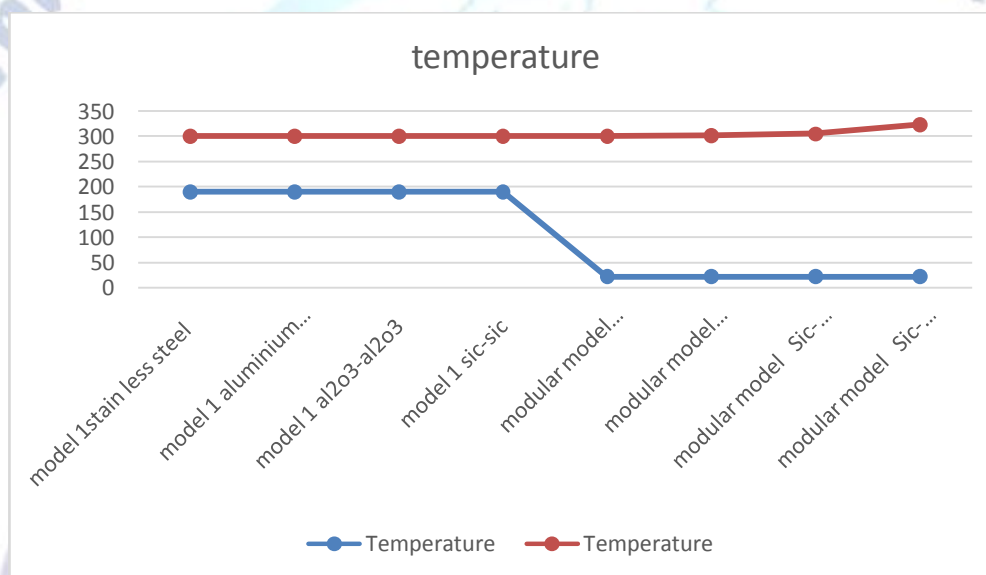
**Graphs:**

Fig. 5.1 Graphical representation for temperature

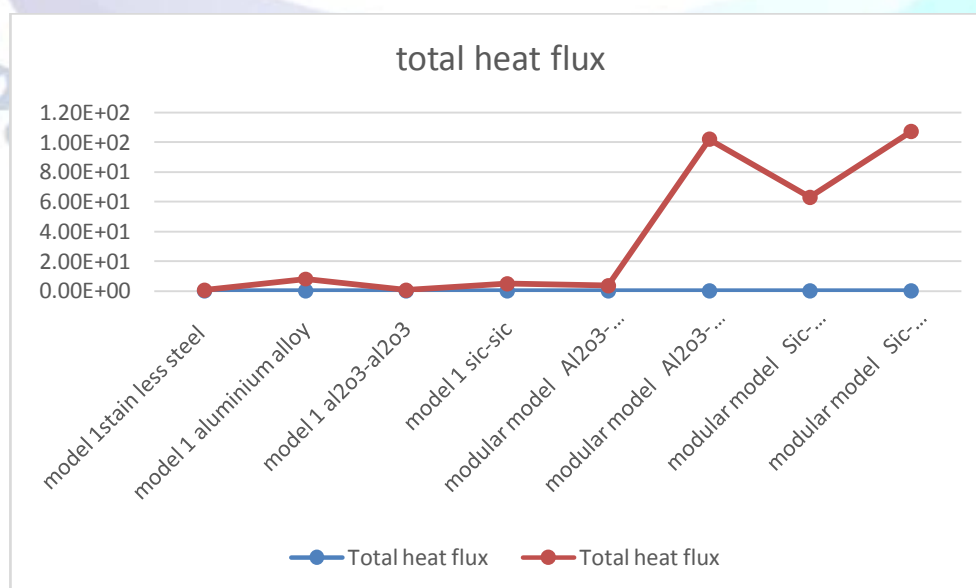


Fig. 5.2 Graphical representation for total heat flux



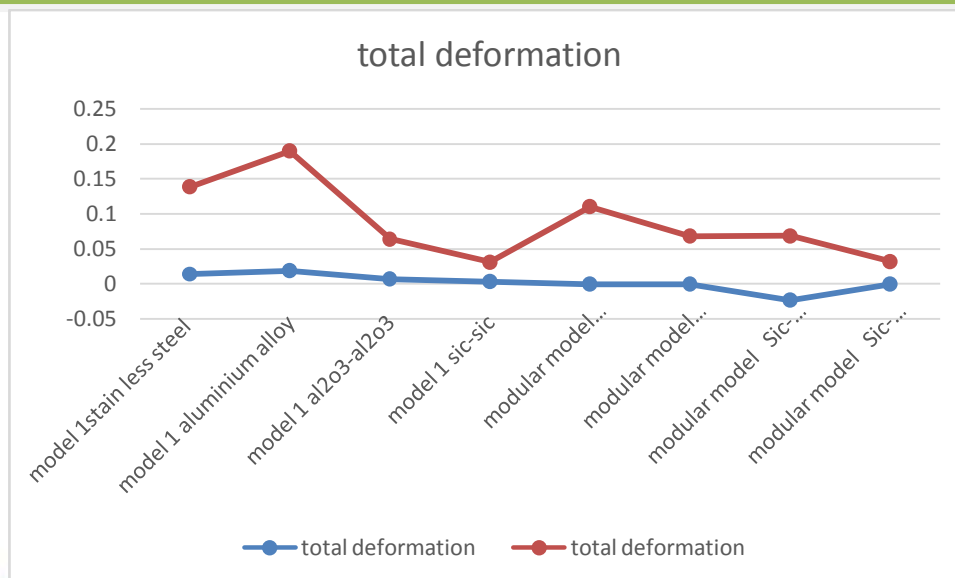


Fig: 5.3 Graphical representation for total deformation

## V. CONCLUSION

From the results modular piston performs far better than single piece piston in all aspect, more over modular piston reduces the cost of manufacturing piston with costly super alloys and composites, the following observations are made from the Ansys simulation

1. Replacing the piston crown material with composite reduces the net heat absorption by the piston
2. By introducing the composite crown we can reduce the thermal expansions in the piston
3. Deformations in the component are reduced by 60% in case of silicon carbide modular piston
4. Deformations in the component are reduced by 50% in case of aluminum oxide modular piston

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