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Design and Analysis of Piston by Using Finite Element Method

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Abstract— **A Piston is the main component of reciprocating engines. It is the most stressed element of all components of the piston assembly. In an engine, its purpose is to transfer force from expanding gas in the cylinder to crank shaft via a piston rod and/or connecting rod. It experiences high gas load, alongwith the inertial and heat load. The piston must able to take these heat and pressure forces millions of times during its life time. These heat and pressure forces will lead to wear and tear in the head of the piston. So by enhancing the strength of Piston's head by using more hard material over Aluminium Alloy for piston head only, will increase the life of piston. This combined material type of piston will be possible by Electron Beam Melting (EBM) which is one of the part forming method in Additive Manufacturing. The comparison of working condition of piston and selecting suitable material for piston head will be possible by Finite Element Method. The ANSYS (Workbench) software will help to analyze the working condition of piston by analyzing different parameters (Heat flux, Vonmisses Stress, vonmisses strain, Deformation). In this study work there are two steps of analysis of the piston, they are Designing and Analyzing. First design the model of the piston in the given design specification on the modelling software like CATIA V5. Then the designed model will be converted into IGES format and imported to ANSYS software. The required parameter will be analyzed. This analysis will help to compare the working condition of piston and select the suitable material for piston crown.**

Keywords— **Electron Beam Melting, CATIA V5, ANSYS (Workbench), IGES format..**

I. INTRODUCTION

An internal combustion Engine is acted upon by the pressure of the expanding combustion gases in the combustion chamber space at the top of the cylinder. This force then acts downwards through the connecting rod and onto the crankshaft. Now a days automobile components are in great demand becouse of increased use of automobiles. The increased demand will happens due to also the minimum life time periods of automobile components. In such case by enhansing the Piston by using combined material type piston means the life of piston will increased.

In our concept the head of the piston only made by more harden material over material used in entire body of the piston. It will lead to reduce wear and tear of piston crown. In practical this combined material type of piston will be possible by Electron Beam Melting (EBM) which is one of the part forming method in Additive Manufacturing. The performance analysis of Piston by using ANSYS (Workbench) software. The analysis of different perameters like Heat flux, Vonmisses Stress, vonmisses strain, Deformation will helps to take copmparisn of single material type piston with combined material type piston.

Fig-1: Internal combustion Engine Pistons

II. MODELING

2.1 Piston design and analyzing overview

The Piston is designed accoording to the Procedure and specification machine design and data hand book. The model of piston is designed in CATIA V5 software as per the specification of piston design. Then the model is converted into IGES format. The converted fill then import to ANSYS (Workbench) software. The Performance of piston for excisted Solid aluminium piston compared with Performance of Sic alloy crown enhanced piston. The perameters such as Heat flux, Vonmisses Stress, vonmisses strain, Deformation are help to analyze and compare the performance of piston.

2.2 Piston design consideration

1. The piston must have the strength to resist the impulse and inertia forces.
2. Ability to disperse the heat of combustion and avoid thermal distortion.
3. Sealing the gas and oil.
4. Sufficient bearing area to work for large number of reciprocating cyles.
5. Minimum weight
6. Smooth noiseless operation
7. Provide adequate support for piston pin

Trunk pistons are used for I.C.Engine. Truck piston refers to pistons with long skirt.
The piston has a head, hollow to accommodate the gudgeon pin or wrist pin and skirt. It also has grooves to accommodate piston rings and grooves for oil passage.

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2.3 Piston design procedure

The procedure for piston designs consists of the following steps:

- Thickness of piston head (tH)
- Heat flows through the piston head (H)
- Radial thickness of the ring (t1)
- Axial thickness of the ring (t2)
- Width of the top land (b1)
- Width of other ring lands (b2)

The above steps are explained as below:

Thickness of Piston Head (th)

The piston thickness of piston head calculated using the following Grashoff's formula,

$tH = \sqrt{(3pD2)/(16\sigma t)}$ in mm

Where

P= maximum pressure in N/mm²

D= cylinder bore/outside diameter of the piston in mm.

σt=permissible tensile stress for the material of the piston.

Here the material is a particular grade of AL-Si alloy whose permissible stress is 50 Mpa- 90Mpa.

Before calculating thickness of piston head, the diameter of the piston has to be specified.

The piston size that has been considered here has a L*D specified as 152*140.

Heat Flow through the Piston Head (H)

The heat flow through the piston head is calculated using the formula

H = 12.56*tH * K * (Tc-Te) Kj/sec

Where

K=thermal conductivity of material which is 174.15W/mk

Tc = temperature at center of piston head in °C.

Te = temperature at edges of piston head in °C.

Radial Thickness of Ring (t1)

$t1 = D\sqrt{3pw/\sigma t}$

Where D = cylinder bore in mm

Pw= pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.025N/mm² to 0.042N/mm². For present material, σt is 90Mpa

Axial Thickness of Ring (t2)

The thickness of the rings may be taken as

t2 = 0.7t1 to t1

Let assume t2 =5mm

Minimum axial thickness (t2) = D/(10*nr)

Where nr = number of rings

Width of the top land (b1)

The width of the top land varies from

b1 = tH to 1.2 tH

Width of other lands (b2)

Width of other ring lands varies from

b2 = 0.75t2 to t2

Maximum Thickness of Barrel (t3)

t3 = 0.03*D + b + 4.5 mm

Where

b = Radial depth of piston ring groove

The Specification of the Piston calculated by using above procedure. These Specification will helps to design the piston by using CATIA V5 software.

2.3 Piston Modeling

The following steps are available to design the piston.

- Drawing a half portion of piston
- Exiting the sketcher
- Developing the model
- Creating a hole and Fillets

The piston is designed using CATIA V%5 software for calculated specification.

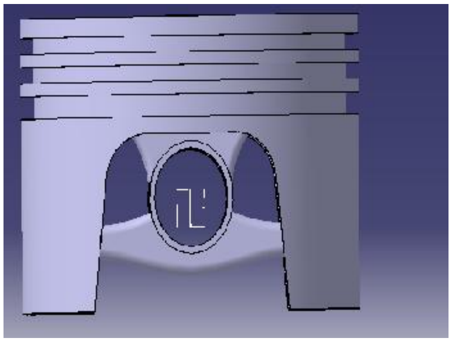

Fig-2 : Piston design using CATIA V5

III. FEA ANALYZING

1. Solid Aluminium alloy

The designed model from CATIA V5 is then converteed into IGES format and ready to import on ANSYS (workbench) software. Anlyzing of the performance of Aluminium piston will precessed by following steps,

- Book the material Required from engineering data source.
- Import the Designed model from external device which must be in IGES format.
- Then the meshing operation takes place like auto mesh mannure.
- The fixed supports are selected to withstand the given load.
- The load applying crown top surface selected and apply the load of 717KN force.
- The result for the perameters such as Vonmisses Stress, vonmisses strain, Deformation, heat flux are generated.
- The reports about the structural and thermal distribution perameters are generated.

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3.1.1 Import to ANSYS software

The designed piston will imported to ANSYS software.

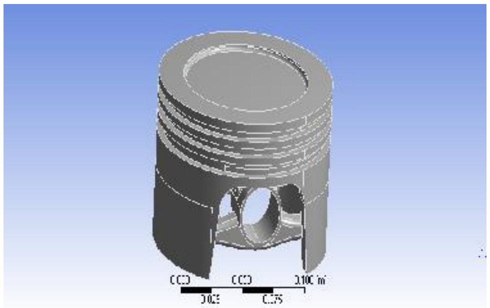

Fig-3 : Piston model imported to ANSYS

3.1.2 Meshing

Finite element mesh is generated using parabolic tetrahedral elements (7146 elements). The vonmises stress is checked for convergence. An automatic method is used to generate the mesh in the present work.

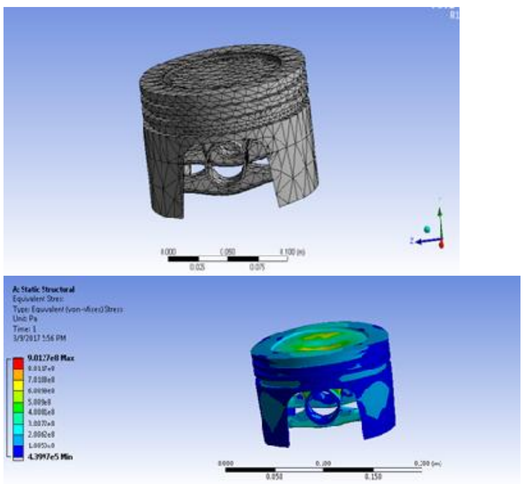

Fig-4 : Meshed view of piston

3.1.3 Applying boundary load of piston design

The maximum explosive pressure is 6.04 Mpa and/or force of 717kN and it acts uniformly on the piston head. The three freedom degrees of the piston pin are restrained to let the piston in a static condition. Coupling restraints are imposed on two points on the bottom of piston in order to eliminate the revolving of the piston around the piston pin. The surface-surface contact unit between the piston pin hole and the piston pin is set from default as 'bonded' to 'no separation' to let some displacement between piston and piston pin during the movement of the piston. The above two boundary conditions are referred as displacement restraints.

In the thermal analysis for model in ANSYS, the convection boundary condition, as the surface load is inflicted on the outside surface. The upper part of the piston is having very high temperature because of direct contact with the gas. So a temperature of 1000 degrees is provided to the upper surface of the piston.

3.1.4 Generating Result

There are four different peramters results such as Heat flux, Vonmisses Stress, vonmisses strain, Deformation are taken by Applying 717KN load and 1000 degree temperature.

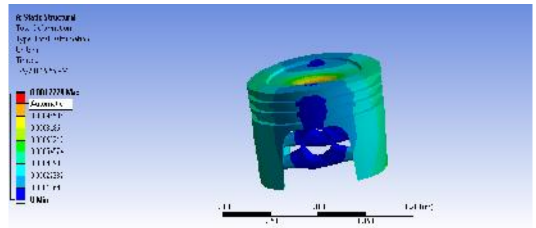

Fig-5 : Total Deformation shape of piston

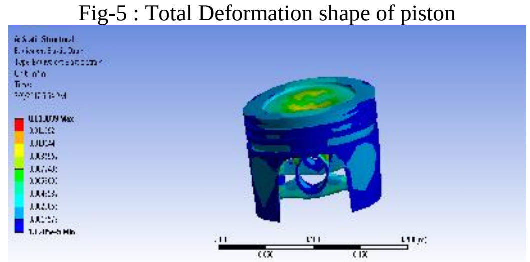

Fig-6 : Vonmisses strain distribuion on piston

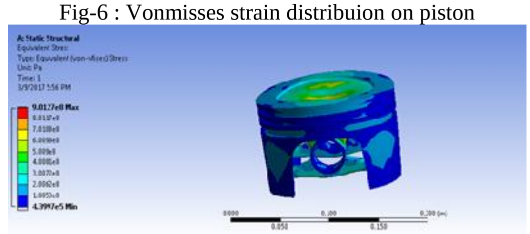

Fig-7 : Vonmisses strain distribuion on piston

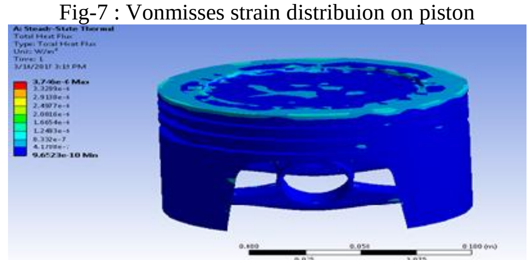

Fig-8 : Heat flux distribuion on piston

3.1.5 Report Generation

Object Name	Total Deformation	Equivalent Elastic Strain	Equivalent Stress
State		Solved	
Scope			
Scoping Method		Geometry Selection	
Geometry		All Bodies	
Definition			
Type	Total Deformation	Equivalent (von Mises) Elastic Strain	Equivalent (von Mises) Stress
By		Time	
Display Time		Last	
Calculate Time History		Yes	
Identifier			
Results			
Minimum	0. m	8.1626e-006 m/m	5.7884e+005 Pa
Maximum	1.2609e-003 m	1.6632e-002 m/m	1.1028e+009 Pa
Information			
Time		1. s	
Load Step		1	
Substep		1	
Iteration Number		1	
Integration Point Results			
Display Option		Averaged	

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Object Name	*Total Heat Flux*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Heat Flux
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged
Results	
Minimum	9.6523e-010 W/m²
Maximum	3.746e-006 W/m²
Information	
Time	1. s
Load Step	1

Table-1 : Generated report for solid Al - Piston

2. Sic crown enhanced type piston

The designed model from CATIA V5 is then converteed into IGES format and ready to import on ANSYS (workbench) software. Anlyzing of the performance of Silicon alloy crown enhanced type piston will precessed by following steps,

- Book the material Required from engineering data source. Aluminium alloy and Silicon alloy are booked
- Import the Designed model from external device which must be in IGES format.
- The piston mhead or crown will sliced for Split the piston crown from skirt to different material for piston's skirt and crown.
- Then the meshing operation takes place like auto mesh mannure.
- The fixed supports are selected to withstand the given load.
- The load applying crown top surface selected and apply the load of 717KN force.
- The result for the perameters such as Vonmisses Stress, vonmisses strain, Deformation, heat flux are generated.
- The reports about the structural and thermal distribustion perameters are generated.

3.2.1 Structural and Thermal analysis

The Imported design model of Piston is sliced and then the crown of the piston booked for Silicon Alloy and then the entire body of the piston is booked for Aluminium alloy material. Then the model is meshed, same load of solid aluminium piston tends to applyed load is applyed then required peramter's result are generated.

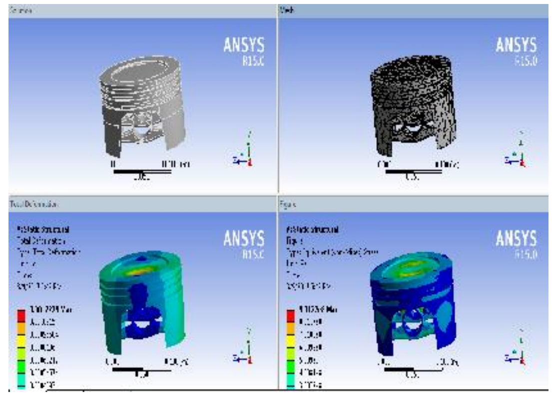
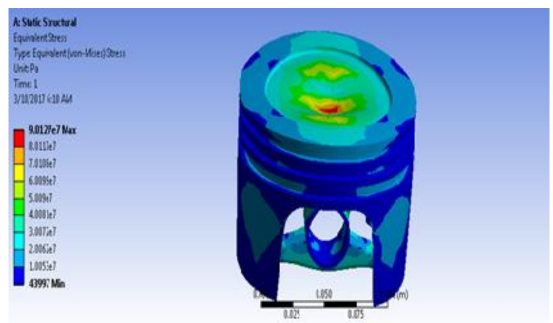


Fig-9 : Meshed view, Total deformation, Vonmisses strain distribuion on piston



V Fig-10 : Vonmisses stress distribuion on piston

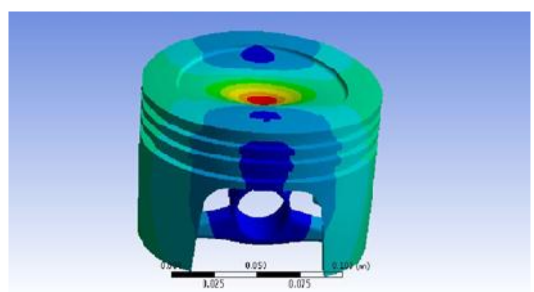


Fig-11 : Heat flux distribuion on piston

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3.2.2ReportGeneration

Object Name	Total Deformation	Equivalent Elastic Strain	Equivalent Stress
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent (von-Mises) Elastic Strain	Equivalent (von-Mises) Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Results			
Minimum	0. m	4.2526e-006 m/m	4.7934e+005 Pa
Maximum	0.5509e-003 m	0.7732e-002 m/m	0.8098e+009 Pa
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option	Averaged		

Object Name	Total Heat Flux
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Heat Flux
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Integration Point Results	
Display Option	Averaged
Results	
Minimum	8.3523e-010 W/m²
Maximum	2.847e-006 W/m²
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

Table-2 : Generated report for S ic crown enhanced Piston

IV. RESULT COMPARISON

The results of the Aluminium alloy and silicon alloy own enhanced piston analyzing report will more nalyze the performance of Piston.

Object Name	Total Deformation	Equivalent Elastic Strain	Equivalent Stress	Total Heat Flux
State		Solved		
Solid Aluminium Piston				
Results				
Minimum	0. m	8.1526e-006 m/m	5.7884e+005 Pa	9.6523e-010 W/m²
Maximum	1.2509e-003 m	1.5532e-002 m/m	1.1028e+009 Pa	3.746e-006 W/m²
Combined Material [Al-crown & Sic-Skirt] type Piston				
Results				
Minimum	0. m	4.2526e-006 m/m	4.7934e+005 Pa	8.3523e-010 W/m²
Maximum	0.5509e-003 m	0.7732e-002 m/m	0.8098e+009 Pa	2.847e-006 W/m²

Table-3 : comparisn of Aluminium alloy and Silicon alloy crown enhanced Pistos

V. MANUFACTURING METHODOLOGY

This approach is to use an electron beam to melt welding wire onto a surface to build up a part. This is similar to the common 3D printing process of FDM, but with metal rather than plastics. The designed part file will converted into SLT [Striolithography] format and feed to the EBM machinary. The eletron gun moves in 3D path as per the design aspects. The electron beam guns provides the energy source used for melting metallic feedstock, which is typically wire. First the head will be formed by harden alloy material and then the entire skirt of piston will be formed by Aluminium Alloy material.

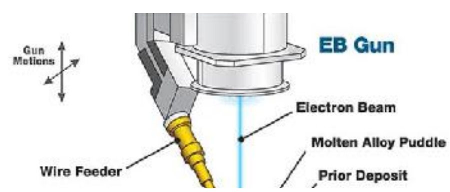

Fig-11 : Electron beam melting

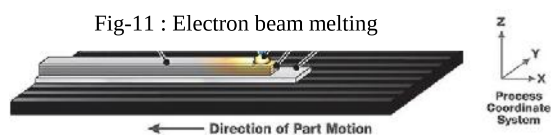

Fig-11 : Electron beam melting

II. CONCLUSION

The Output of the comparisn result indicates that the Silicon alloy crown enhanced type piston will be more effective and efficientive than existed solid Aluminium alloy type piston.

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