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Design Analysis and Optimization of Piston and Determination of its Thermal Stresses Using CAE Tools

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Abstract

In I.C. Engine, piston is most complex and important part therefore for smooth running of vehicle piston should be in proper working condition. Pistons fail mainly due to mechanical stresses and thermal stresses. Analysis of piston is done with boundary conditions, which includes pressure on piston head during working condition and uneven temperature distribution from piston head to skirt. The analysis predicts that due to temperature whether the top surface of the piston may be damaged or broken during the operating conditions, because damaged or broken parts are so expensive and difficult to replace and generally are not easily available.

The main purpose of the preliminary analyses presented in the book is to compare the behaviour of the combustion engine piston made of different type of materials under thermal load. FEA analysis is carried out using ANSYS software. Development of the FEA model is also presented. Geometrical CAD model of the piston is developed based on the actual engine piston of TATA MOTORS four stroke diesel engine.

The piston is loaded by a temperature field inside it. Appropriate averaged thermal boundary conditions such as temperatures and heat fluxes were set on different surfaces of the FEA model.

In this study, firstly, thermal analyses are investigated on a conventional diesel piston, made of structural steel for design 1.

Secondly, thermal analyses are performed on optimized piston, made of aluminium alloy and titanium alloy material by means of using a commercial code, namely ANSYS. The proposed new material is characterized by a low density, high thermal conductivity, easy machinability, high reliability and very good recycling characteristics.

The results obtained for the piston made of a new material are compared with those for the current standard material.

The analysis is carried out to reduce the stress concentration on the upper end of the piston i.e. (piston head/crown and piston skirt and sleeve) so as to increase life of piston.

Keywords:Piston, Thermal Stresses, CAE Tool.

Introduction

The Piston is a 'heart' of an automobile engine. It's one of the key components of the engine and it's working the hard condition. The function of the piston is bearing the gas pressure and making the crankshaft rotation through the piston pin. Piston works in high temperature, high pressure, high speed and poor lubrication conditions. Piston contact with high temperature gas directly, the instantaneous temperature can be up to 2500K. Because of the high temperature and the poor cooling condition, the temperature of the top of the piston can be reach 600~700K when the piston working in the engine. And the temperature distribution is uneven. The top of the piston bears the gas pressure, in particular the work pressure. The investigations indicate that greatest stress appears on the upper end of the piston and stress concentration is one of the mainly reason for fatigue failure.

In this study, the piston is used in low idle and rated speed gas engine. In order to enhance the engine dynamic and economic, it is necessary for the piston to implement optimization. Based on the analysis of optimal result, the stress concentration on the upper end of piston has become evaluate, which provides a better reference for redesign of a piston.

As one of the major moving parts in the power-transmitting assembly, the piston must be so designed that it can withstand the extreme heat and

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pressure of combustion. Pistons must also be light enough to keep inertial loads on related parts to a minimum. The piston also aids in sealing the cylinder to prevent the escape of combustion gases. It also transmits heat to the cooling oil and some of the heat through the piston rings to the cylinder wall.

Piston Design

The design data for designing of I. C engine piston with the help of CATIA V5R17 is collected from TATA MOTORS for Diesel engine vehicle. [1]

Fig 2.1 CATIA Model

Dimensions are as per follows:

Sr No.	Component	Dimension(mm)
1.	Bore Diameter	74
2.	Stroke Length	70
3.	Compression Ring Thickness	2
4.	Oil Control Ring Thickness	4
5.	Internal Diameter	64
6.	Wrist Pin Diameter	23
7.	Contour Depth	2

Analysis

Meshing

Firstly, Automatic meshing method is used to mesh the model. For greater accuracy, we have given fine mesh. The mesh grid is shown as figure3.1. The model has a total of 37471 nodes and 23128 elements.

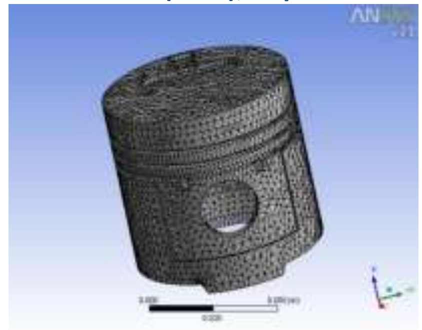

Fig 3.1 Mesh Model

Material selected is structural steel and properties are as per follows:

Material	Structural Steel
Density	7850 Kg/m3
Coefficient of Thermal Expansion	$1.2 * 10^{-5}$/ºC
Specific Heat	434J/KgºC
Thermal Conductivity	60.5W/mºC
Resistivity	$1.7 * 10^{-7}$ohm-m
Young's Modulus [Pa]	$2 * 10^{11}$Pa
Poisson's Ratio	0.3

Boundary Conditions:

Following boundary conditions are applied: [2]

3.2.1 Static forces boundary conditions

Load Location	Effect size [MPa]
Top of the Piston	3
Wrist Pin Hole	0.4

Thermal Boundary Conditions

Piston	**Convection coefficient[w/($m2k$)]**	**Temperature[℃]**
Top	320	720
Upper surface of first ring	800	160
Side surface of first ring	750	160
Lower surface of first ring	2300	160

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Between the first and second ring	500	160
Upper surface of second ring	700	140
Side surface of second ring	650	140
Lower surface of second ring	2000	140
Between the second and third ring	500	160
Upper surface of third ring	900	120
Side surface of third ring	9800	120
Lower surface of third ring	1500	120

Optimization

Wrist Pin Padding

Wrist Pin Padding is provided to reduce the stress concentration.

Wrist Pin Padding	15mm

The model has a total of 56568 nodes and 30916 elements.

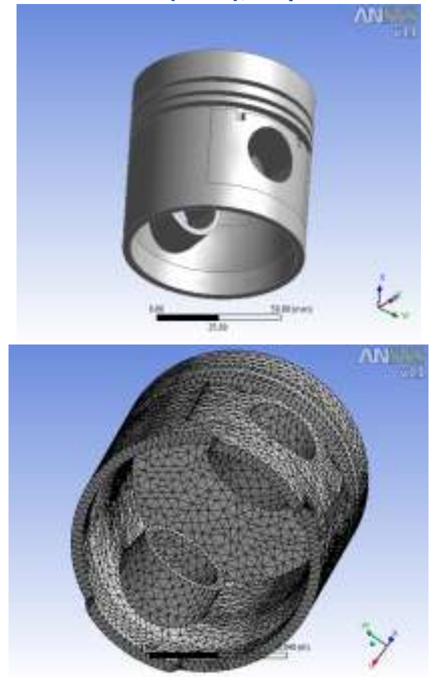

Fig 4.1 CATIA and mesh model of piston with Wrist Pin Padding

Materials

Material	Aluminium Alloy	Titanium Alloy
Density	2770Kg/m3	4620Kg/m3
Coefficient of Thermal Expansion	$2.3* 10^{-5}$/ºC	$9.4* 10^{-6}$/ºC
Specific Heat	875J/KgºC	522J/kgºC
Resistivity	5.7e-8ohm-m	1.7e-6ohm-m
Young's Modulus [Pa]	$7.1* 10^{10}$Pa	$9.6* 10^{10}$Pa
Poisson's Ratio	0.33	0.36

Result and Discussion

By applying above boundary conditions for structural steel, aluminium Alloy and Titanium Alloy, we get following results for Total Deformation, Shear Stress, Von-mises Stress, Von-mises Strain, Total heat Flux and Shape Optimization.

Total Deformation

Fig 5.1 shows Total Deformation of Piston for Structural Steel, Aluminium Alloy, and Titanium Alloy respectively.

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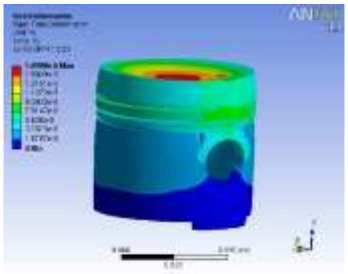
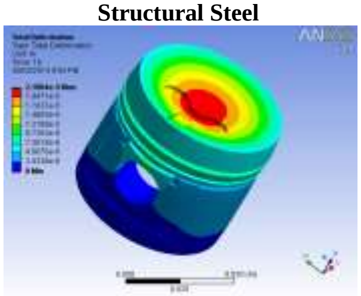
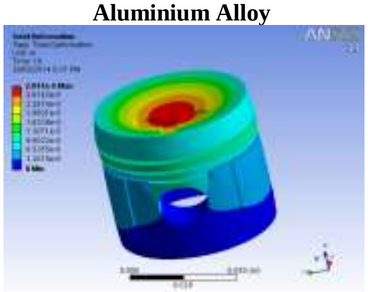


Structural Steel



Aluminium Alloy

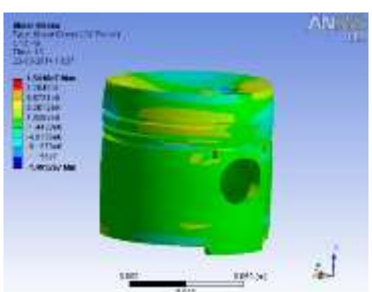


Titanium Alloy

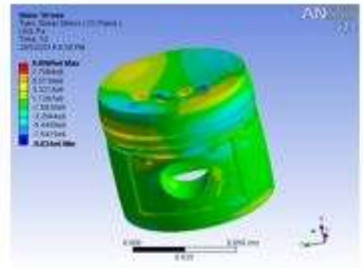
Fig 5.1Comparison between total deformation

Shear Stress

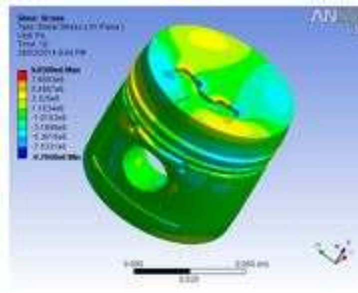
Fig 5.2 shows Total Deformation of Piston for Structural Steel, Aluminium Alloy, and Titanium Alloy respectively.



Structural Steel



Aluminium Alloy

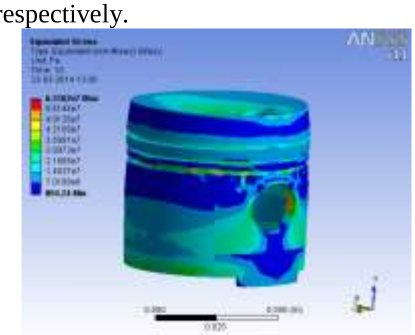


Titanium Alloy

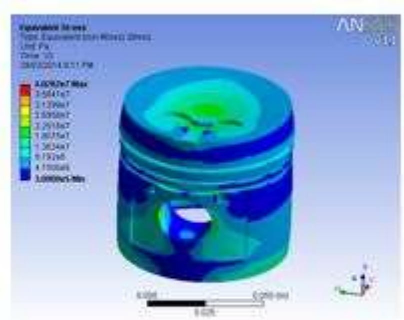
Fig 5.2 Comparison between Shear stress

Von-mises Stress

Fig 5.3 shows Von-mises stress of Piston for Structural Steel, Aluminium Alloy, and Titanium Alloy respectively.



Structural Steel



Aluminium Alloy

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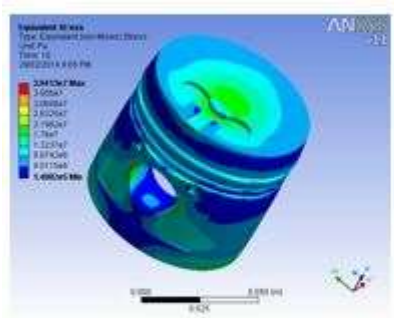
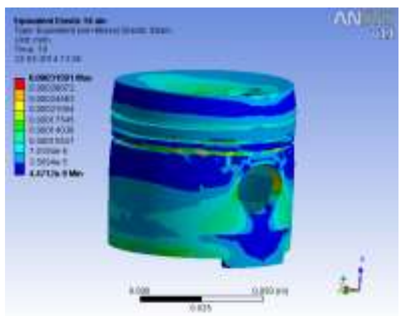


Titanium Alloy

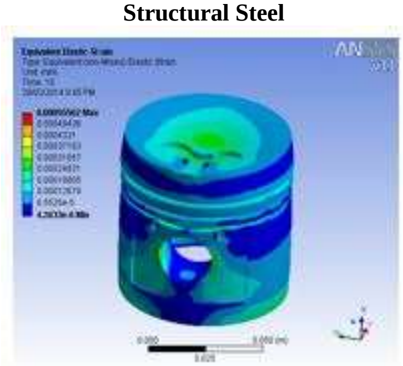
Fig 5.3 Comparison between Von-mises stress

Equivalent Von-mises strain

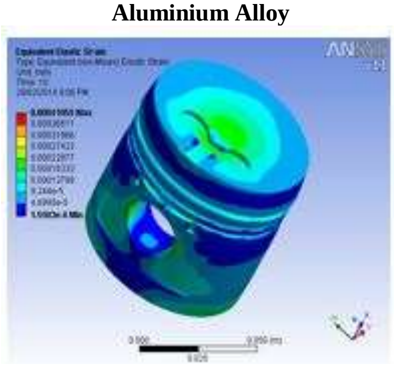
Fig 5.4 shows Von-mises strain of Piston for Structural Steel, Aluminium Alloy, and Titanium Alloy respectively.



Structural Steel



Aluminium Alloy



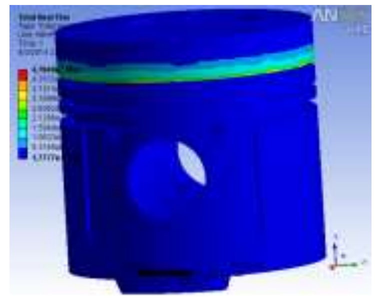
Titanium Alloy

Fig 5.4 Comparison between Von-mises strain

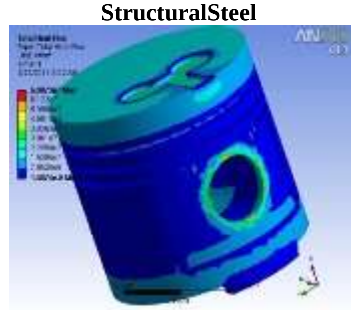
Thermal Stress

Total Heat Flux

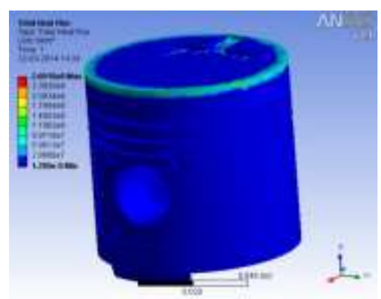
Fig 5.5 shows Total Heat Flux of Piston for Structural Steel, Aluminium Alloy, and Titanium Alloy respectively.



StructuralSteel



Aluminium Alloy



Titanium Alloy

Fig 5.5 Comparison between total heat Flux

Shape Optimization

Fig 5.6 shows shape optimization of Piston for Structural Steel, Aluminium Alloy and Titanium Alloy respectively

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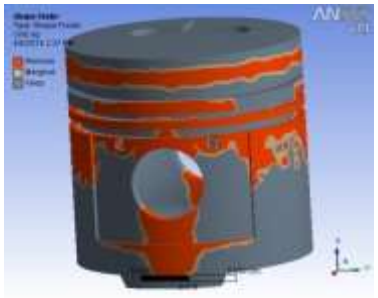
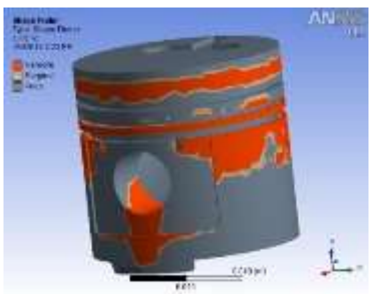


Structural Steel

Aluminium Alloy



Titanium Alloy

Fig 5.5 Comparison between Shape optimization

Table 5.1&5.2 shows final results for structural Steel, Aluminum Alloy and Titanium Alloy in Tabular form.

Table 5.1 Comparison of results

Material	**Structural Steel**	**Aluminum Alloy**	**Titanium Alloy**
Total Deformation(mm)	0.0169	0.029	0.0219
Shear Stress(Pa)	$1.5418 * 10^7$	$9.8989 * 10^6$	$9.8399 * 10^6$
Von-mises Stress(Pa)	$5.6144 * 10^7$	$3.33 * 10^7$	$2.625 * 10^7$
Equivalent Von-mises strain	0.00024563	0.000371863	0.00027422
Thermal Stress			
Total Heat Flux(W/m2)	$3.18 * 10^7$	$3.82 * 10^7$	$1.49 * 10^8$

Table 5.2 Shape Optimization

Material	**Structural Steel**	**Aluminum Alloy**	**Titanium Alloy**
Original mass(Kg)	0.75269	0.28506	0.28506
Optimized mass(Kg)	0.61966	0.23719	0.23709
Marginal Mass(Kg)	$3.329 * 10^{-003}$	$1.4606 * 10^{-003}$	$1.395 * 10^{-003}$

Conclusion

Aluminum Alloys are the preferred material for pistons both in gasoline and diesel engines due to their specific characteristics:- low density, high thermal conductivity, easy machinability, high reliability and very good recycling characteristics. Proper control of the chemical composition, processing conditions and final heat treatment results in a micro structure which ensures the required mechanical and thermal performance, in particular the high thermal fatigue resistance.

The result showed that titanium alloy and aluminium alloy piston has a better performance in shear stress and von-mises stress in comparison with structural steel. The von misses stress initially was 56.14MPa for structural Steel, after optimization it is obtained as 33.3MPa and it is permissible up to 90MPa for aluminium Alloy. For Titanium Alloy, it is 26.25MPa and it is permissible up to 90MPa for Titanium Alloy. Factor of safety is considered as 1.2 for design purpose. So the piston with these considerations can withstand easily.

Total heat Flux for structural steel 31.8MPa, whereas it 38.2Mpa for Aluminium Alloy and 149 MPa for Titanium Alloy.

In this analysis the pressure as well as temperature loads are taken into consideration for applying on the piston. The deflection before optimization is given as 0.0169 for structural Steel, and optimization it is obtained as 0.0294mm for aluminium Alloy and 0.0219mm for Titanium Alloy, this value is taken into consideration for design purpose.

A conclusion can be drawn that titanium has better thermal property. Besides it can be seen that titanium can help us to improve piston qualities. Although titanium is expensive and maybe it is uneconomical for large-scale applications, it can be used in some special cases.

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Refererences

[1] 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, pp.2919-2921, 2012.

[2] Yaochen Xu, Mo Yang, Structure Design and Simulation of Titanium Engine Piston Based on Thermal-Mechanical Coupling Model

[3] Ch.Venkata Rajam ,P.V.K.murali Krishna ,G.M.Prasad design analysis and optimization of piston using CATIA and ANSYS, international journal of innovative research in engineering & science

[4] R.S.Khurmi, J.K.Gupta, A Text Book of Machine Design, S.Chand & Co.2004, pp. 1132-1144.