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RESEARCH ARTICLE

STRUCTURAL, THERMAL AND THERMO-MECHANICAL ANALYSIS OF FOUR STROKE PETROL ENGINE PISTON USING CAE TOOLS

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ABSTRACT

As we are known numerous reciprocating parts is contained in IC Engine which are responsible for giving the motion. The abnormal piston working is given poor performance in comparison of other parts. The main intention of this research is to investigate and analyse the stress distribution of automobile piston at definite engine Condition. In this paper pressure (Mechanical), thermal (Heat) and thermo-mechanical analysis is accomplished by help of CAE Tool. The constraint used for the analysis is pressure of operating gas, temperature and material properties of piston. In this research piston are designed for a single cylinder four stroke petrol engine using CATIA V5R20 and analysis is performed by ANSYS 14. Two different material are induced in this investigation. First one is Aluminium alloy and second is Cast Iron. In this end of the Results are shown and a comparison is made to find the most suited material for splendour automobile vehicle piston by various CAE analyses.

KEYWORDS

IC engine, Piston, structural, thermal, pressure, CATIAV5R20, ANSYS14.

1. INTRODUCTION

CAET propose the incredible benefit to enabling designers to consider virtually any modelling option without incurring the expensive actual manufacturing of the machine component. The ability to try new methodology on the computer concedes the chance to omitted the problems before production. Additionally, designers can easily and shortly identify the sensitivity of specific modeling parameters on the quality and production of the final part. The complex parts of the component can be simply simulated by CAET. Among the engine components exposed to thermal effects, the piston is considered to be one of the most stressed, where an enormous amount of the heat energy transferred to a coolant fluid goes through it, this coefficient mostly depends on the thermal conductivity of the materials employed. A piston is nothing but it is a component of reciprocating Internal Combustion engines (Bhagat and Jibhakate, 2012). It is contained by a cylinder and in this moving part is made gas-tight by piston rings. In an engine, its purpose is to transmit force from expanding gas in the cylinder to the crankshaft with the help of a piston rod (Calbureanu, 2013; Reddy, 2013). Piston endures the cyclic gas pressure and the inertial forces at work besides this working Condition may cause the fatigue damage of pistons, such as piston head cracks and side wear.

So there is a need to optimize the piston design by different parameters. These parameters selected to thermal analysis of piston at different temperatures and different stroke (Bhagat and Jibhakate, 2012; Singh and Sharma, 2014). This analysis could be helpful for the design engineer for piston modification at the time of frame the design. In this research, we find the stress (structural) calculation, thermal analysis form that we can find out the various region where chances of damage of piston are possible (Reddy, 2013; Myagkov et al., 2014; Reddy et al., 2013).The main requirement of piston design is to compute the prediction of temperature distribution on the surface of the piston which enables us to optimize the thermal aspects for the design of a piston at a lower cost. Most of the pistons are made of an aluminum alloy which has thermal expansion coefficient, 80.5% higher than the cylinder bore is made on cast iron material (Bhagat and Jibhakate, 2012).

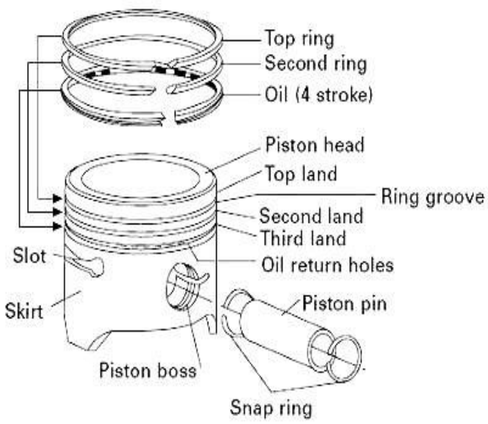

Figure 1: Piston Assembly

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This leads to some differences between running and the design clearances (Vinay and Kuppast, 2013; Devan and Reddy, 2015). Therefore, analysis of the piston thermal behavior is extremely resolvable in designing more efficient compressor (Patel and Bhabhor, 2012). Good sealing of the piston with the cylinder is the basic requirement to design of the piston. Also to improve or reform the mechanical efficiency and reduce the inertia force in high-speed machines the weight of the piston also plays a major role (Junker, 2011).

2. Literature Review

Ch.Venkata Rajam et al, they designed, analyzed and optimized to piston which is stronger, lighter-weight with minimum cost and with less manufacturing time (Rajam et al., 2013). In their paper they analyzed stress distribution in the various parts of the piston to know the stresses due to the gas pressure and thermal variations using with Ansys (Buyukkaya and Cerit, 2007; Cerit, 2010; Lu et al., 2013). The Piston of an engine is designed, analyzed and optimized by using graphics software. The CATIA V5R16, CAD software for performing the design phase and ANSYS 11.0 for analysis and optimization phases are used. They reduced the volume of the piston by 24%, the thickness of barrel is reduced by 31%, width of other ring lands of the piston is reduced by 25%, von-mises stress is increased by 16% and deflection is increased after optimization. But all the parameters are well within design consideration.

Ekrem Buyukkaya et al, in their paper performed thermal analyse on a conventional (uncoated) diesel piston, made of aluminum silicon alloy and steel (Khurmi and Gupta, 2005). And then, thermal analyse are performed on pistons, coated with MgO–ZrO2 material by using ANSYS. From the obtained results, the maximum temperature value of the coated piston was shown at the piston's combustion bowl lip. Therefore, this area must be coated oversensitivity. The maximum surface temperature of the coated piston with material which has low thermal conductivity is improved approximately 48% for the AlSi alloy and 35% for the steel (Carvalheira and Goncalves, 2006). The maximum surface temperature of the base metal of the coating piston is 261 °C for AlSi and 326 °C for steel, and also find out by using of ceramic coating, strength and deformation of the materials are improved.

Muhammet Cerit in his paper determined the temperature and the stress distributions in a partial ceramic coated spark ignition engine's piston. Effects of coating thickness and width on temperature and stress distributions were investigated including comparisons with results from an uncoated piston (Buyukkaya, 2007). It is observed that the coating surface temperature increase with increasing the thickness in a decreasing rate. Surface temperature of the piston with 0.4 mm coating thickness was increased up to 82 °C. The normal stress on the coated surface decreases with coating thickness, up to approximately 1 mm for which the value of stress is the minimum. However, it rises when coating thickness exceeds 1mm. As for bond coat surface, increasing coating thickness, the normal stress decreases steadily and the maximum shear stress rises in a decreasing rate. The optimum coating thickness was found to be near 1 mm under the given conditions.

Xiqun Lu et al, inverse heat transfer method is employed to conduct thermal numerical analysis on a 4-ring articulated piston of marine diesel engine and determine the coefficient of heat transfer at each interface in the thermal system. The secondary motion of piston and piston ring, and the lubrication oil film has been considered in estimating the coefficient of heat transfer values. They manufactured metal plugs were installed in the head of an articulated piston and the piston skirt to measure the temperature distribution of them. A Series of thermal couples were used for cylinder temperature measurement. The boundary condition for numerical simulation is verified with experiment result and applied to predict the temperature distribution of a new piston design which had small change of piston head profile and one less ring scheme.

3. Material

3.1 Aluminum Alloy and Cast Iron

The most common materials used for the piston in cast iron and aluminum alloy. The moderately rated engine's piston made cast iron. in this piston speeds below 6.5 meters/ s and aluminum alloy Pistons are used for highly rated engines running at piston heavy speeds (Gupta and Tripathi, 2014). It may be noted (Vinay and Kuppast, 2013).The coefficient of thermal expansion for aluminum is about 2.5 times that of cast iron, therefore, a large clearance must be conceded between the piston and the cylinder wall in order to prevent seizing (piston failure) of the piston when the engine runs continuously under heavy loads (Patel and Bhabhor, 2012; Gawale et al., 2012). The aluminum alloys have high thermal conductivity (nearly four times that of cast iron), therefore, these type of pistons transfer high-level heat energy and thus keeps down the temperature difference between the centre and edges of the piston top (Gawale et al., 2012; Jaber and Rai, 2014). The aluminum alloys are about three times lighter than cast iron, therefore, its mechanical strength is good at low temperatures, but they lose their strength (about 50%) at temperatures above 325°C (Pandey et al., 2014; Rao and Hasu, 2014). Sometimes, the pistons of aluminum alloys are coated with aluminum oxide (Al2O3) by an electrical method.

Table 1: Material Properties

S/No	Material	Aluminium alloy	Cast Iron
1	Young's modulus [GPa]	7.10E+10	1.80E+11
2	Poisson's ratio	0.33	0.26-0.3
3	Thermal conductivity [W/m °K]	209w/m-k	27-46 w/m-k
4	Thermal expansion	2.20E-05	1.00E-05
5	Specific heat [J/kg °C]	900J/kg^{0}C	840J/kg^{0}C
6	Density [kg/m3]	2710kg/m3	6800-7800kg/m3

3.2 Design Consideration for Apiston

In designing a piston, the following Points should be taken into consideration:

It should have a high strength to withstand the high gas pressure and inertia forces.2. It should have a minimum mass 3. It should form a most effective gas and oil Sealing of the cylinder.4. It should concede sufficient bearing area to deter undue wear. 5. It should disperse the heat of combustion Shortly to the cylinder walls. 6. It should have high(heavy) speed reciprocation Without unwanted noise. 7. It should be of important rigid Construction to withstand thermal (heat) and Mechanical (structural load) distortion.8. It should have sufficient support for the Piston pin

3.3 Theoretical Calculation

1) Piston Diameter D= 78.5 mm

2) Piston inside diameter Di=D-2(s+t+Δt)

S= 5 (piston crown wall thickness)
t= 3.5 (ring radial thickness)
Δt= 0.8 (ring radial clearance in the piston groove)
Di =78-2(5+3.5+0.8)

Di= 59.9mm

3) Skirt radial thickness

$$ST=\frac{D-Di}{2}$$

D= piston diameter
Di = piston inside diameter

$$ST=\frac{78-59.9}{2}$$

ST=9.05

4) Piston outer diameter (dδ)

$$h1 + hc = \frac{d\delta)}{2}$$

h1 = height of piston top part
dδ = piston pin outer diameter
h1 = 0.60 × 78
h1 = 46.8mm
hc=h- hS
hc= Piston Crown Height
h - Piston Height
hS – Piston Skirt Height

h=88.5
hS=58.5

hc= 88-58

hc=30.5

h1 +hc =$\frac{d\delta)}{2}$

dδ = 34.1

5) Piston Pin inside Diameter
dP= 0.27 × 78
dP= 21.19
6) Web Thickness = $\frac{di+b}{2}$
b = distance between boss end faces
b = 0.4 × 78
b= 31.2
Web thickness = $\frac{(59.9-31.2)}{2}$ = 14.1

Web thickness =14.35

Table 2: Dimensions of Piston

S/NO	DIMENSIONS	SIZE RANGES	PREFERABLE SIZE
1	Piston Diameter	-	78.5
2	Piston Height	(0.8-1.3)D	88.5
3	Skirt Height	(0.6-0.8)D	58.5
4	Radial Thickness	(0.040-0.045)D	3.5
5	Ring Radial Clearance	(0.70-0.95)D	0.8
6	Crown Wall Thickness	(0.05-0.10)D	5
7	Piston Crown Thickness	(0.05- 0.10)D	7.5
8	Crown Depth	-	1.5
9	Top Ring Land Height	(0.03- 0.05)D	3.5
10	Piston Inner Diameter	-	59.9
11	Crown Diameter	-	53.36
12	Radial Skirt Thickness	-	9.3
13	1st Piston Groove Thickness	(0.06- 0.12)D	7.8
14	Oil Ring Height & Thickness	-	3
15	Piston pin Outer Diameter	(0.22-0.28)D	34.1
16	Piston Hub Inside Diameter	(0.65- 0.75)D	21.19
17	Web Thickness	-	14.35
18	Top Head Thickness	-	6
19	Piston Inner Fillet	-	1.5
20	Skirt Undercut Height	-	5.8
21	Skirt Undercut Thickness	-	5
22	Skirt radial thickness	-	9.05

3.4 The Boundary Conditions

One of the most important aspects to be Considered during the analysis in order to achieve maximum accuracy is the selection of the boundary conditions. The top surface of the piston is subjected to hot gases which take different values of temperature of gases Tg and convective heat transfer coefficient Hg for the different crank angles. The boundary condition for the present problem have been undertaken to be as given below:

1. Temperature Level of piston head =573K (273+300)

2) Temperature Level of piston ring =493K (273+220)

3) Temperature Level of piston skirt=463K (190+273)

4) Temperature Level of piston bottom portion =243K (273+70)

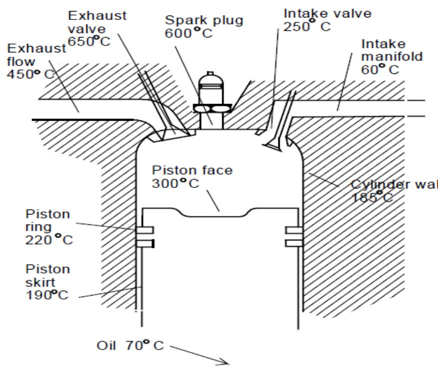


Figure 2: Boundary conditions(Thermal load)

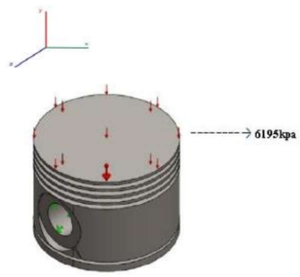


Figure 4: Boundary conditions (Pressure load)

Pressure load is act the on the top portion of the piston, it is called piston head, pressure load will be vary according to engine specification now I have take single cylinder four stroke engine piston

3.5 Finite Element Model

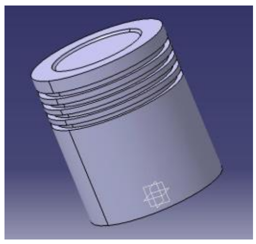


Figure 3: CATIA V5R20 Model

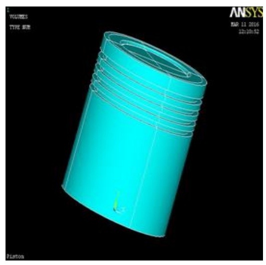
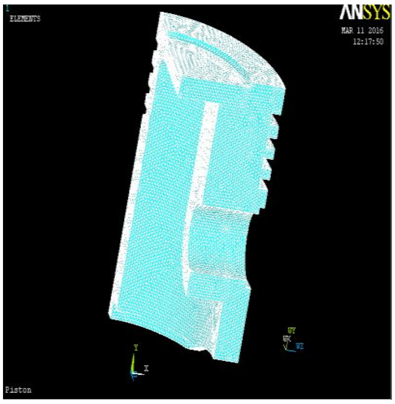


Figure 4: Imported ANSYS Model

The Computer Aided Interactive Three-Dimensional Application (CATIA) Model Imported To ANSYS 14.

4. RESULT AND DISCUSSIONS



In order to avoid complexity, the model was divided in to four equal parts & one part is taken for analysis.

4.1 Structural Analysis

4.1.1 Aluminum Alloy

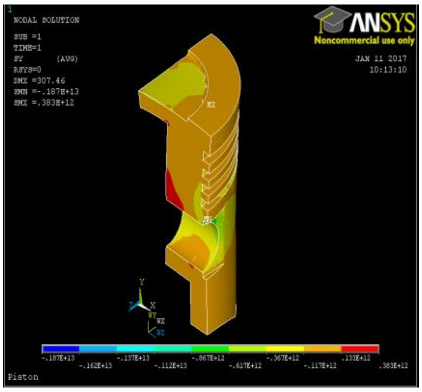


Figure 5: Stress (Y Direction)

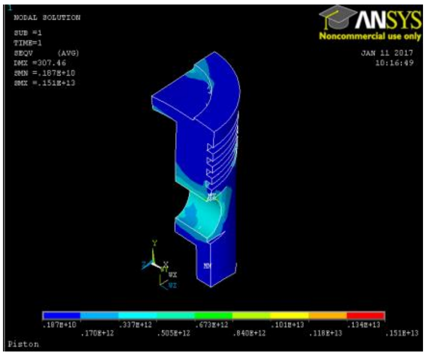


Figure 6: Von Misses Stress

4.1.2 Cast Iron

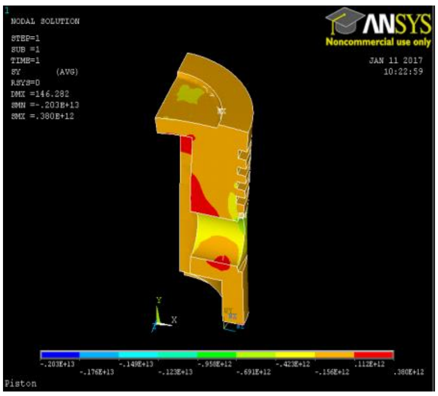


Figure 7: Stress (Y Direction)

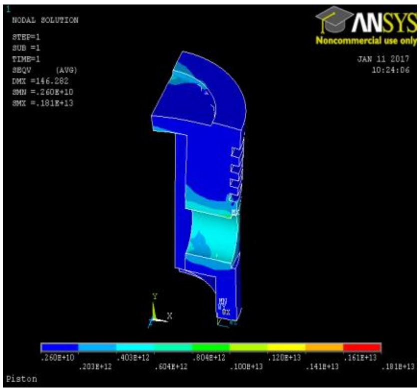


Figure 8: Von Misses Stress

4.2 Thermal Analysis

MATERIAL	STRESS (Y direction)	VONMISSES STRESS
ALUMINIUM ALLOY	383GPA	151e10
CAST IRON	380GPA	181e10

4.2.1 Aluminum alloy

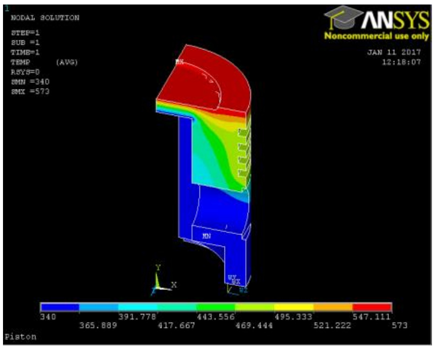


Figure 9: Nodel Temperature Distribution

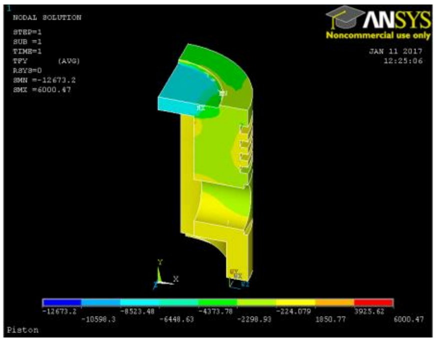


Figure 10: Thermal Flux

4.2.2 Cast Iron

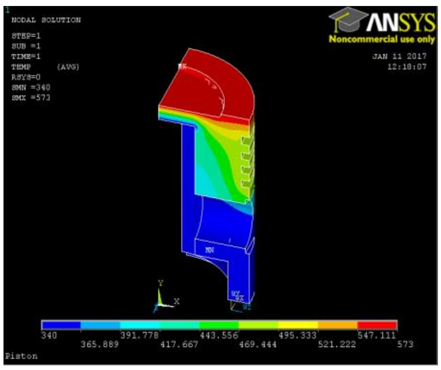


Figure 11: Nodel Temperature Distribution

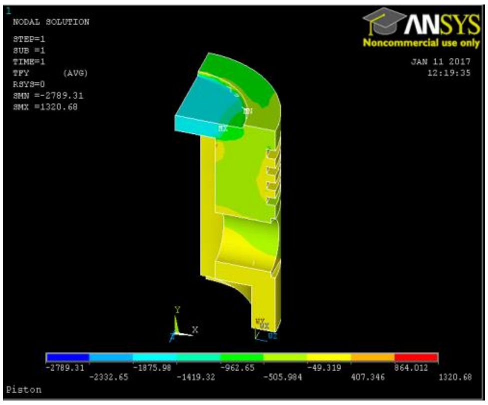


Figure 12: Thermal Flux

4.3 Thermo Mechanical Analysis

4.3.1 Aluminum Alloy

Figure 13: Stress (Y Direction)

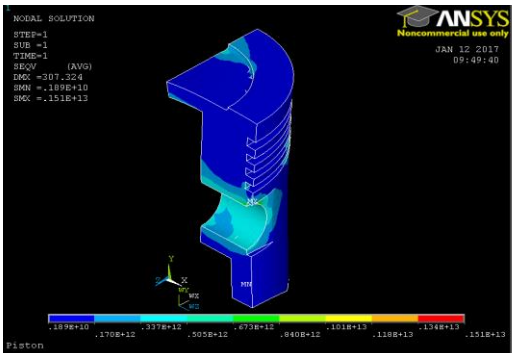


Figure 14: Von Misses Stress

4.3.2 Cast Iron

Figure 15: Stress (Y Direction)

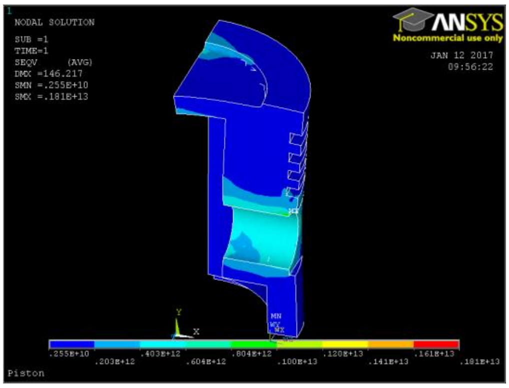


Figure 16: Von Misses Stress

MATERIAL	STRESS (Y direction)	VONMISSES STRESS
ALUMINIUM ALLOY	330GPA	151e10
CAST IRON	370GPA	181e10

5. Conclusion

It is concluded from this research using CATIA utilized design and modeling of piston. Aluminum alloy and cast iron used for piston material because it is withstanding more Pressure and temperature compare to other materials. The Pressure and temperature distribution of piston is very significant because the piston easily damage due to same. The maximum and minimum temperature acted through the piston head and piston skirt. In this research concern hero splendor pro bike piston analyzed the structural, thermal and thermo mechanical analysis is done by using ANSYS software. so conclude as shown above different results cast iron sustain high pressure and temperature compare to the aluminum alloy hence cast iron is suggested material for which is above mentioned application.

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