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# COMPARATIVE STUDY AND STATIC ANALYSIS OF PISTON USING SOLIDWORKS AND ANSYS

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**Abstract** *A piston is a component of reciprocating engines. Its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and a connecting rod. It is one of the most complex components of an automobile. This paper describes the structural analysis of four different aluminium alloy pistons, by using finite element method (FEM). The specifications used for designing the piston belong to four stroke single cylinder engine of Bajaj Pulsar 220cc. Modeling of various aluminium alloy piston are done using SOLIDWORKS. Static structural analysis is performed by using ANSYS WORKBENCH R15.0. The parameters used for the simulation are operating gas pressure, material properties of piston. The results predict the maximum stress and strain on different aluminium alloy pistons using FEA. The best aluminum alloy material is selected based on stress analysis. The analysis results are used to optimize piston geometry of best aluminum alloy.*

***Key Words*: Piston, FEA, Ansys, Aluminium**

## 1. INTRODUCTION*:*

Piston is one of the mechanical component, which was invented by a German scientist Nicholas August Otto in the year 1866 [1]. Piston is considered to be one of the most important parts in a reciprocating engine, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms in which it helps to convert the chemical energy obtained by the combustion of fuel into useful (work) mechanical power. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. The purpose of the piston is to provide a means of conveying the expansion of gases to the crankshaft via connecting rod, the piston acts as a movable end of the combustion chamber piston is essentially a cylindrical plug that moves up & down in the cylinder it is equipped with piston rings to provide a good seal between the cylinder Wall.

### 1.1 LITERATURE SURVEY

The cast iron pistons were superseded by aluminum alloy piston around the year 1920 (Sarkar 1975). Cole G.S. and Sherman A.M.(1995) explained that a considerable interest had been grown in replacing cast iron and steel in automotive component like piston with light weight aluminum alloy casting to improve the performance and efficiency. Haque M.M and Young J.M. (2001) referred the low expansion group of aluminum–silicon alloy as piston alloy, since this group of alloy provides the best overall balance of properties [6].According to Morishita (1981), in internal combustion engines particularly diesel cycle Engine, piston with aluminum based alloy is provided for the purpose of better heat radiation and lower weight [1]. **A.R. Bhagat et al. 2012 [2]** stated that, Piston skirt may appear deformation at work, which usually causes crack on the upper end of piston head. Due to the deformation, the greatest stress concentration is caused on the upper end of piston, the situation becomes more serious when the stiffness of the piston is not enough, and the crack generally appeared at the point A which may gradually extend and even cause splitting along the piston vertical.The stress distribution on the piston mainly depends on the deformation of piston. Therefore, in order to reduce the stress concentration, the piston crown should have enough stiffness to reduce the deformation.The optimal mathematical model which includes deformation of piston crown and quality of piston and piston skirt is used.The FEA is carried out for standard piston model used in diesel engine and the result of analysis indicate that the maximum stress has changed from 228MPa. to 89MPa. And biggest deformation has been reduced from 0.419 mm to 0.434 mm. **Hitesh Pandey et al. 2014 [3]** stated that, Aluminum alloy should be used as a piston material as it has minimum thermal stress and mechanical distortion in same working condition as that of cast iron and structural steel as piston material.Aluminum alloys are lighter in weight thus provides good mechanical strength at low temperatures. Aluminium alloys have high heat conductivity thus; high rate of heat transfer is possible between the centre and edge of the piston head.Use of CAE software eliminates the human effort in determination of stress, distortion values and so are referred as good tool for piston mechanical as well as thermal analysis. It is concluded that the maximum thermal stress and the maximum distortion of piston in decreasing order are as follows: **Structural Steel > Cast Iron > A2618 Aluminium Alloy.**So, it is convenient to use aluminum alloy as piston material rather than cast iron or structural steel. **Dilip Kumar Sonar et al. 2015 [4]** stated that, the stress distribution on piston of internal combustion engine by using FEA. The FEA is performed by CAD and CAE software. It describes the FEA technique to predict the higher stress and critical region on the component. With using CATIAV5 software the structural model of a piston will be developed. Using ANSYS V14.5 software, simulation and stress analysis is performed. The first main conclusion that could be drawn from this work is that although thermal stress is not the responsible for biggest slice of damaged pistons, it remains a problem on engine pistons and its solution remains a goal for piston manufacturers. From the analysis, it is evident that thermal stress was higher than mechanically induced stress hence it could be concluded that the piston would fail due to the thermal load rather than the mechanical load and hence during optimization design, this could be put into consideration to ensure that thermal load is reduced.It can also be deduced that individually, thermal and mechanical stress proportions have a direct influence on the coupled thermal-mechanical stress hence during design each load can be considered and reduced independently. It can be concluded that the piston can safely withstand the induced stresses during its operation. **Subodh Kumar Sharma et al. 2015 [5]** stated that, a methodology is proposed for the estimation of the temperatures in piston and cylinder wall, piston body distortions, and radial stresses of a water-cooled fourstroke single cylinder direct injection diesel engine. The purpose is to obtain a generalized method (FEM) for analyzing temperature field, piston distortion, and corresponding thermal stresses so simulated temperatures are to be verified by direct measured temperatures. In this work, seven thermocouples were used, in which four thermocouples were mounted on the piston inner surface and three were mounted on the cylinder wall. By installing thermocouple at seven points on piston and cylinder wall, variation in temperature of piston and cylinder wall at no load, half load, three-quarters load, and full load conditions was determined. As engine load increases, temperature of the piston and cylinder wall increases exponentially and has a positive relationship. The piston temperature for every engine load condition tested was estimated and good agreement was obtained with the expected results. **Ankit Kumar Pandey et al. 2016 [6]** stated that, Solid Model of piston has been made using ANSYS 16.2 Geometric module. Thermo-Mechanical (Static Structural Analysis + Steady-State Thermal Analysis) analysis is done for Piston. The objective of FEA is to investigate stresses and problem area experienced by piston. Aluminium alloy is material of piston for the FEA, since this piston is also used at optimization. Thermo-mechanical analysis is used for analysis of piston. Analysis of S.I. engine piston using ANSYS The piston is divided into the areas defined by a series of grooves for sealing rings. The boundary conditions for mechanical simulation were defined as the pressure acting on the entire piston head surface. It is necessary to load certain data on material that refer to both its mechanical and thermal properties to do the coupled thermo-mechanical calculations. After Response Surface Optimization percentage of weight reduces is 26.074%, Resultant percentage of increase in factor of safety, percentage of decease in equivalent von-mises stress is 3.072%, 2.982% respectively. After optimization Equivalent von-mises stress, factor of safety and weight is 259.99 mpa, 1.0769 and 0.10065 Kg respectively. Here factor of safety is greater than 1 and Maximum Equivalent Von-mises stress is less than yield stress of aluminium alloy so designed model of piston is safe. **Amitanand B Suralikerimath et al. 2016 [7]** stated that, Aluminium alloy is selected for the design and analysis of the piston head. After designing the model in CATIA V5R20 the model is converted to STP file and imported to ANSYS 14.5. Then analysis is carried out accordingly. Aluminum alloy is chosen and applied to the imported model. All the material properties of aluminum alloy are predefined by the software.In order to analyze the model by FEM meshing of the model must be done.

The analysis can be further carried out for thermal analysis from which we can compute the thermal stress induced in various portions of piston head.

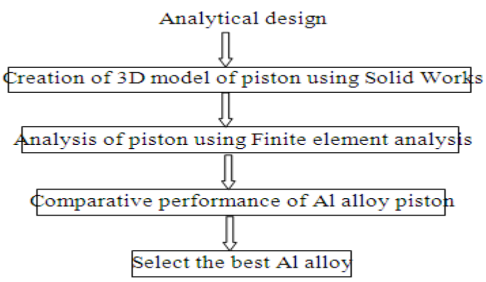
### 1.2 Materials used for piston

The most commonly used materials for pistons of I.C. engines are cast iron, cast aluminium, forged aluminium, cast steel and forged steel. The cast iron pistons are used for moderately rated engines with piston speeds below 6 m/s and aluminium alloy pistons are used for highly rated engines running at higher piston speeds. Since the aluminium alloys used for pistons have high heat conductivity (nearly four times that of cast iron), therefore, these pistons ensure high rate of heat transfer and thus keeps down the maximum temperature difference between the centre and edges of the piston head or crown.

For a cast iron piston, the temperature at the centre of the piston head ($T_c$) is about 425°C to 450°C under full load conditions and the temperature at the edges of the piston head ($T_e$) is about 200°C to 225°C. For aluminium alloy pistons, $T_c$ is about 260°C to 290°C and $T_e$ is about 185°C to 215°C [1].The piston should have enormous strength to withstand the high gas pressure and inertia forces, with minimum mass to minimize the inertia forces. The piston should be designed in such a way that it should disperse the heat of combustion quickly with minimum noise and sufficiently rigid construction to withstand thermal and mechanical distortion. The piston should form an effective gas and oil sealing of the cylinder and provide sufficient bearing area to prevent undue wear and mechanical distortion.

### 1.3. METHODOLOGY

In this paper the stress distribution is evaluated on the four stroke engine piston by using FEA. The finite element analysis is performed by using FEA software. The materials used in this project are aluminium alloy i.e. A2618 aluminium alloy, A4032 aluminium alloy, Ti-6Al-4V aluminium alloy, Al-GHS1300 aluminium alloy. In this project the natural characteristics are analysed. With using computer aided design (CAD), SolidWorks software the structural model of a piston will be developed. Furthermore, the finite element analysis performed with using software ANSYS.Analytical design of piston, using specification of four stroke single cylinder engine specified by the manufacturer of Bajaj Pulsar 220cc motorcycle created




**Engine specification**

| S.No. | Parameters | Values |
|---|---|---|
| 1 | Engine type | Four stroke engine |
| 2 | No. of cylinder | Single cylinder |
| 3 | Maximum pressure | 13.65 MPa |
| 4 | Break power | 14.015 Kw |
| 5 | Indicated power | 17.518 Kw |
| 6 | Torque | 19.12 Nm |
| 7 | RPM | 7000 |
| 8 | Bore | 79.5 mm |

**Table 1 : Details of Engine Specification**

### 1.4 Properties of Materials

The material chosen for this work are conventional Al alloy i.e.

- A2618 aluminium alloy,
- A4032 aluminium alloy,
- Al-GHS1300 aluminium alloy,
- Ti-6Al-4V aluminium alloy

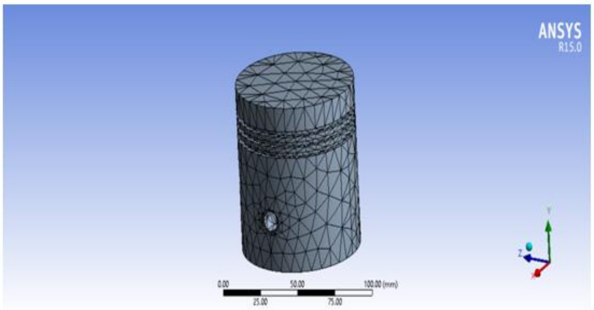
For an IC engine piston. The Mechanical properties of conventional Al alloy i.e. A2618 aluminium alloy, A4032 aluminium alloy, Ti-6Al-4V aluminium alloy, Al-GHS1300 aluminium alloy are listed in following table.

The working condition of the piston of an internal combustion engine is so worst as compare to other parts of I.C. engine. There are high chances of failure of piston due to wear and tear. So there is necessary to analyze area of maximum stress concentration on piston. The objective of the present work is to design and analysis of piston made of A2618 aluminium alloy, A4032 aluminium alloy, Al-GHS 1300 aluminium alloy, Ti-6Al-4V aluminium alloy.

| S.No. | Material/Properties | Elastic modulus | Poisson's ratio | Ultimate tensile strength | Tensile yield strength | Density |
|---|---|---|---|---|---|---|
| 1 | A2618 aluminium alloy | 73.7GPa | 0.33 | 480MPa | 420MPa | 2767.99kg/m$^3$ |
| 2 | A4032 aluminium alloy | 79GPa | 0.33 | 380MPa | 315Mpa | 2684.95 kg/m$^3$ |
| 3 | Al-GHS 1300 aluminium alloy | 98GPa | 0.30 | 1300MPa | 1220Mpa | 2780 kg/m$^3$ |
| 4 | Ti-6Al-4V aluminium alloy | 113.8GPa | 0.33 | 950MPa | 880Mpa | 4430 kg/m$^3$ |

Table 2: Properties of Aluminum alloy

### 1.5 MESHING AND ANALYSIS

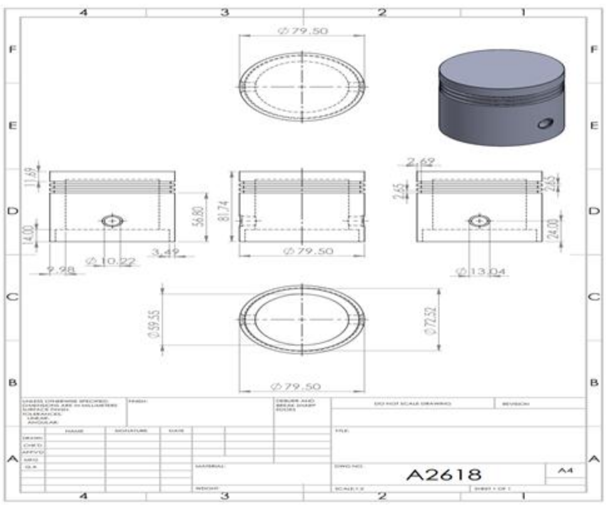


Analytical Anlysis of Piston design

| Material Type | Thickness of piston head | Piston rings | Piston Barrel | Piston Skirt |
|---|---|---|---|---|
| Material Type | Thickness of piston head | Piston rings | Piston Barrel | Piston Skirt |
| A-2618 | 9.308 mm | Radial thickness = 2.69 mm. Axial thickness =2.65mm. Width of the top land =11.69mm | $t_3$ = 9.975mm $t_4$ =2.99mm | 81.74mm |
| A-4032 | 10.74 mm | Radial thickness = 2.69 mm. Axial thickness =2.65mm. Width of the top land=12.89mm. | $t_3$ = 9.975mm $t_4$= 3.49mm | 82.94mm |
| AL-GHS-1300 | 5.46 mm | Radial thickness = 2.69 mm. Axial thickness =2.65mm. Width of the top land =6.55mm. | $t_3$ = 9.975mm $t_4$= 3.49mm | 76.6mm |
| TI-6AL-4V | 6.43 mm | Radial thickness = 2.69 mm. Axial thickness = 2.65mm. Width of the top land =7.717mm. | $t_3$ = 9.975mm $t_4$= 3.49mm | 77.76mm |

Table 3: Analytical Anlysis of piston Design

## 1.5 Modeling In solid works




### A2618 aluminium alloy

The figure illustrates the variation of von-misses stress in the piston. The value of maximum stress found to be 291.19 MPa. The value of minimum stress is found to be 0.86017 MPa.

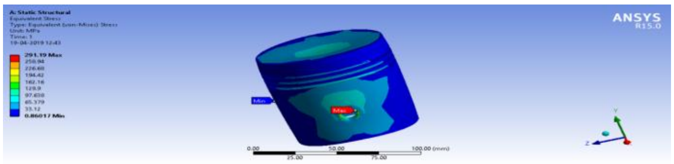



**Fig. 2 Ansys model of piston.**

## 1.6 RESULT & DISCUSSION

Comparison between stresses in theoretical result and analytical result for A2618 aluminium alloy, A4032 aluminium alloy, Al-GHS1300 aluminium alloy and Ti-6Al-4U aluminium alloy used as piston material. The comparative performance of simulated results of various parameters like maximum and minimum value of Total Deformation, Equivalent von-misses stress, Equivalent von-misses strain for different material with the theoretical results is done.The comparative performance of Simulated result of various parameters like maximum and minimum value of Total Deformation, Equivalent von-misses stress, Equivalent von-misses strain for different material are as shown in table

| S.No. | Piston material /Parameter | Deformation (mm) | | Stress (MPa) | | Strain | |
|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum |
| 1 | A2618 | 0.13983 | 0.00 | 291.19 | 0.86017 | 0.0040216 | $2.6416e^{-5}$ |
| 2 | A4032 | 0.11221 | 0.00 | 291.32 | 1.0968 | 0.0037581 | $2.3457e^{-5}$ |
| 3 | Al-GHS-1300 | 0.22769 | 0.00 | 273.45 | 1.009 | 0.0028241 | $1.9740e^{-5}$ |
| 4 | Ti-6Al-4U | 0.085779 | 0.00 | 275.06 | 1.0803 | 0.0014028 | $5.5675e^{-6}$ |

Table 4: Equivalent von-misses strain for different Material

Following table shows the comparison between stresses in theoretical result and analytical result for A2618 aluminium alloy, A4032 aluminium alloy, Al-GHS1300 aluminium alloy, Ti-6Al-4U aluminium alloy used as piston material.

| S.No. | Parameters | A2618 | | A4032 | | Al-GHS-1300 | | Ti-6Al-4U | |
|---|---|---|---|---|---|---|---|---|---|
| | | Stress (MPa) | Strain | Stress (MPa) | Strain | Stress (MPa) | Strain | Stress (MPa) | Strain |
| 1 | Theoretical results | 226.22 | 0.0031032 | 187.23 | 0.0024104 | 342.32 | 0.0035315 | 311.25 | 0.0027464 |
| 2 | Simulated results | 291.19 | 0.0040216 | 291.32 | 0.0037581 | 273.45 | 0.0014028 | 275.06 | 0.0014028 |

Table 5: Comparison of Theoretical and simulated Results

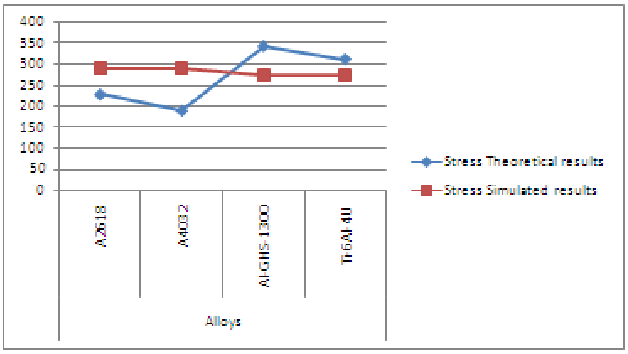



**Fig. 3 comparison Graph**

**Comparative Analysis of four Aluminum alloys under static stress analysis method:**

The load variation analysis is performed for the four different piston alloys i.e. A2618 aluminium alloy, A4032 aluminium alloy, Al-GHS1300 aluminium alloy, Ti-6Al-4U aluminium alloy. The load is varied from 125% to 225% of the calculated pressure of the Bajaj Pulsar four stroke petrol engine.

| S.No. | Pressure Load (Mpa) | Material | Ansys Result | | |
|---|---|---|---|---|---|
| | | | Deformation (mm) | Stress (Mpa) | Strain |
| 1 | 13.65 = 100% | A2618 | 0.13983 | 291.19 | 0.0040216 |
| | | A4032 | 0.11221 | 291.32 | 0.0037581 |
| | | Al-GHS 1300 | 0.22769 | 273.45 | 0.0028241 |
| | | Ti-6Al-4V | 0.085779 | 275.06 | 0.0014028 |
| 2 | 125% = 13.65×1.25 = 17.0625 | A2618 | 0.17479 | 363.99 | 0.005027 |
| | | A4032 | 0.14027 | 364.15 | 0.0046976 |
| | | Al-GHS 1300 | 0.28461 | 341.31 | 0.0035301 |
| | | Ti-6Al-4V | 0.10722 | 343.83 | 0.0017535 |
| 3 | 150% = 13.65 × 1.50 = 20.475 | A2618 | 0.020975 | 436.79 | 0.0060325 |
| | | A4032 | 0.16832 | 436.98 | 0.0056371 |
| | | Al-GHS 1300 | 0.34153 | 410.17 | 0.0042361 |
| | | Ti-6Al-4V | 0.12867 | 412.59 | 0.0021041 |
| 4 | 175% = 13.65 ×1.75 = 23.885 | A2618 | 0.24468 | 509.54 | 0.007037 |
| | | A4032 | 0.19635 | 509.76 | 0.0065759 |
| | | Al-GHS 1300 | 0.39841 | 478.48 | 0.0049416 |
| | | Ti-6Al-4V | 0.1501 | 481.31 | 0.0024546 |
| 5 | 200% = 13.65 × 2.00 = 27.30 | A2618 | 0.27966 | 582.39 | 0.0080433 |
| | | A4032 | 0.22443 | 582.64 | 0.0075161 |
| | | Al-GHS 1300 | 0.45538 | 546.89 | 0.0056481 |
| | | Ti-6Al-4V | 0.17156 | 550.13 | 0.0028055 |
| 6 | 225% = 13.65 × 2.25 = | A2618 | 0.31462 | 655.19 | 0.0090487 |
| | | A4032 | 0.25248 | 655.47 | 0.0084557 |
| | | Al-GHS 1300 | 0.5123 | 615.25 | 0.0063542 |

Table 6: Comparison of Results in different conditions

After doing comparative analysis of various type of Al alloy i.e.in between A2618 aluminium alloy, A4032 aluminium alloy, Al-GHS1300 and Ti-6Al-4U aluminium alloy for total deformation, equivalent von-mises stress and equivalent von-mises strain. From the analyzed result through this work, it is concluded that stress occurred by using this material is lower than the permissible stress value, so that Al-GHS1300 is best material for piston.

### 1.7 Conclusion

In the results all the four aluminium alloys pistons are compared for the best possible material.

After doing comparative analysis of various type of Al alloy i.e.in between A2618 aluminium alloy, A4032 aluminium alloy, Al-GHS1300 and Ti-6Al-4U aluminium alloy for total deformation, equivalent von-mises stress and equivalent von-mises strain. From the analyzed result through this work, it is concluded that stress occurred by using this material is lower than the permissible stress value, so that Al-GHS1300 is best material for piston.

Having analyzed all stresses, strains and total deformation in an allowable range, the main design questions have been answered and the objectives of the project achieved.

### 1.8 FUTURE SCOPE

1. This work can be extended by using some more type of aluminium alloys as piston material such as cast aluminium, forged aluminium, cast steel and forged steel.
2. Aluminium alloys may be coated with aluminium oxides for pistons working at elevated temperatures.
3. The analysis can be further carried out for thermal analysis from which we can compute the thermal stress induced in various portions of piston head.

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