

Coupled Analysis of Single Cylinder Piston with Different Materials

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ABSTRACT: The aim of the project is to increase the strength of the piston. To achieve this need a new material of piston. Using the alloy material is framed by mixing of two or more material to accomplished properties that are better than those its constituents. From very beginning day's piston has been made up of cast iron or Aluminum for their high heat transfer rate, but after some days cast iron expands much more on heating than aluminum i.e. to improve the efficiency of piston used the materials i.e. Al-Si-Mg, Al-6061, LM13 and steel etc. To achieve above we are going to do coupled analysis of piston with different materials. A Coupled analysis is an analysis that takes into account the interaction between two or more disciplines of engineering. Such as handles the interaction between structural and thermal fields. In analytical calculations we are going to calculate bending stress, dimensions of pistons by maintain the same geometry and changing the different materials. This calculated value are validating with analysis results.

KEYWORDS: AL-Si-Mg, Al-6061 Piston, Stainless steel, LM13, Coupled analysis.

I. INTRODUCTION

The piston is important component of engine. It reciprocates inside the cylinder bore. The cylinder head is the stationary end of the combustion chamber. Piston head is the top surface of the piston which is subjected to pressure fluctuation, thermal stresses and mechanical load during normal engine operation. By the forces of combustion, piston reciprocates inside the cylinder bore. In order to increase the efficiency of operation and better functionality, the piston material should satisfy the following requirements: Light weight, Good wear resistance, Good thermal conductivity, High strength to weight ratio, Free from rust, Easy to cast, Easy to machine Nonmagnetic and Nontoxic Piston should be designed and fabricated with such features to satisfy the above requirements.

A recessed area located around the circumference of the piston is used to retain piston ring. These rings are expandable and split in type. They are used to provide a seal between piston and cylinder wall. Compression ring is used to prevent the leakage from combustion chamber during combustion process. It is located closest to the piston head. The wiper ring is placed between compression ring and oil ring. It further seals the combustion chamber and keeps the cylinder wall clean by wiping out the excess oil. Combustion gases passed through the compression ring are stopped by the wiper ring. Oil ring is located near the crank case which is used to wipe excess oil from the cylinder wall during piston movement. K.R. Padmavathi, Dr.R.Ramakrishnan [1]: The wear and friction behaviour of Al6061 alloy reinforced with multi wall carbon Nano tubes (MWCNT) and Sic to form light weight, high performance hybrid metal matrix Nano composite material. CNTs were well dispersed and embedded in the aluminium matrix. The coefficient matrix decreases with increasing volume fraction of CNTs. And wear rate decreased of composite & increase of CNTs content (0 to 20% volume).The addition of silicon carbide and alumina in the aluminium alloy then

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form a mixture which have good properties and improve wear resistance. Multi wall Nano tubes are defect free , excellence tensile strength and thermal stability more than 600°C. Aluminum reinforced with Sic and multi wall Nano tubes then it gives better dry abrasive wear resistance. Hardness of composite increases because of hybrid ratio increases. Ranvier Singh Panwar, O.P Pandey[2]: Aluminum alloy LM13 containing 12 wt. % Si was chosen as a matrix and commercial grade zirconium silicate ($ZrSiO_4$) called zircon sand reinforcement with each other. Wear resistance and hardness of composite increases with increasing reinforcement of zircon sand, although increasing zircon sand content from 15wt% to 20wt% does not result in an appreciable change. Zircons have high hardness, high modulus of elasticity and god thermal stability. Zircon sand reinforced composite shows better wear resistance than alumina reinforced composite due to its superior matrix bonding. O. Yilmaz, H. Turhan[3]: The CuSn/FeCr MMCs which were prepared by addition of 5, 10, 15&20 % volume of FeCr, were produced by powder metallurgy and size of particle taken as 16 μ m. FeCr reinforcement is beneficial in increasing wear resistance of CuSn MMCs. FeCr particles in MMCs also reduce the extent of plastic deformation in sub surface region of matrix there by delaying of nucleation and propagation of sub surface micro cracks. The effect FeCr particles on the wear resistance of a CuSn alloy was investigated under 125N load, and 300-475K temperature range. Then result shows the transition temperature between the ambient and high temperature behaviors was found to be 340 \pm 15K for the CuSn alloy and 375-420K temperature interval for CuSn/FeCr MMCs. The CuSn/FeCr MMCs shows greater wear resistance than CuSn alloys. Michael Oluwatosin Bodunrin, Kenneth Kanayo Alaneme, Lesley Heath Chown[4]: Aluminum hybrid composites are a new generation of metal matrix composites that have the potentials of satisfying the recent demands of advanced engineering applications. These demands are met due to improved mechanical properties, amenability to conventional processing technique and possibility of reducing production cost of aluminum hybrid composites. The performance of these materials is mostly dependent on selecting the right combination of reinforcing materials since some of the processing parameters are associated with the reinforcing particulates. A few combinations of reinforcing particulates have been conceptualized in the design of aluminum hybrid composites. This paper attempts to review the different combination of reinforcing materials used in the processing of hybrid aluminum matrix composites and how it affects the mechanical, corrosion and wear performance of the materials. The major techniques for fabricating these materials are briefly discussed and research areas for further \ improvement on aluminum hybrid composites are suggested. Hashem F. El-Labban, M. Abdelaziz, Essam R.I. Mahmoud

[5]: A mixture of Ni and Nano Al_2O_3 particles of different ratios was added to the melted Al-Si piston alloy at 700° C and stirred under pressure. The hardness and tensile properties of the Al- based Nano composites wear at room temperature by using Vickers hardness and universal tensile tester. The ultimate tensile strength increased by adding Ni and Al_2O_3 particles up to 10 and 2wt%. The ductility improving increasing by addition of Ni particles. The 5wt% Ni and 2wt% Al_2O_3 shows the ultimate tensile strength and good ductility than other. In Al-Si piston was different contents of Ni particles-5%, 10%, 15%. Al_2O_3 Nano particles=2%, 3% with 5% nickel through squeeze casting. K. Umanath, K. Palanikumar, S.T. Selvamani[6]: The wear behavior of Al6061-T6 discontinuously reinforced with silicon carbide (Sic) and aluminum oxide (Al_2O_3) composite. The test specimens are prepared and tested as per ASTM standard. The experiments are conducted by using a pin on disc wear tester. Empirical relation is established to estimate the wear using statistical regression analysis and analysis of variance (ANOVA). The results indicated that the wear resistance of the 15% hybrid composite is better than that of the 5% composite. The fracture surface of composites shows the ductile tear ridges and cracked Sic and Al_2O_3 particles indicating both ductile and brittle fracture mechanism. N. Mathan Kumar, S. Senthil Kumaran, L.A. Kumarswamidhas[7]: Al 2618 matrix material was mixed with the Silicon Nitride (Si_3N_4), Aluminum Nitride (AlN) and Zirconium Boride (ZrB_2) reinforced particles. AMC was synthesized successfully by the stir casting method with the various X-wt. % of reinforcements ($X = 0,2,4,6, 8$). Tribological behavior was studied in this composite with various temperature conditions. The working conditions were Temperature (o C), Load (N), Velocity (m/s) and Sliding Distances (m). Before wear testing the mechanical behavior has been analyzed. EDAX was confirmed by the matrix material composition. The Al 2618 alloy and the reinforcement mixers were confirmed by the X-ray Diffraction analysis. Wear rate (mm³/m), Wear resistance (m/mm³), Specific Wear rate (m/Nm) and Co-efficient of friction were analyzed with various conditions. The worn surfaces were analyzed before and after wear testing by Scanning Electron Microscope (SEM). Bharath V, Madev Nagaral, V Auradi and

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S.A.Kori[8]: Synthesis metal matrix composite using 6061Al has matrix material reinforced with ceramic Al₂O₃ particulates using liquid metallurgy route in particular stir casting technique. The addition of reinforcement is being varied from 6 to 12wt% in step of 3wt% .For each composite reinforcement particles are free heat to a temperature of 2000 o C and then dispersed in next step of molten Al6061 alloy to improve wettability. Hardness and tensile properties of given composite were find out before and after addition Al₂O₃.Unreinforced 6061Al matrix have lower hardness and tensile properties than reinforced 601Al matrix. If we increase reinforced level then increases the hardness and tensile strength. Keneth Kanaya Alaneme, Idris B. Akintunde, Peter Apata Olubambi[9]: Al-Mg-Si alloy matrix composites reinforced with Alumina (Al₂O₃) and rice husk ash (agro waste) was investigated.Al₂O₃ particulates added with 0,2,3and 4wt% rice husk ash were utilized to prepare 10wt% of the reinforcing phase with Al-Mg-Si alloy as matrix using two step stir casting method. Density measurement, optical microscopic, tensile testing, estimated percent porosity. Micro hardness measurement and SEM examination were used to characterize the composite produced. The result show that the less dense Al-Mg-Si/RHA/Al₂O₃ hybrid composites have estimated percent porosity levels as low as the single Al₂O₃ reinforced grade (<2.3%porosity).

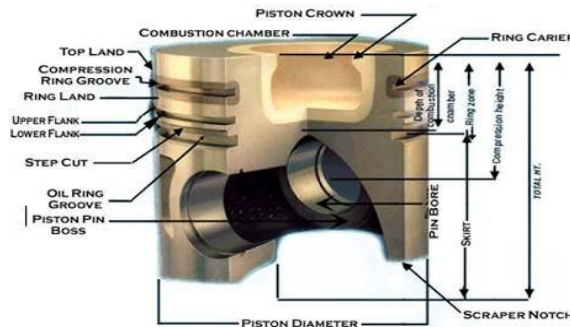


Fig.1. Piston

During working condition in IC engine high pressure and temperature is developed is causes the following problems in automobile: 1. Piston wear & failure of piston. 2. Expansions of piston and jamming. 3. Reduces overall efficiency of engine. To overcome thisproblemour aim isdevelop a piston has greater wear resistance and high strength. And Reducing the inertial weight of the piston is the most important to increase efficiency. To achieve above we are going to1.Determine the thermal stresses on the pistons2. Determine the structural stresses on the pistons. 3. Calculate total deformation in pistons 4.Calculate the total weight of pistons.

Table No.1. Materials Properties

S.NO.	Materials Properties	A1-6061	Al-si-mg	LM13	Steel	Grey Cast Iron
1	Elastic modulus(GPa)	71	69	79	193	110
2	Ultimate tensile strength(MPa)	320	310	280	586	240
3	Poisson's Ratio	0.33	0.33	0.31	0.31	0.28
4	Thermal Conductivity (W/m°C)	105	188	117	15.1	52
5	Density(Kg/m ³)	2770	2700	2680	7750	7200

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II. RELATED WORK

- **Analytical calculations:**

Mechanical efficiency of the engine = 80 %.

$$\eta = \frac{\text{Brake Power (BP)}}{\text{Indicated Power (IP)}} = 2.64 \text{ kW}$$

$$\text{IP} = P \times A \times L \times N / 60 = 2.7 \times 10^5 \text{ N/mm}^2$$

$$P_{\text{max}} = 2.7 \text{ MPa}$$

- **Design for Steel piston:-**

- **Thickness of the Piston Head (t_h):-**

Tensile Stress (σ_t) = $S_{ut} / f_s = 195.33 \text{ MPa}$

According to Grashoff's formula,

$$t_h = D \sqrt{3 P_{\text{max}} / 16 \sigma_t} = 4.32 \text{ mm}$$

On the basis of the heat dissipation, the thickness of the piston head is given by:

$$t_h = \frac{[C \times \text{HCV} \times m \times \text{BP}] \times 10^6}{12.56 \times K (T_c - T_e)} = 2.29 \text{ mm}$$

For steel ($T_c - T_e$) = 75°C $K = 45 \text{ W/m}^\circ\text{C}$

The maximum thickness from the above formula is $t_h = 4.32 \text{ mm}$

- **Piston Rings:**

The radial width (b) = $D \sqrt{3 p_w / \sigma_t} = 2.21 \text{ mm}$

Axial thickness (h) = $(0.7b \text{ to } b) = 1.54 \text{ mm}$

- **Width of Top Land and Ring Lands:-**

Width of top land (h_1) = $(t_h \text{ to } 1.2 t_h) = 4.32 \text{ mm}$

Width of ring land (h_2) = $(0.75 X h) = 1.155 \text{ mm}$

- **Piston Barrel:-**

Thickness of piston barrel at the top end (t_1) = $0.03 D + b + 4.9 = 9.66 \text{ mm}$

Thickness of piston barrel at the open end (t_2) = $(0.25 t_1 \text{ to } 0.35 t_1) = 2.41 \text{ mm}$

- **Length of the skirt:-**

$l_s = (0.6 D \text{ to } 0.8 D) = 51 \text{ mm}$

- **Length of piston pin in the connecting rod bushing:-**

$l_1 = 45\%$ of the piston diameter = 38.25 mm

- **Piston pin diameter:-**

$d_o = (0.28 D \text{ to } 0.38 D) = 23.8 \text{ mm}$

$d_i = 0.6 d_o = 14.4 \text{ mm}$

The centre of the piston pin should be $0.02 D$ to $0.04 D$ above the centre of the skirt.

- **Totallength Of Piston:-**

$L_p = \text{Top land} + \text{Length of ring section} + \text{Skirt length} = 64.96 \text{ mm}$

- **Maximum load on the piston due to gas pressure:-**

$$= \frac{\pi D^2}{4} \times P = 15321.15 \text{ N}$$

- **Maximum bending moment at the center of pin:**

$M = PD/8 = 162.78 \times 10^3 \text{ N-mm}$

$$162.78 \times 10^3 = \frac{\pi}{32} \left[\frac{d_o^4 - d_i^4}{d_o} \right] \sigma_b$$

$\sigma_b = 135.65 \text{ MPa}$

Piston pin made up of heat treated alloy steel for which bending stress $\sigma_b = 140 \text{ MPa}$. Hence bending stress induced in pin less than permissible value of 140 MPa . Therefore design is safe.

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- **Total weight of piston:**

Total weight of piston= density × volume = density × ($\pi r_1^2 h - \pi r_2^2 h$)=1214 gm

- **Theoretical Stress Calculation:**

$$\sigma_b = P_{max} \times [(r_i / \delta)^2] = 2.7 \times [(0.04126 / 0.0068)^2] = 99.40 \text{ Mpa.}$$

Hence required theoretical stress obtained from calculation is 99.40Mpa. For the design to be failsafe, the obtained value of theoretical stress must be less than the allowable stress. Allowable stress for steel material was 195.33Mpa, which is greater than the obtained stress (99.40Mpa). Similar calculations has been done for remaining material.

III. ANALYSIS

- **Coupled analysis:**

A coupled analysis is a combination of analyses from different engineering disciplines that interact to solve a global engineering problem hence we often refer to a coupled analysis, when the input of one analysis depends on the result from another analysis , the analysis are coupled. Some analysis can have one-way coupling, for example, in a thermal stress problem, the temperature field introduced thermal strain in the structural field, but the structural strains generally do not affect the temperature distribution. This there is no need to iterate between the two fields. More complicated cases involve two coupling.

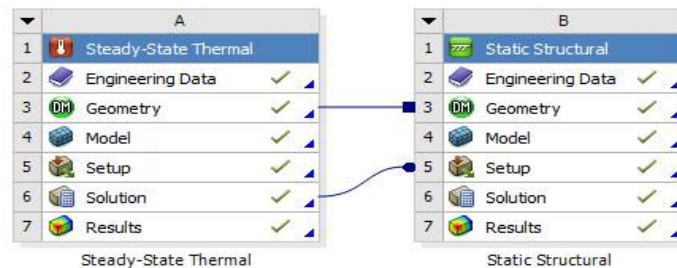


Fig.2. Coupled Analysis

- **Meshing of the piston:**

Mesh generation is the process of dividing the analysis continuum into a number of discrete parts or finite elements. The finer the mesh, the better the result, but the longer the analysis time. First the piston is imported to ansys workbench for meshing and the piston is meshed with tetrahedron meshing is on the whole 3D model as shown in fig.3.

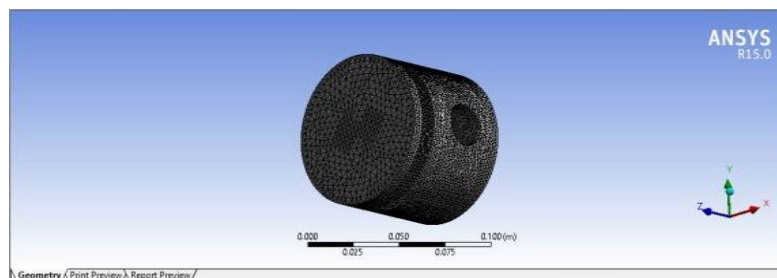


Fig.3. Meshing

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VI. RESULT AND DISCUSSION

- Thermal analysis of steel piston:-**

Thermal analysis is used to determine the temperature distribution, heat accumulation or Dissipation, and other related thermal quantities in an object. In thermal analysis we can simulate the condition of a system subjected to individual or combined effects such as Conduction, Convection and radiation. ANSYS is chosen for thermal analysis of aluminum alloy cast iron and steel for piston to find the suitability at maximum temperature.

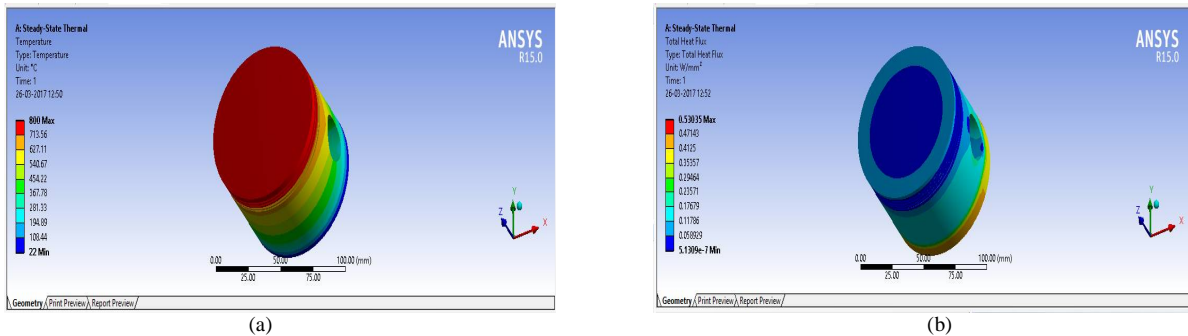


Fig.4. (a) Steady State Thermal-Temperature. (b) Steady State Thermal-Total Heat Flux

Fig.4 (a).shows the temperature distribution in piston and temperatures value varying from maximum & minimum at different cross section. Here maximum temperature is 800°C at top surface of piston and minimum temperature is 22°C at bottom of piston.

Fig.4 (b) shows the heat flux generation on piston under the given temperatures. The total heat flux values varying from the maximum and minimum and different cross sections and the crown temperature is more.

- Static analysis of steel piston:-**

Structural analysis is the determination of the effects of loads on physical structures and their components. The result of analysis is used to verify structures fitness for use. Static Structural analysis is one in which the load/field conditions does not vary with time and the assumption here is that the load or field conditions are gradually applied (Not suddenly applied).

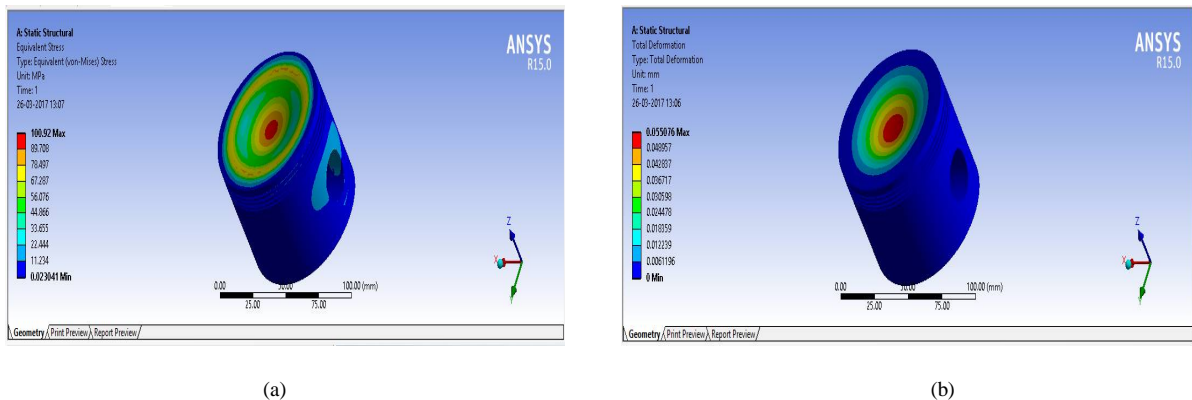


Fig.5. (a) Static Structural-Equivalent Stress. (b) Static Structural-Total Deformation

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Fig.5.(a) shows that equivalent stress acting on the piston by static analysis. The maximum & minimum equivalent stress observed is 100.92MPa & 0.023041MPa resp. The permissible strength of the steel material is 195.33MPa. From the result the stresses on the piston is less than the permissible strength of material.

Fig.5.(b) shows the total deformation of piston by static structural analysis and observed that maximum deformation is at top surface of piston and it is 0.055076 mm.

- **Coupled analysis of steel piston:-**

The coupled analysis is done in ANSYS by taking the combine effect of thermal and structural analysis. The results are as shown below. The stresses for coupled are much greater than the stress in static analysis.

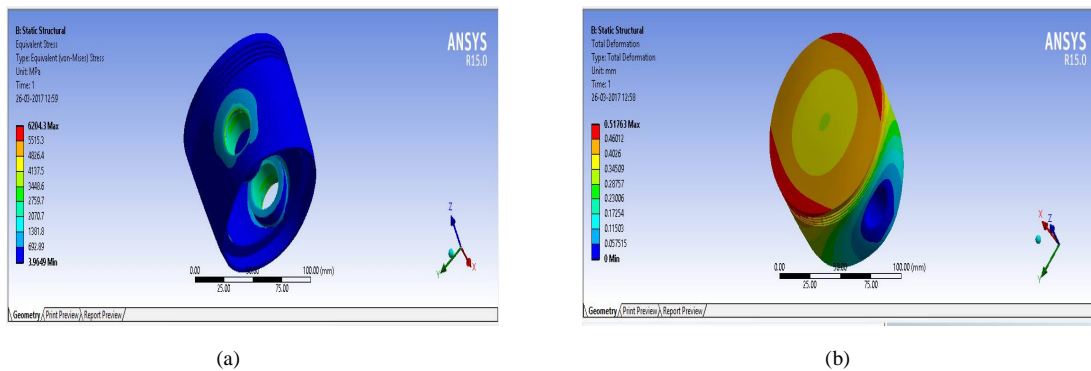


Fig.6.(a) Coupled analysis-Equivalent Stress. (b) Coupled Analysis – Total Deformation

Fig.6.(a) shows that equivalent stress acting on the piston by coupled analysis. The maximum & minimum equivalent stress observed is 6204.3MPa & 3.9649MPa respectively. Fig.6.(b) shows the total deformation of piston by coupled analysis and observed that maximum deformation is at top surface of piston and it is 0.51763mm. Similarly analysis is carried out for other material.

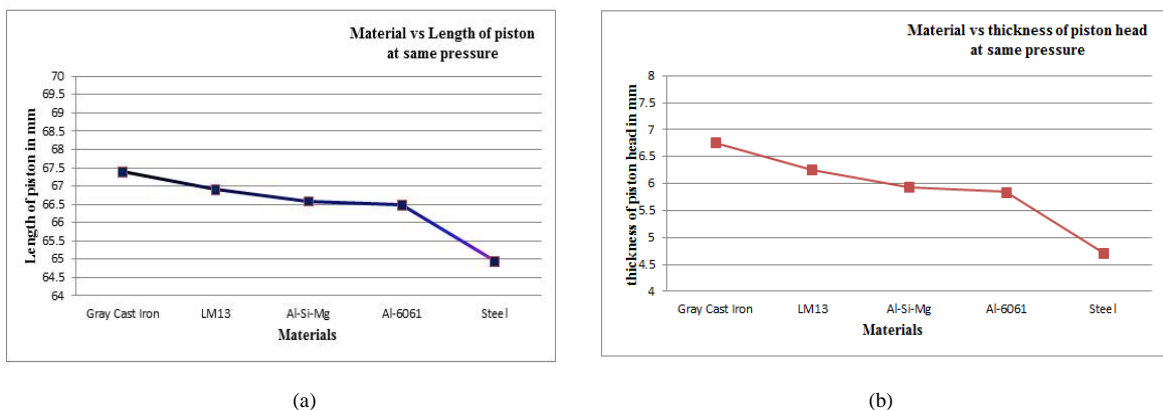


Fig.7. (a) Materials v/s Length of piston. (b) Materials v/s Thickness of piston head

Fig.7.(a) shows that the relation between materials and length of piston at same pressure. On the x-axis materials are arranged in ascending order by their ultimate tensile strength & on Y-axis length of piston is taken. If ultimate strength of material is increases then length of piston decreases. Fig.7.(b) shows that the relation between materials and thickness of piston head at same pressure. And on the x-axis, a material is arranged in ascending order by

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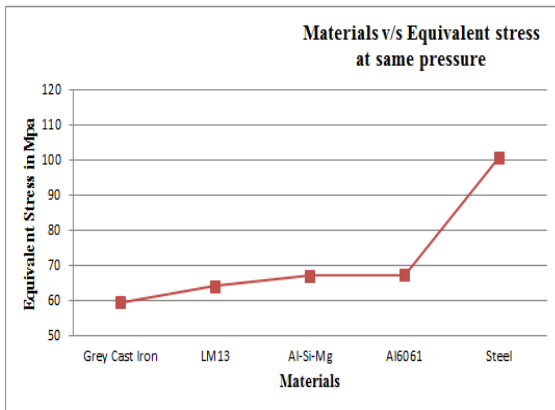
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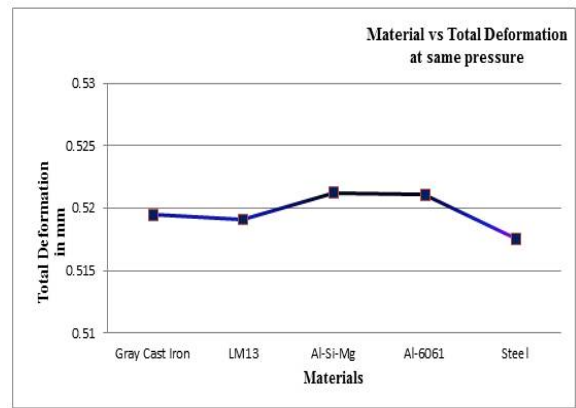
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their ultimate tensile strength & on Y-axis thickness of piston head is taken. If ultimate strength of material is increases then thickness of piston head decreases.

Fig.8.(a) shows that the relation between materials and equivalent stress at same pressure. And on the x-axis, a material is arranged in ascending order by their ultimate tensile strength & on Y-axis equivalent stress is taken. Fig.8.(b) shows that the relation between materials and total deformation at same pressure. And on the x-axis, materials are arranged in ascending order by their ultimate tensile strength & on Y-axis total deformation are taken.



(a)



(b)

Fig.8. (a) Materials v/s Equivalent stress. (b) Materials v/s total deformation

Table no.2. Result by analysis

No.	Material	Total Deformation (mm)	Static Equivalent Stress (MPa)	Coupled Equivalent Stress (MPa)	Total Heat Flux (W/mm ²)
1	LM13	0.5191	64.073	5706.3	4.0316
2	Al-Si-Mg	0.5213	67.076	4797.7	6.6516
3	Al-6061	0.5211	67.322	5424.6	3.4952
4	Cast Iron	0.5195	59.447	5142.6	1.7912
5	Steel	0.5176	100.92	6204.3	0.5303

VIII. CONCLUSION

Thus in this report, we made a detailed analysis and comparison of aluminium alloy piston, cast iron piston and steel piston. From the above analytical and analysis results, we can conclude the steel material have better design characteristics than other material. The steel material piston having less deformation for applied pressure and temperature. It is observed that stresses of all materials are within the allowable limit of the respective material. The

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stress developed in steel piston is lesser than aluminium alloy and cast iron piston but on the other hand weight of steel piston is increases. The total deformation, and equivalent stress developed in the steel is lesser than other material.

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