DESIGN AND ANALYSIS OF ALUMINUM MATRIX COMPOSITE PISTON

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Abstract. The Piston is meant to be the maximum load withstanding structure in an internal combustion engine. The Piston of an IC engine is assigned to transform thermal energy into mechanical energy by expanding gases and to sustain for a longer period. To increase the lifetime and thermal resistance of the piston, the material should have higher strength to density ratio and lower coefficient of thermal expansion. Thus, the study of reinforced Aluminum metal (A2024 alloy) as a frame and organic compound (fly ash) as a filler or matrix (metal matrix or hybrid composites), which has higher strength to weight ratio is done and this paper deals with the determination and study of structural and thermal stress distribution on Piston made of Aluminum Matrix Composite. A piston model is prepared in CATIA V5R20 (Modelling software) and the properties is examined using CAE software (ANSYS).

Keywords: AMCs, A2024, engine, energy, Ansys

1. INTRODUCTION
Piston is the most crucial part in an engine. The advancement and development in the material selection geometry and manufacturing have been drastically increasing from past few years. The purpose of piston in an internal combustion engine is to transfer the maximum amount of force extracted from the expanding of gases in the cylinder to the crank shaft through the connecting rod [3,6]. A piston engine is said to be sustainable and efficient if the piston is capable of transferring the maximum amount of force extracted from expanding of gases in the cylinder to the crank shaft with in a suitable short period of time and do the same for a longer run with minimal wear and tear and minimal deformation. In this research, a piston is made up of Aluminum metal matrix (light weight metal matrix) [1,2,4]. Essential and increasing advancement in the development of light metal composite framework has been attained in the last decades and thus the advancements could be introduced into most of the industrial applications. Metal matrix (MMC’s) has been utilized monetarily as reinforced piston [7-9]. Thus, the study of reinforced Aluminum metal (A2024 alloy) as a frame and organic compound (fly ash) as a filler or matrix (metal matrix or hybrid composites) which has higher strength-to-weight ratio and high stress withstanding structure [5,10]. This paper deals with the determination and study of temperature distribution, structural and thermal stress distribution on piston made of Aluminum matrix composite.
2. MATERIAL SELECTION
The composite material is fabricated by stir casting method with Aluminum 2024 (A2024) alloy as a reinforcement metal and fly ash (organic compounds) as filler or matrix. Stir casting is the method of fabricating composite material in liquid state, where the dispersed phase is mixed with the matrix metal (molten state) by means of mechanical stirring. Aluminum matrix composites have strength and are highly ductile. The properties of metal matrix composite has been tabulated down in Table 1.

| SR. No. | PARAMETER            | VALUE    |
|---------|-----------------------|----------|
| 1.      | Density               | 2.2 g/cm³ |
| 2.      | Tensile strength      | 227 N/mm² |
| 3.      | Elongation            | 0.80     |
| 4.      | Poison’s              | 0.22     |
| 5.      | Young’s modulus       | 185.3 Gpa |
| 6.      | Thermal conductivity  | 156 W/mK  |

3. DESIGN OF PISTON
A prototype of piston is designed in CATIA V5R20 modelling software as it an easy modelling tool in which files can be easily exported to any analysis software in igs format. Figure 1. shows the front view of the piston with dimensions whereas Figure 2. demonstrates the isometric view of piston model in CATIA V5 R20 modeling software.

Figure 1. Front view of piston

Figure 2. Isometric view
4. ANALYSIS

Analysis of temperature distribution, thermal stress and stresses acting in static condition on piston. Analysis of any material is done by the following process:

Selecting the mode of analysis
(Transient thermal, steady state thermal, fluent, etc)

Selection of material or feed on material properties.

Create or input geometry

Meshing

Applying boundary condition

Applying load

Result

Interpretation of graphs

This type of analysis is called as FEA (Finite Element Analysis).

4.1 STATIC STRUCTURAL ANALYSIS

The material properties of the metal matrix as given in the table has been feed to the imported CATIA geometry file and is ready for discretization.

4.2 MESHING

A fine mesh with 100 percent relevance and fast transition has been applied. The piston has been divided into 499529 nodes and 336082 elements as shown in Figure 3.

Figure 3. Fine mesh
4.3 BOUNDARY CONDITION
The surface of the piston and piston pin hole are subjected to frictionless support. When a face is subjected to frictionless support, the transitional and rotational motion normal to the face is locked. In this paper, we consider the effect of side thrust face to be negligible but in reality, it has some impact on deformation and stress on the piston surface, but pressure forces are taken in record and uniform temperature is maintained throughout the analysis. 9Mpa of force is applied on the piston crown as shown in the figure 5.

4.4 THERMAL ANALYSIS
Thermal analysis of Aluminum matrix piston is done in ANSYS to find the suitability at maximum temperature. The maximum and minimum temperature values are set as 1500ºC and 22ºC respectively and convection film coefficient of $1.2 \times 10^{-7}$ is applied.

4.5 THERMAL STRESS
A hollow circular cylinder of some cross section as metal matrix composite piston is modelled with 10mm depth. Thermal stress analysis is done in static structural solver by applying the boundary conditions on inner and outer face of cylinder as 200ºC and 300ºC respectively. The outer face of the cylinder is locked to 6 degrees of freedom and a pressure load of 500Mpa is applied on the inner wall of piston. The figure 8. shows the boundary and loading conditions over the aluminum metal matrix composites.
5. RESULTS AND DISCUSSIONS

5.1 STATIC STRUCTURAL ANALYSIS

The static structural analysis is used to find out the total deformation, von misses, stresses and strains. The static analysis of Aluminum matrix piston is done by ANSYS software for the combustion pressure of 9Mpa. The results of total deformation, equivalent stress and elastic strain has been shown from Figure 9-11.

The maximum deflection induced in the piston is at top of the piston. The maximum von misses stress is developed in the inner boss fillet area which is due to the concentrated stress and application of pressure on the top surface of the piston. The maximum stress is visualized at the inner side of the piston pin boss fillet area. The results of total deformation, equivalent stress, equivalent strain has been tabulated in Table 2.
5.2 THERMAL ANALYSIS

Transient thermal, steady-state thermal and static structural solver of ANSYS workbench is chosen for thermal analysis of metal matrix composite piston. The Figure 12-14 displays the result of temperature distribution, thermal stress and total heat flux generated in aluminum metal matrix composite piston.

Figure 13. shows the total heat flux generation on the metal matrix composite piston under the given temperatures. The maximum heat flux region is on the interior region of the piston and is not accessible which shows that the restriction of thermal stress is also not accessible and thus the material is safe. The results of thermal stress, total heat flux has been tabulated in Table 3.

Figure 12. Temperature distribution

Figure 13. Total heat flux

Figure 14. Thermal stress
Table 2. STATIC STRUCTURAL ANALYSIS OF PISTON

| MATERIAL                        | TOTAL DEFORMATION (mm) | VON MISES STRESS (Mpa) | VON MISES STRAIN |
|--------------------------------|------------------------|------------------------|------------------|
| Aluminum metal matrix composite piston | 0.075048              | 250.59                 | 0.0016287        |

Table 3. THERMAL ANALYSIS

| MATERIAL                        | TEMPERATURE | TOTAL HEAT FLUX | THERMAL STRESS (Mpa) |
|--------------------------------|-------------|-----------------|----------------------|
| Aluminum metal matrix composite | 1500        | 26.61           | 1951.7               |

6. CONCLUSION

Thus, the result of thermal and structural analysis of Aluminum matrix composite piston is interpreted and studied and it is proven that Aluminum matrix composite piston with A2024 as reinforcement metal and fly ash (organic compound) as filler or matrix is light weight structure, has a high tensile strength and also has a high-pressure withstand structure. Aluminum matrix composite (A2024 + fly ash) piston have a greater strength and the structure is highly ductile, thus the heat energy is easily transformed to mechanical energy. As the maximum heat flux generated in the piston is inaccessible, it says that the piston is safe throughout the combustion and sustainable. The deformation in the piston due to application of heavy pressure load is very minimum and negligible. Hence, in this research paper it is proven that the metal matrix composite can be used in industrial applications especially in automobile industries cause of its unique structural and thermal properties.

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