DESIGN AND ANALYSIS OF CYLINDER AND CYLINDER HEAD OF 6-STROKE SI ENGINE FOR WEIGHT REDUCTION

Mr. Rajashekhar Siddanayak[1], Mr. S. G. Saraganachari[2]

[1]M. Tech student, Machine Design, Department of Mechanical Engineering, BEC Bagalkot, Karnataka, India
[2]Professor, Department of Mechanical Engineering, BEC Bagalkot, Karnataka, India

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Abstract - *The six-stroke engine is a type of internal combustion engine with the advanced feature of increased power generation and some complexity designed to make it more efficient and use fuel. The fifth stroke, known as the water injection stroke and the penultimate stroke, known as the exhaust stroke, are the two additional strokes. Furthermore, the stroke engine is also known as a two-stroke, four-stroke, or six-stroke engine, all of which are unfamiliar terms to us. The six-stroke engine will have the same specific power as a four-stroke petrol engine, with the gain in thermal efficiency compensating for the two extra strokes. Pollution levels are lowered in terms of chemical, noise, and temperature factors.*

In this study, a model of a six-stroke engine's cylinder and cylinder head will be created and examined using a coupled field analysis. The model is subsequently imported and examined in the ANSYS solver. Different materials are being considered as potential replacements for the current iron-based substance. The engine's weight would be decreased as a result of the material modification without impacting its performance. Based on the provided conditions, the findings should reveal the best material to utilize for the six-stroke engine.

Key Words: Internal Combustion Engine, Six-Stroke, Water Injection, Aluminium Matrix Composite, Heat Flux.

1. INTRODUCTION

The six-stroke engine is a type of internal-combustion engine based on the four stroke engine, but with additional complexity to make it more efficient and reduce emissions. The 6 stroke internal combustion engine is an advance over the existing four stroke which employs the same principle as that of the four-stroke. The 5th stroke or the second power stroke used the heat evolved in the exhaust stroke (directly or indirectly) as the heat required sudden expansion of the secondary fuel (air or water) which pushes the piston downward for the 2nd power thereby rotating the crankshaft for another half cycle. As heat evolved in the 4th stroke is not wasted, the requirement for a cooling system is eliminated.

1.1 Principles of Six Stroke Engine

A six stroke is an engine in which we use exhausted gas from four Otto cycle and use it to generate more power. Generally, the one compression and one power strokes are added to cycles which have higher thermal efficiency and reduce the fuel consumption. This Design either use a steam or air as a working fluid for the additional power stroke as well as extracting power, the additional stroke cools the engine and removes the cooling system making the engine lighter and giving 40% increased efficiency over the Otto cycle.

2. LITERATURE SURVEY

James C. Conklin, James P. Szybist [1] In the fifth stroke, water injection was suggested after partial exhaust of the combustion product. Water is turned to steam as a result of the superheated cylinder walls and the high temperature of the exhaust products. The second power stroke is achieved on the fifth stroke, when the steam expands. Using waste heat from engine cooling and exhaust gas, more power stroke can be generated. To attain the highest mean effective pressure, the exhaust valve's operation must be adjusted.

Kiran P. [2] In order to complete his mission, he must use the approach of injecting water into the fifth stroke and recovering waste heat from the exhaust. He had to change the crankshaft to camshaft gear ratio and the angle of the cam lobes for this, and after testing, he had to conclude that by using the internal combustion engine, the engine's performance was significantly improved, that the fuel efficiency would be improved by the development of a six-stroke engine, and that the internal combustion engine would use less fuel with the same amount of fuel.

A. Kéromnès et. al. [3] Current engine development trends are guided by increasingly stringent emission rules, with the goal of reducing consumption and emissions in order to achieve cleaner engines. The expansion ratio of a reciprocating internal combustion engine is directly proportional to its efficiency, as increasing the expansion ratio improves fuel conversion efficiency. In normal internal combustion engines, however, mechanical stress and combustion problems limit the compression ratio. The majority of the engine's power loss is caused by thermal losses.

Prakash Haridas Pande [4] Air was injected instead of water or methanol to generate power in the fifth stroke of the Velozeta six-stroke engine. A fundamental distinction between Crower's six stroke engine and Velozeta's six stroke engine is the working fluid for the Rankine cycle in the remaining two strokes. The first four stokes of these engines are identical to those of a standard four-stroke engine. The fifth stroke, on the other hand, is distinct in that it introduces and heats air to produce work. The exhaust valve is forced open in the sixth stroke, forcing a mixture of air and remaining exhaust gases out.

3. OBJECTIVES

- To understand the working and previous work on six stroke engine.
- To compare different aluminium composite materials for compatibility with the six stroke engine cylinder and cylinder head.
- To assess the amount of weight reduced by changing the material of construction.

4. METHODOLOGY

- 3D Modelling of the cylinder and the cylinder head.
- Identifying the thermal and structural loads acting on the engine.
- Applying different composite material properties to the models.
- Discretization and application of loads for couple field analysis.
- Comparison of analysis results for identifying the optimum material for the engine cylinder and cylinder head.

4.1 Basic Engine Design

The engine design parameters used in the analysis are given in Tables 1 to 4. The parameters needed for analysis are cylinder diameter, stroke length, brake power and cylinder wall thickness. Using these parameters the assembled model of the cylinder and the cylinder head are generated using CATIA V5.

Table 1 Cylinder Design Parameters

Design Parameters	Calculated Value
D	78mm
L	78mm
Bmep	11.76 bar
Imep	13.85 bar
Pmax	138.5 bar
Volume	1500cc
Indicated Power	141.176 HP
Friction Power	21.176 HP
Mechanical Efficiency (Assumed)	85%
Break Power	120HP

4.2 Geometric Modeling

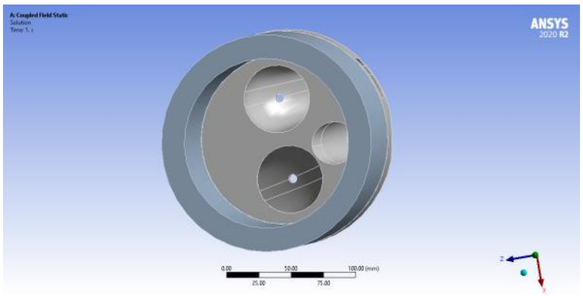

Fig -1: Cylinder Assembly for Six Stroke Engine

Figure 1 shows the model of the cylinder assembly with the cylinder and the cylinder head. The cylinder is modeled using dimensions from the literature survey. These dimensions include bore and stroke length of the cylinder. The cylinder head contains the inlet and the exhaust ports required for the combustion cycle. Another port is made available in the design so that water can be inlet to the cylinder after recompression to absorb the remaining heat and improve the efficiency of the engine. The next part of the process is to generate a finite element model by discretization.

4.3 Material Properties

4.4

Table 2 Al6061-SiC Material Properties

Properties	Values
Density	2730 kg/m³
Young's Modulus	72100 MPa
Poisson's Ratio	0.29
Yield Strength	182 MPa
Ultimate Strength	193.2 MPa
Co-efficient of Thermal Expansion	2.168×10^{-5} /°C
Thermal Conductivity	141.5 W/m.°C

Table 3 Al6061-T6 Material Properties

Properties	Values
Density	2700 kg/m³
Young's Modulus	68900 MPa
Poisson's Ratio	0.33
Yield Strength	276 MPa
Ultimate Strength	310 MPa
Co-efficient of Thermal Expansion	2.278×10^{-5} /°C
Thermal Conductivity	155.3 W/m.°C

4.5 Finite Element Modelling

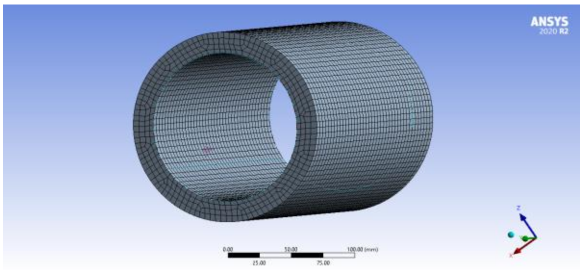

Fig -2: Meshing of Cylinder Model of a Six Stroke Engine

The meshing of the cylinder uses hexahedral elements for discretization and the cylinder head uses tetrahedral shapes for discretization. The number of nodes and elements used in the meshing process is as given in Table 3.8.

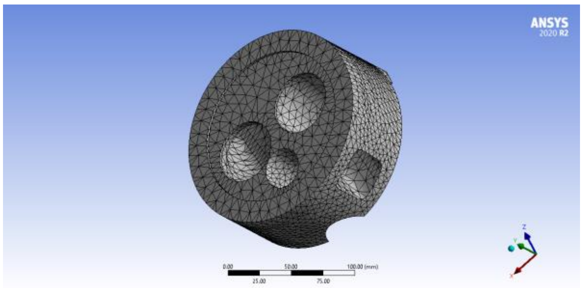

Fig -3: Meshing of Cylinder Head Model of a Six Stroke Engine

Table 4 Number of Nodes and Elements Generated for the Assembly

Parts	Nodes	Elements
Cylinder	73164	15200
Cylinder Head	26257	14871
Total	99421	30071

4.5 Loads and Boundary Conditions

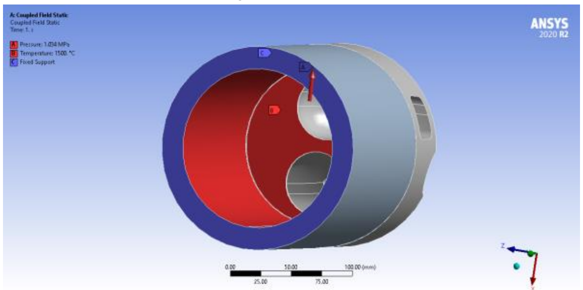

Fig -4: Loads and Boundary Conditions for the Cylinder Assembly of the Engine

The Figure 4.5 gives the loads and boundary conditions applied to the cylinder assembly. The load is applied inside the cylinder head and the inner wall of the cylinder. A temperature of 1500°C and a pressure of 1MPa or N/mm^{2}or 10bar are applied considering the maximum temperature and pressure the inside of the cylinder can reach in a single power stroke. The analysis or simulation is a coupled field analysis which performs thermal analysis on the cylinder assembly and then uses the results from the thermal analysis to perform a structural analysis.

5. RESULTS AND DISCUSSION

5.1 Cylinder

5.1.1 Al6061/SiC

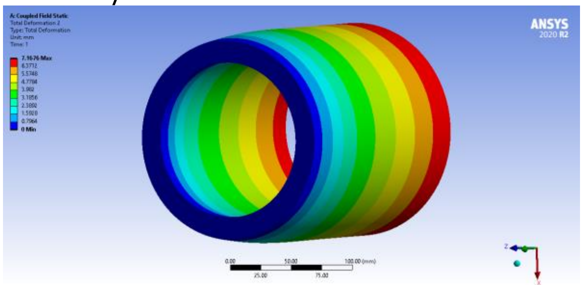

Fig -5: Total Deformation Plot for Six Stroke Cylinder with Material Al6061-SiC

Figure 5 shows the results plot for the total deformation in a cylinder of the six stroke engine with material Al6061/SiC. The results indicate that a maximum deformation of 7.167mm is seen towards the TDC of the assembly since the cylinder was constrained near the BDC. The deformation in the cylinder appears to be in the elastic region of the stress strain curve for Al6061/SiC and the value appears to be gradually increasing towards TDC.

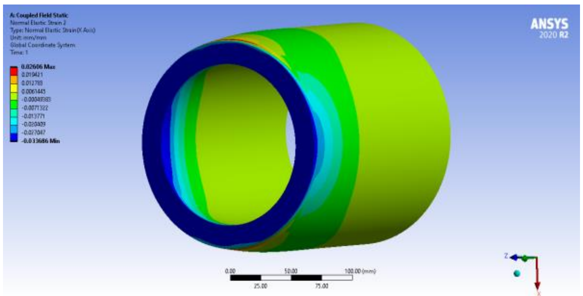

Fig -6: Normal Elastic Strain Plot for Six Stroke Cylinder with Material Al6061/SiC

Figure 6 shows the results plot for the normal elastic strain in a cylinder of the six stroke engine with material Al6061/SiC. The results indicate that a maximum strain of 0.031mm/mm is seen towards the BDC of the assembly since the cylinder was constrained near the BDC. The highest strain induced in this assembly is well within the yield point in the stress-strain curve of the Al6061/SiC.

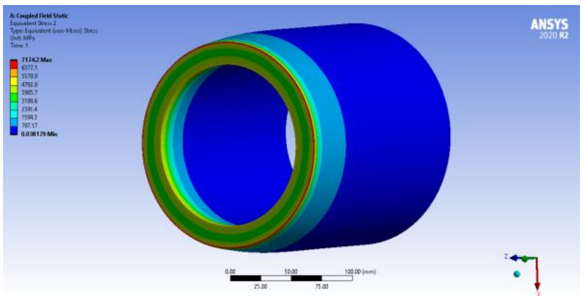

Fig -7: Equivalent Stress Plot for Six Stroke Cylinder with Material Al6061-SiC

Figure 7 shows the results plot for the Equivalent or Von Mises Stress in a cylinder of the six stroke engine with material Al6061/SiC. The results indicate that a maximum stress of 717.4MPa is seen near the BDC of the assembly since the cylinder was constrained at BDC.

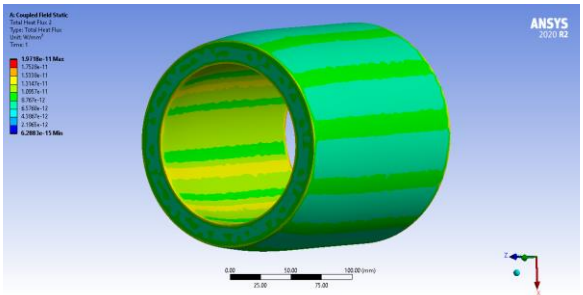

Fig -8: Total Heat Flux Plot for Six Stroke Cylinder with Material Al6061-SiC

Figure 8 shows the results plot for the total heat flux in a cylinder of the six stroke engine with material Al6061/SiC. The plot shows that the maximum heat flux is seen at a value of 1.971X10^{-11}W/mm^2 near the TDC of the cylinder because the start of the combustion is near the TDC and the part is exposed to the heat for the longest time.

5.1.2 Al6061-T6

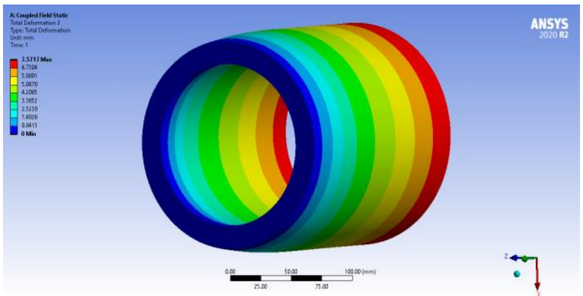

Fig -9: Total Deformation Plot for Six Stroke Cylinder with Material Al6061-T6

Figure 9 shows the results plot for the total deformation in a cylinder of the six-stroke engine with material Al6061-T6. The results indicate that a maximum deformation of 7.571mm is seen towards the TDC of the assembly since the cylinder was constrained near the BDC. The deformation in the cylinder appears to be in the elastic region of the stress strain curve for Al6061-T6 and the value appears to be gradually increasing towards TDC.

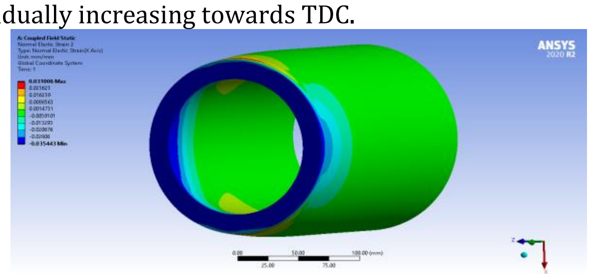

Fig -10: Normal Elastic Strain Plot for Six Stroke Cylinder with Material Al6061-T6

Figure 10 shows the results plot for the normal elastic strain in a cylinder of the six stroke engine with material Al6061-T6. The results indicate that a maximum strain of 0.031mm/mm is seen towards the BDC of the assembly since the cylinder was constrained near the BDC. The highest strain induced in this assembly is well within the yield point in the stress-strain curve of the Al6061-T6.

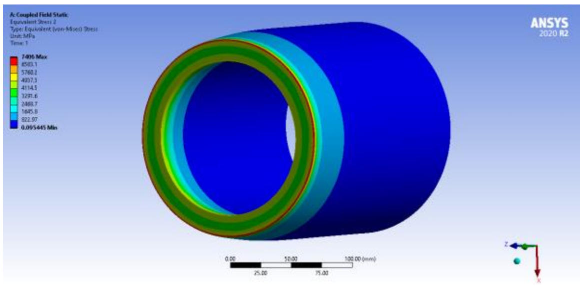

Fig -11: Equivalent Stress Plot for Six Stroke Cylinder with Material Al6061-T6

Figure 11 shows the results plot for the Equivalent or Von Mises Stress in a cylinder of the six stroke engine with material Al6061-T6. The results indicate that a maximum stress of 740MPa is seen near the BDC of the assembly since the cylinder was constrained at BDC.

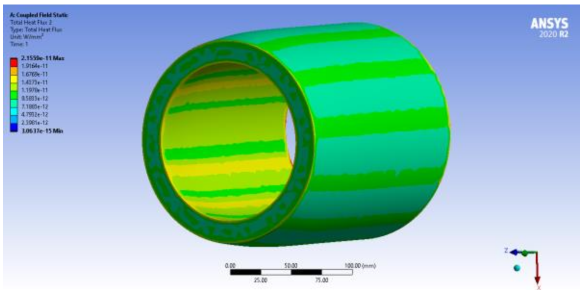

Fig -12: Total Heat Flux Plot for Six Stroke Cylinder with Material Al6061-T6

Figure 12 shows the results plot for the total heat flux in a cylinder of the six stroke engine with material Al6061-T6. The plot shows that the maximum heat flux is seen at a value of 2.155X10^{-11}W/mm^{2}near the TDC of the cylinder because the start of the combustion is near the TDC and the part is exposed to the heat for the longest time.

5.2 Cylinder Head

5.2.1 Al6061/SiC

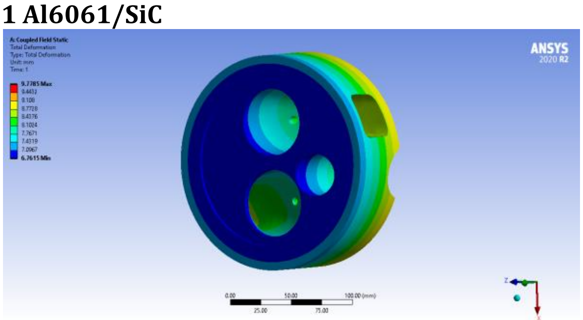

Fig -13: Total Deformation Plot for Six Stroke Cylinder Head with Material Al6061/SiC

Figure 13 shows the results plot for the total deformation in a cylinder of the six stroke engine with material Al6061/SiC. The results indicate that a maximum deformation of 9.778mm is seen towards the TDC of the assembly since the cylinder was constrained near the BDC. The deformation in the cylinder appears to be in the elastic region of the stress strain curve for Al6061/SiC and the value appears to be gradually increasing towards TDC.

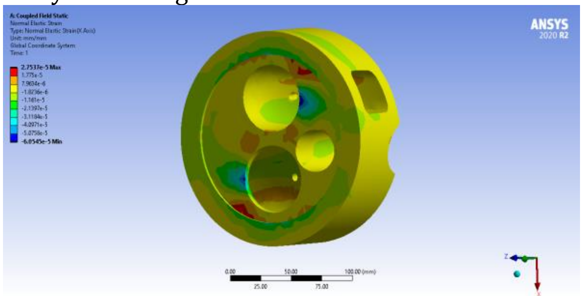

Fig -14: Normal Elastic Strain Plot for Six Stroke Cylinder Head with Material Al6061/SiC

Figure 14 shows the results plot for the normal elastic strain in a cylinder of the six stroke engine with material Al6061/SiC. The results indicate that a maximum strain of 2.753e-5mm/mm is seen towards the BDC of the assembly since the cylinder was constrained near the BDC. The highest strain induced in this assembly is well within the yield point in the stress-strain curve of the Al6061/SiC.

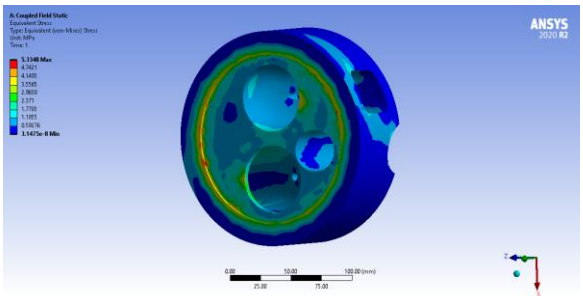

Fig -15: Equivalent Stress Plot for Six Stroke Cylinder Head with Material Al6061-SiC

Figure 15 shows the results plot for the Equivalent or Von Mises Stress in a cylinder head of the six stroke engine with material Al6061/SiC. The results indicate that a maximum stress of 5.334MPa is seen near the TDC of the assembly in the cylinder head.

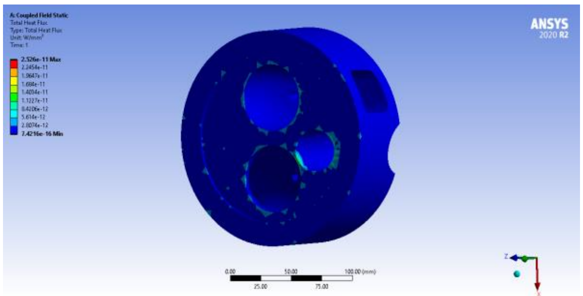

Fig -16: Total Heat Flux Plot for Six Stroke Cylinder with Material Al6061-SiC

Figure 16 shows the results plot for the total heat flux in a cylinder head of the six stroke engine with material Al6061/SiC. The plot shows that the maximum heat flux is seen at a value of $2.526X10^{-11}W/mm^2$ near the TDC of the cylinder because the start of the combustion is near the TDC and the part is exposed to the heat for the longest time.

5.2.2 Al6061-T6

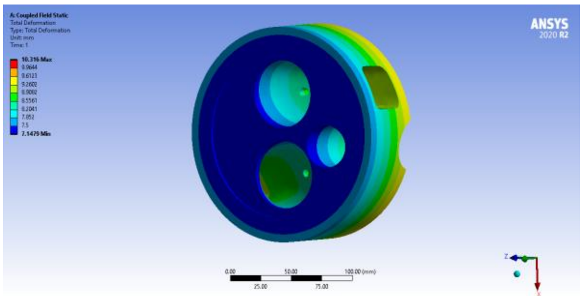

Fig -17: Total Deformation Plot for Six Stroke Cylinder with Material Al6061-T6

Figure 17 shows the results plot for the total deformation in a cylinder of the six stroke engine with material Al6061-T6. The results indicate that a maximum deformation of 10.316mm is seen towards the TDC of the assembly since the cylinder was constrained near the BDC. The deformation in the cylinder appears to be in the elastic region of the stress strain curve for Al6061-T6 and the value appears to be gradually increasing towards TDC.

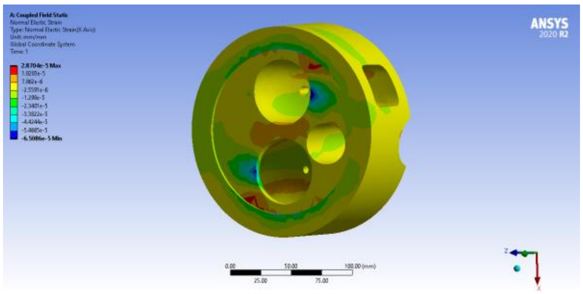

Fig -18: Normal Elastic Strain Plot for Six Stroke Cylinder Head with Material Al6061-T6

Figure 18 shows the results plot for the normal elastic strain in a cylinder of the six stroke engine with material Al6061-T6. The results indicate that a maximum strain of 2.87e-5mm/mm is seen towards the BDC of the assembly since the cylinder was constrained near the BDC. The highest strain induced in this assembly is well within the yield point in the stress-strain curve of the Al6061-T6.

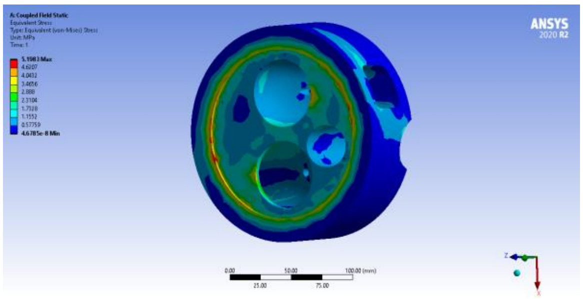

Fig -19: Equivalent Stress Plot for Six Stroke Cylinder Head with Material Al6061-T6

Figure 19 shows the results plot for the Equivalent or Von Mises Stress in a cylinder head of the six stroke engine with material Al6061-T6. The results indicate that a maximum stress of 5.198MPa is seen near the TDC of the assembly in the cylinder head.

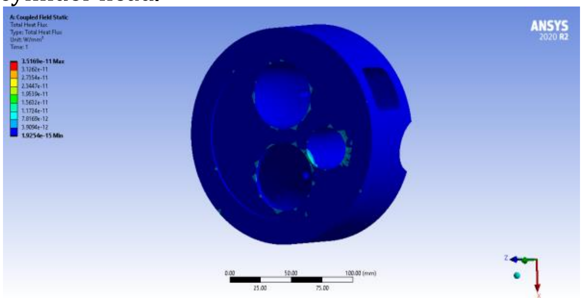

Fig -20: Total Heat Flux Plot for Six Stroke Cylinder Head with Material Al6061-T6

Figure 20 shows the results plot for the total heat flux in a cylinder head of the six stroke engine with material Al6061-T6. The plot shows that the maximum heat flux is seen at a value of $3.516X10^{-11}W/mm^2$ near the TDC of the cylinder because the start of the combustion is near the TDC and the part is exposed to the heat for the longest time.

5.3 Results Comparison

5.3.1 Cylinder

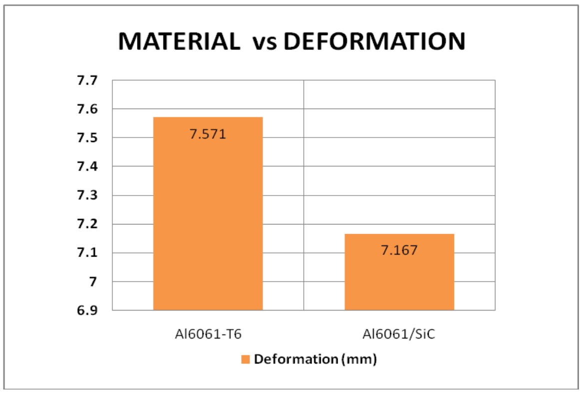

Fig -21: Graphical Representation of the Total Deformation Results Comparison for Cylinder Model

Figure 21 shows the comparison of results for the total deformation occurring in the cylinder of a six stroke engine. The comparison shows that all results fall within the elastic limit of the materials. The lowest deformation can be seen in the material Al6061/SiC with a deformation value of 7.167mm.

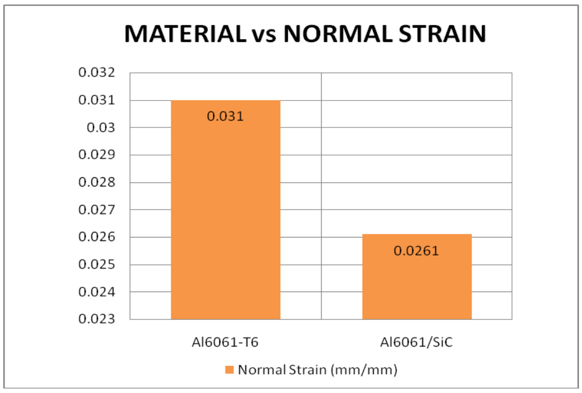

Fig -22: Graphical Representation of the Normal Strain Results Comparison for Cylinder Model

Figure 22 shows the comaprison of results for the Normal Strain occuring in the cylinder of a six stroke engine. The comaprison shows that all results fall within the elastic limit of the materials. The lowest normal strain can be seen in the material Al6061/SiC with a strain value of 0.0261mm/mm.

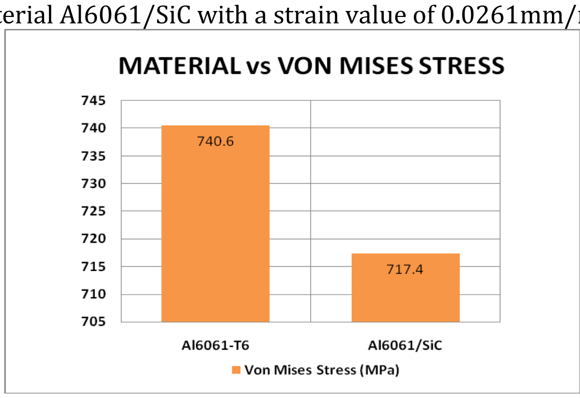

Fig -23: Graphical Representation of the Von Mises Stress Results Comparison for Cylinder Model

Figure 23 shows the comaprison of results for the Von Mises Stress occuring in the cylinder of a six stroke engine. The comaprison shows that all results fall within the elastic limit of the materials. The lowest Von Mises Stress can be seen in the material Al6061/SiC with a stress value of 717.4MPa.

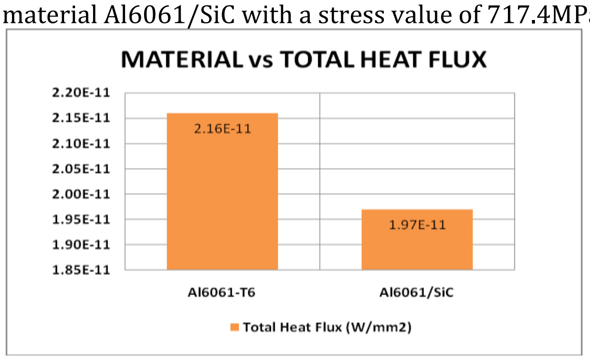

Fig -24: Graphical Representation of the Total Heat Flux Results Comparison for Cylinder Model

Figure 24 shows the comaprison of results for the Total Heat Flux occuring in the cylinder of a six stroke engine. The comaprison shows that all results fall within the limits of the materials. The lowest Heat flux can be seen in the material Al6061/SiC with a value of 1.97 x 10^{-11} W/mm^2.

5.3.2 Cylinder Head

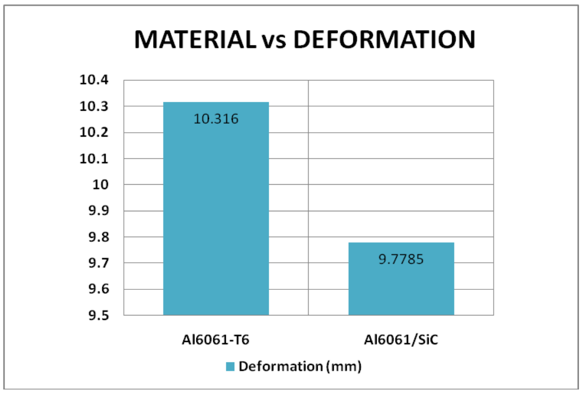

Fig -25: Graphical Representation of the Total Deformation Results Comparison for Cylinder Head Model

Figure 25 shows the comaprison of results for the total deformation occuring in the cylinder head of a six stroke engine. The comaprison shows that all results fall within the elastic limit of the materials. The lowest deformation can be seen in the material Al6061/SiC with a deformation value of 9.7785mm.

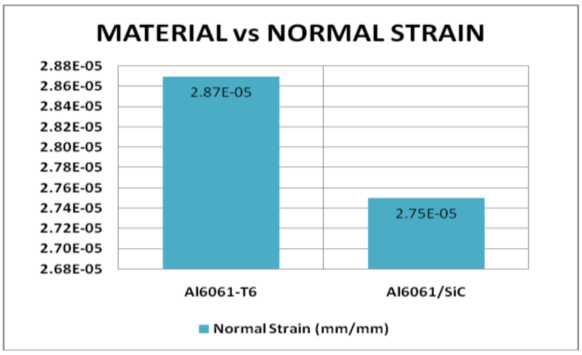

Fig -26: Graphical Representation of the Normal Strain Results Comparison for Cylinder Head Model

Figure 26 shows the comaprison of results for the Normal Strain occuring in the cylinder head of a six stroke engine. The comaprison shows that all results fall within the elastic limit of the materials. The lowest normal strain can be seen in the material Al6061/SiC with a strain value of 2.75 x 10^{-5}mm/mm.

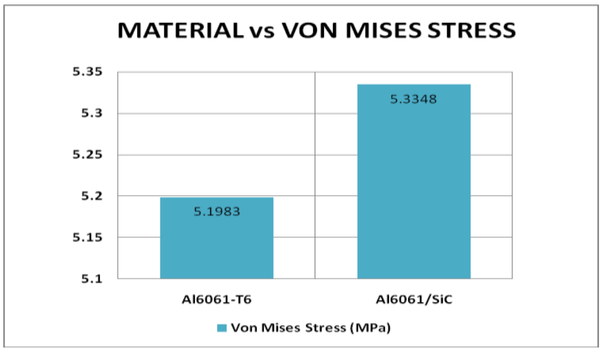

Fig -27: Graphical Representation of the Von Mises Stress Results Comparison for Cylinder Head Model

Figure 27 shows the comaprison of results for the Von Mises Stress occuring in the cylinder of a six stroke engine. The comaprison shows that all results fall within the elastic limit of the materials. The lowest Von Mises Stress can be seen in the material Al6061/WC with a stress value of 4.9988MPa.

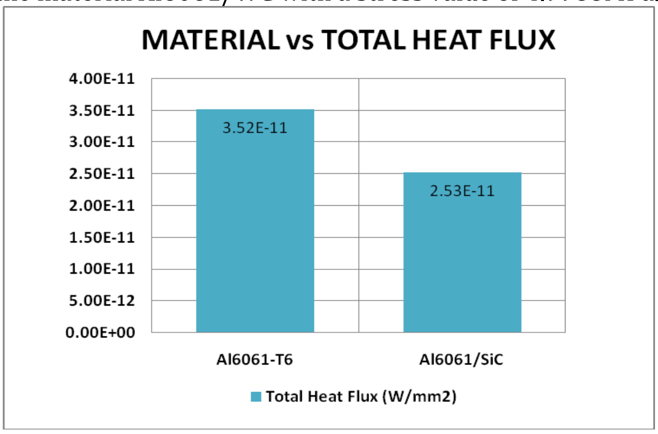

Fig -28: Graphical Representation of the Total Heat Flux Results Comparison for Cylinder Head Model

Figure 28 shows the comparison of results for the Total Heat Flux occurring in the cylinder head of a six stroke engine. The comparison shows that all results fall within the limits of the materials. The lowest Heat flux can be seen in the material Al6061/SiC with a value of 2.53 x 10^{-11} W/mm^2.

5.4 Weight Reduction

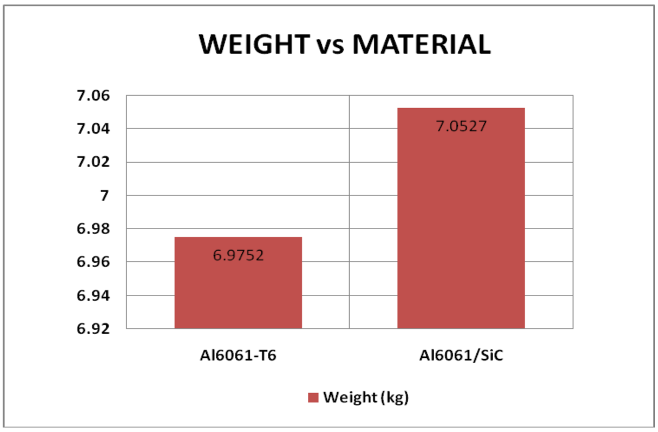

Fig -29: Graphical Representation of the Weight of the Cylinder and the Cylinder Head with Different Materials

Figure 29 gives the weight data for the cylinder and the cylinder head for different materials. The data indicates that under the conditions of this work, the weight of the cylinder and cylinder head are slightly higher than the selected standard materials. This is not in any way an indication of the actual variation in weight percentage as the analysis only considers a part of the engine model.

6. CONCLUSIONS

The research was conducted to identify the optimum material for the given cylinder assembly of a six stroke engine. Two materials were analysed and compared to determine the optimum material. The 3D model of the cylinder and the cylinder head was generated using CATIA modelling software. Then the model is exported to ANSYS and a coupled field analysis was performed to find the thermal and structural stability of the design.

Based on the results, it can be seen that

- The AMC Al6061/5 wt. % SiC gives the best results under the given conditions. The material gives the lowest deformation and lowest stress values but high heat flux value which is ideal during comparison with other materials.
- The total weight reduction after changing the material to Al6061/SiC is also the lowest when compared with the other materials under the given conditions.

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BIOGRAPHIES

“Mr. Rajashekhar Siddanayak, M. Tech student, Machine Design, Dept. of Mechanical Engg, Basaveshwar Engineering College Bagalkot, Karnataka, India.”

“Dr. S. G. Saraganachari, Professor, Dept. of Mechanical Engg, Basaveshwar Engineering College Bagalkot, Karnataka, India.”