DESIGN AND ANALYSIS OF A CYLINDER HEAD IN A DUAL FUEL ENGINE

A thesis submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

By

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CERTIFICATE

This is to certify that the project work " **DESIGN AND ANALYSIS OF A CYLINDER HEAD IN A DUAL FUEL ENGINE**" titled is a bonafide work carried out by **KUCHARLAPATI VINAY SANKARA VARMA, HARSHA VARDHAN PANDRANKI, SHILPIKA MOHANTY, VANA SRI RAM** during the year 2021-2022 in partial fulfillment of the requirements for the award of the degree of **BACHELOR OF TECHNOLOGY** submitted to the department of mechanical engineering, College of Engineering, Andhra University, Visakhapatnam. This work is not submitted to any university for the award of any degree.

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EXECUTIVE SUMMARY

The emerging issue of global warming is one of the most concerned issues around the globe, the major contributor being the automobile industry and their fossil fuel dependence. The nations and tech giants have come up with electric vehicle solution, but the transition from IC engines to electric engines won't be smooth and rapid. To counter such rough transition the idea of dual fuel engines has been formulated which use non-conventional fuels majorly that decrease the pollution than the traditional fuels. Dual fuel engines are basically a modification for the CI / Diesel engine's cylinder heads that allow us to convert the major chunk of the existing automobiles into dual fuel engine machines. In this work as an added benefit the recently discovered creep resistant magnesium alloys have been used as the material for cylinder head to reduce the weight even more and thus reducing the pollution.

With the use of AUTODESK Fusion 360 software the cylinder head has been designed based on the machine design calculations. Later the same model was imported into ANSYS Workbench where the Static Structural, Steady State Thermal and Vibration analysis were performed to tabulate the results and derive conclusions that will be discussed as the report progresses.

Keywords: *Static Structural analysis;Steady State Thermal analysis; CI engine; Dual Fuel Engines; Cylinder Head;*

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LIST OF SYMBOLS AND ABBREVIATIONS

^0C	Degree Centigrade
CAD	Computer-Aided-Design
CAE	Computer-Aided-Engineering
CFD	Computational-Fluid-Dynamics
CH	Hydro-Carbons
CI	Compression Ignition
D	Bore Diameter
m	Meters
m^3	Cubic Metre
N-m	Newton Meter
NO_x	Nitrogen Oxides
rpm	Revolutions Per Minute
UTS	Ultimate Tensile Strength
W/m^3	Watts per Square Meter

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

In this chapter, a ray of light is thrown on the Dual Fuel engines and the reasons they have to be chosen as the transition path from fossil fuel engines to electrical engines. This is followed by the nomenclature of the cylinder head and design parameters that have been considered were discussed. In parallel the consideration of the recently discovered creep resistant magnesium alloys for the cylinder head has been talked about. Lastly, the Motivation, objectives and the thesis layout of this research has been briefed.

1.1 DUAL FUEL ENGINES

When two different fuels can be mixed to operate an engine, it is known as a dual-fuel/ Bi-fuel engine. Often, Diesel and natural gas fuel are combined in dual-fuel engines. The feature they possess to switch seamlessly between gas and liquid fuels makes it even more useful to try out the different combination of fuels. It is possible to compare the effectiveness of dual-fuel engines with that of diesel engines, as well as decrease the emissions of nitrogen oxides (NO_x) and particulate matter. The other advantages of dual fuel diesel/gas engines is the existing diesel engines can be converted into dual fuel engines with minor modifications, as a fact the bulk of diesel operated engines present in the market can all be converted into dual fuel engines and can this would result in a large chunk of savings in capital cost.

1.2 CREEP RESISTANT MAGNESIUM ALLOYS

Magnesium alloys even when being lighter than aluminium have not been used as the engine parts material, because of its weak creep resistance at higher elevated temperatures. An extensive amount of research has been carried out by many leading firms and the recent developments have been made in the creep resistance properties of the magnesium alloys. Alloys such as AM-HP2+, AXJ530, AE44, WE43, WE54, etc have shown better creep resistance at higher elevated temperatures. Whereas it was observed that the increase in creep resistance has also resulted in loss of Tensile stress properties. Only few materials such as WE43 and WE54 have retained their mechanical properties with the addition of creep resistance.

1.3 CYLINDER HEAD

An internal combustion engine mainly consists of three parts Cylinder head, Head Gasket and Engine Bock. The Cylinder head sits on top of the Head gasket and Engine block and houses the valve ports and the inlet/ exhaust ports along with the coolant and oil passages.

1.3.1 TYPES OF CYLINDER HEADS

The Cylinder heads are basically divided into three types, they are as follows:

- **Flathead Cylinder Head :** These are the earliest types of cylinder heads in which only the passages, valves & ports are present
- **Overhead Valve (OHV) Cylinder Head :** This has been the most popular and extensively used design for many decades. It houses the valve train along with the components that flathead cylinder head possess.
- **Overhead Camshaft (OHC) Cylinder Head :** This design is a complex and upgraded version of the previous type as it houses all the components OHV possess with the camshaft.

1.4 LITERATURE REVIEW & KNOWLEDGE GAINED FROM IT

Diesel Engine Cylinder Head Design: The Compromises and the Techniques.

To discuss the ways how to design the cylinder head on basis of injector, number of intake valves,etc. For most of the observations or requirements of engine head the calculations and designs have been discussed. Thorough mathematical calculations and machine design principles each design has been formulated.

Design / Analysis and Development of Cylinder Head for High Performance 3 Euro-V

Diesel Engine for a High Combustion Cylinder CRDi operated at 200 bar pressure. Design of cylinder head for a high pressure of 200 bar is done to meet the Euro-IV/V emission norms of automotive passenger cars. The cylinder head was developed using CAD, CFD and FE softwares and that has resulted in a reduced lead time to a greater degree. Using CAD-CAE and simulations the development of the new cylinder head was designed and the experimental validation was carried out and the results were tabulated.

Numerical study on trio-fuel combustion: Ignition properties of hydrogen-enriched methane-diesel and methanol-diesel mixtures.

Combustion of three fuels with different properties simultaneously and interactively that have different re-activities were investigated by numerical simulations. This study , conventional dual-fuel (DF) ignition phenomena, similar to DF compression ignition (CI) engines, are extended and explored in trio-fuel (TF) context.Minor changes are observed at first and second stage ignition delay time (IDT) when $x < 0.6$ of trio-fuel compared to dual-fuel blends (x ¼ 0). For methane, IDT increases by a factor of 1.4e2 during first and second stage when $x > 0.6$. In case of methanol, a corresponding decrease by a factor of 1.2e2 has been observed. Present TF setup, a low reactivity fuel (LRF), methane or methanol, is perfectly mixed with hydrogen and air to form the primary fuel blend at the lean equivalence ratio of 0.5.

A review on ignition mechanisms and characteristics of magnesium alloys

Characteristics of magnesium alloys and the ignition mechanisms have been reviewed in this paper to analyse the transfer processes and thermodynamic conditions of magnesium alloys. The ignition of 6magnesium is due to the formation of the oxide layer due to high pressure and temperature. From the point of mechanism the the ignition criteria are analyzed and the results are concluded.

Dual-fuel Engines – An Elegant Alternative for Tier 4f Compliance.

It has been investigated whether converting into dual fuel engines would help in achieving the Tier 4f emissions compliance. With minimal modifications to the tier 2 compliance diesel engine it can be made to tier 4f compliance diesel engine. The emissions tests are used to analyze the emissions of conventional engines and dual fuel engines. An integral investigation of diesel-natural gas dual fuel combustion with dual direct injection for commercial car applications. To find out the advantages and disadvantages of the fuel injections systems and the emissions produced by them. By this study it has been found out out that the late injection of the natural gas helps in lowering the unburned CH-emissions. A series of tests have been performed and the data has been collected like particle count and the injection timing data to come to the conclusion of the optimal timing for the fuel injection and the optimal pressure for the fuel injection.

Cast magnesium alloys for elevated temperature applications.

Review of cast magnesium alloys with respective to elevated temperature applications. Development of dispersion strengthened magnesium alloys and improvement of current Mg-AI-RE and Mg- AI-Si systems are the potential routes to expand die-cast magnesium alloys for elevated temperature applications. Mechanical properties at room temperature and elevated temperatures are observed also the castability, corrosion resistance and micro-structure are analyzed.

1.5 GAPS IDENTIFIED

It has been identified that the recent discovery of the creep resistant magnesium alloys have not yet been put into use for the manufacturing of engine cylinder heads despite their comparable the tensile strengths and creep resistance to the traditional aluminium alloys that are being currently used. Magnesium being 33% more lighter than aluminium, it can give an edge over the weight reduction of cylinder head in an engine.

1.6 OBJECTIVES OF THE PROJECT

To smoother the transition of vehicles from fossil fuel engines to electric engines the intermediary phase is the conversion of existing diesel engines into dual fuel engines till their end stage of usage. So in this project we aim to work on the design and analysis (namely; Static Structural analysis, Steady State Thermal and Vibrations analysis) of the cylinder-head of a diesel-natural gas dual fuel engine. In addition, we have also considered recently discovered creep resistant magnesium alloys as the materials for the cylinder head and to perform the above mentioned analysis.

1.7 MOTIVATON

The alarming rate of increase in the global warming has become a major concern. And automobile industry has always been a major cause of the issue. In order to tackle this the governments throughout the world are encouraging the citizens to transition into electric vehicle users. But due to the presence of bulk amounts of the combustion engines it is not a straight way into the electric future. Here is where the dual fuel engines have been idealized to fill in this gap. Also to lighten the weight of the engine components may help in reducing the load on the engine and thus reducing the pollution.

With this two motives this project has been carried out and been pursued to successful completion with favorable outcomes.

CHAPTER 2
METHODOLOGY AND EXPERIMENTAL WORK

2.1 PROJECT EXECUTION STAGES

i. **Task-01:** We started by identifying the engine specifications that could fulfill the motives this project was intended to. In the commercial vehicle industry, we identified the most commonly used engine specifications and considered the same for the project.

ii. **Task-02:** Simultaneously we have searched for the creep resistant magnesium alloys that also posses the mechanical properties that are required for the engine cylinder head.

iii. **Task-03:** Based on the engine specifications, we have calculated the dimensions of the cylinder head by using the formulas of machine design and implemented the same in the modelling process.

iv. **Task-04:** A 3-D model of the cylinder head has been made in the AUTODESK Fusion 360 software.

v. **Task-05:** The model and the material properties have been imported into the ANSYS Workbench, where the further Static Structural, Steady State Thermal and Vibration analysis have been performed, based on the results the model has been redesigned and the same task has been repeated.

vi. **Task-06:** And finally the derived results have been tabulated and the conclusions have been drawn out.

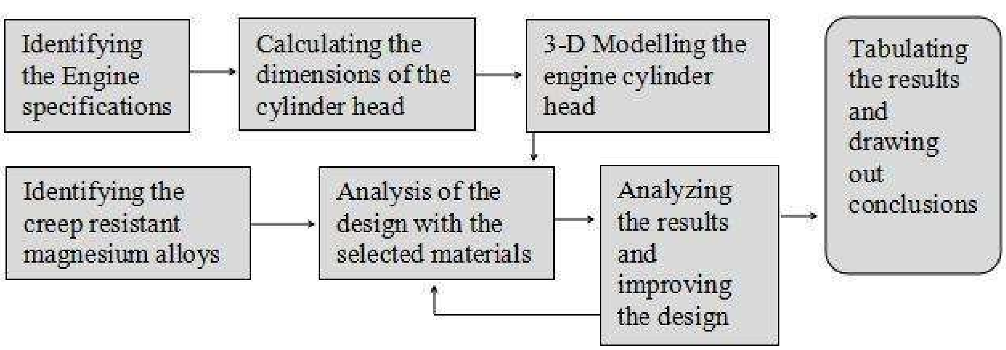


Figure 2.1. Project Key Tasks and Flow.

2.2 TECHNICAL SPECIFICATIONS

For this project as mentioned earlier we have chosen a commonly used commercial vehicles engine specifications, therefore, we have considered a 1.4 litre inline 4-cylinder 1396cc engine with Bore Diameter as 75mm and Stroke length as 79mm. The compression ratio of the engine was described to be 16:1. The power of the engine was noted to be 90ps @ 4000rpm and torque produced was stated to be 240 N-m @1500-2500 rpm.
The design was considered to be a uni-material design with no extra coatings.

2.3 DESIGN APPROACH DETAILS

Design approach for this model has been kept simple and conventional. It starts with the Calculation of the bottom thickness of the cylinder, in parallel the valve dimensions are calculated based on the bore diameter ratios as mentioned below.

Valve Dimensions:

1. **Exhaust:** Inner Diameter= 0.3D = 22.5mm.; Outer Diameter= 0.35D = 26.25mm.
2. **Intake:** Inner Diameter= 0.32D = 24mm.; Outer Diameter= 0.27D = 20.25mm.

Thickness of Cylinder Head Bottom(t_h):

$$t_h = K_1 D \sqrt{\frac{P_{max}}{\sigma_{allowable}}}$$

$$=15\text{mm.}$$

Once the bottom thickness and the valve dimensions are calculated for the cylinder head diameter of the bolt has to calculated along with the pitch circle diameter of the bolt, on whose circumference the bolt will be situated. Number of bolts has been considered to be 4.

Diameter of the bolt:(d_c)

$$= \sqrt{a \quad /_{alloal}}$$

$$= 20\text{mm.}$$

Bolt Pitch Circle Diameter:(D_p)

$$= \; + 2$$

$$= 140\text{mm.}$$

{Where $= /0.84$}

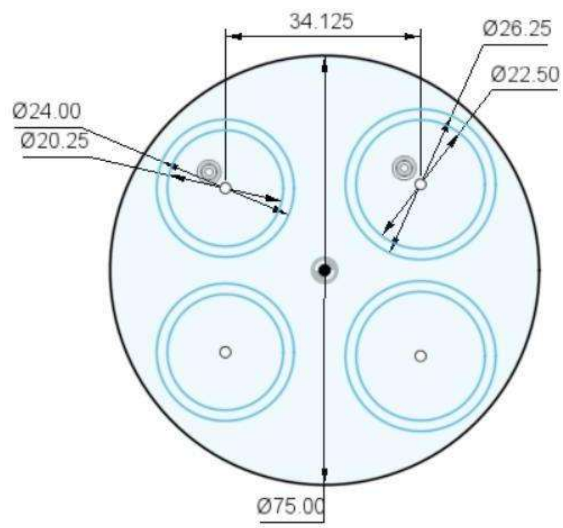


Figure 2.2. Port Layout.

2.4 REALISTIC AND DESIGN CONTRAINTS ADDRESSED

Considering the real life constraints and the design constraints the valve bridge is taken to be 12% of Bore Diameter i.e. 9mm. And the factor safety of 1.5 has been applied to the bottom thickness of the cylinder head. While considering the materials tensile strength and ultimate tensile strength factor of safety has been applied.

2.5 CODES AND STANDARDS

ASME, BS,IS codes have been looked over while designing the components and the calculating their dimensions.

CHAPTER 3

RESULTS AND DISCUSSION

The model has been designed and modeled in AUTODESK Fusion 360 with previously calculated dimensions. The same model has been revised according to the simulations and refined.

MODEL:

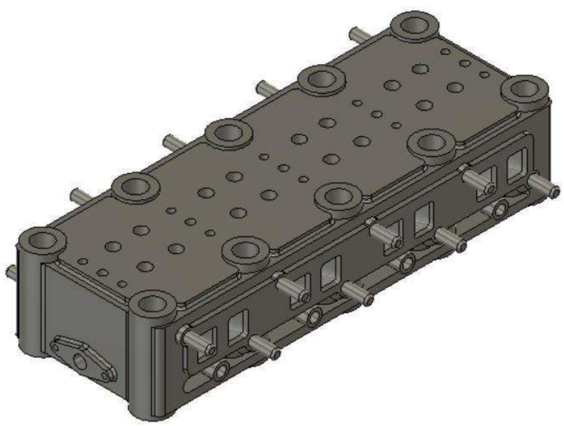


Figure 3.1. Model Isometric View

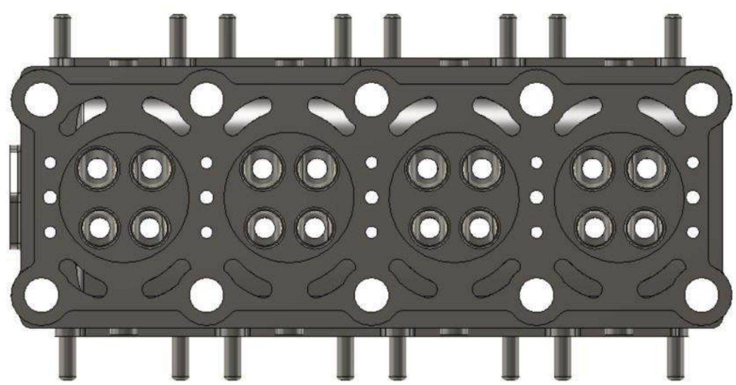


Figure 3.2. Model Bottom View.

The simulations were performed in ANSYS Workbench the project schematic is as shown in

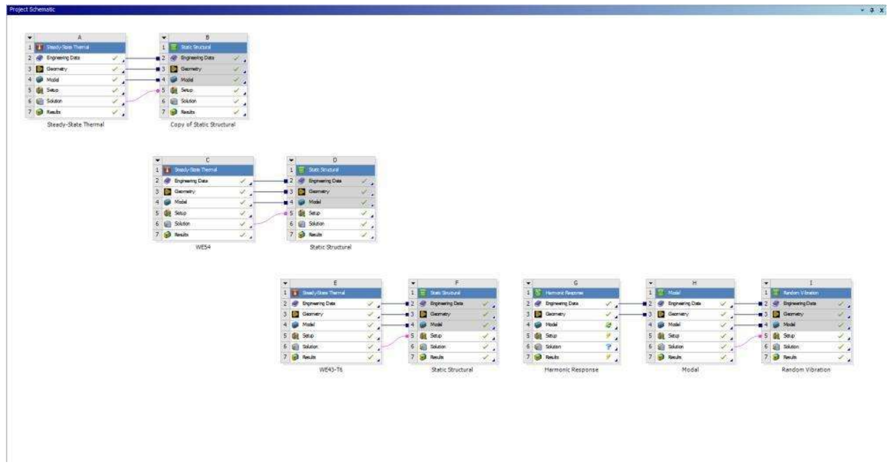


Figure 3.3. ANSYS Workbench

The modeled design has been imported to the ANSYS Workbench for further analysis and for analysis the model has been meshed using the enterprise license as the student version has limitations. The meshed component image has been presented below.

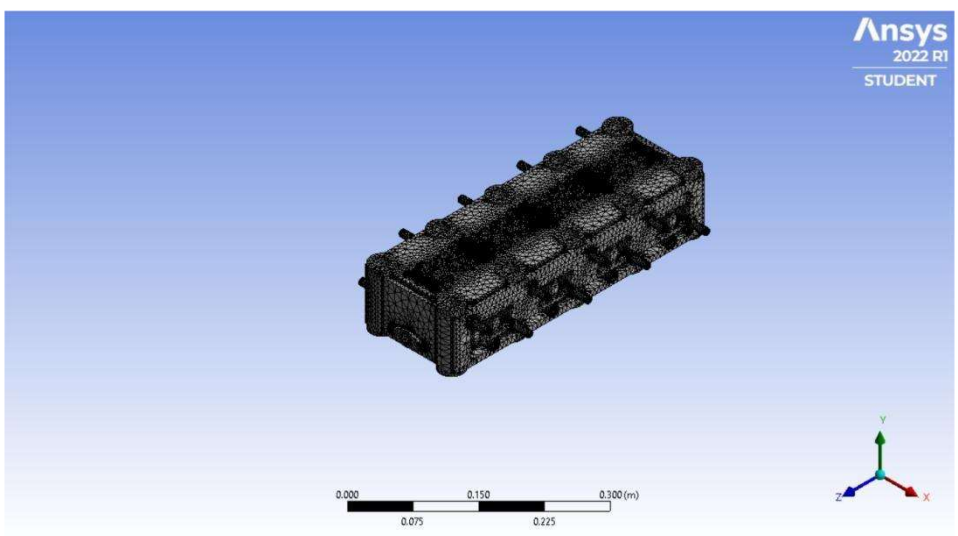


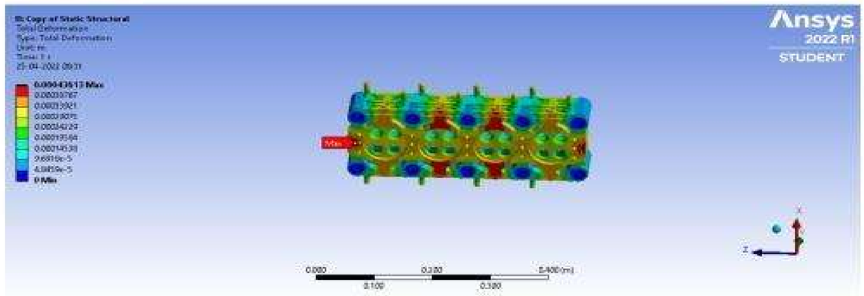
Figure 3.4. Meshed Model

As shown in the …. static structural analysis along with steady state thermal are performed on the components with the three materials. The von-Misses stresses and total deformation are the solutions obtained from static structural.

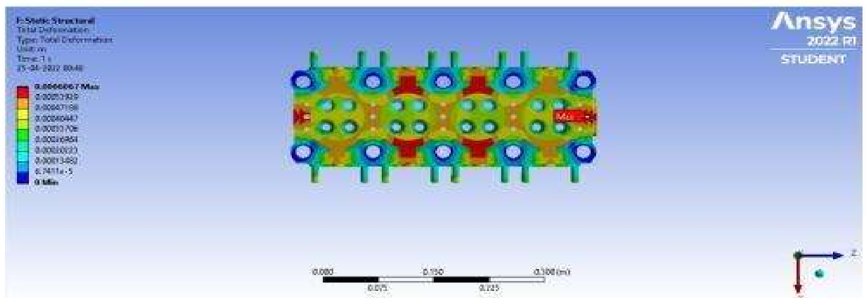
3.1 RESULTS

Total Deformation results of all the three materials:

A-356 Material:



WE43 Material:



WE54 Material:

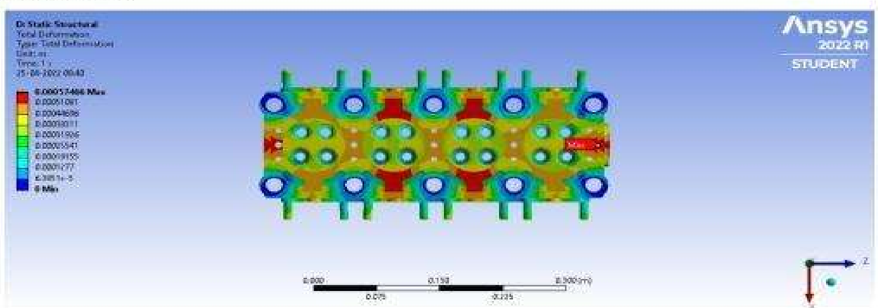


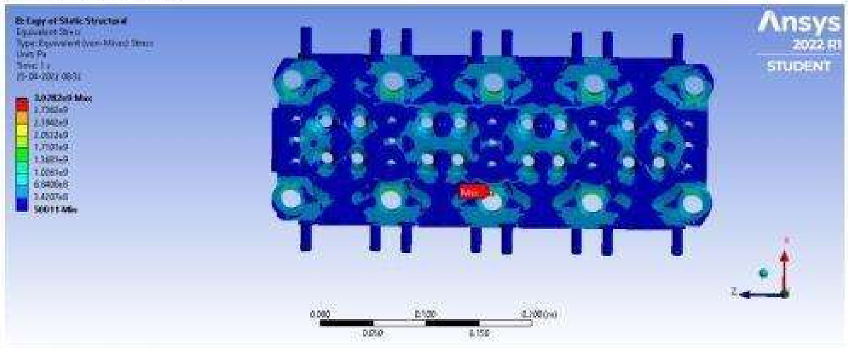
Figure 3.5. Total Deformation Results of all three materials

Sr.No.	Material	Total Deformation (m)
1.	A-356	4.3613×10^{-4}
2.	WE43	6.067×10^{-4}
3.	WE54	5.7466×10^{-4}

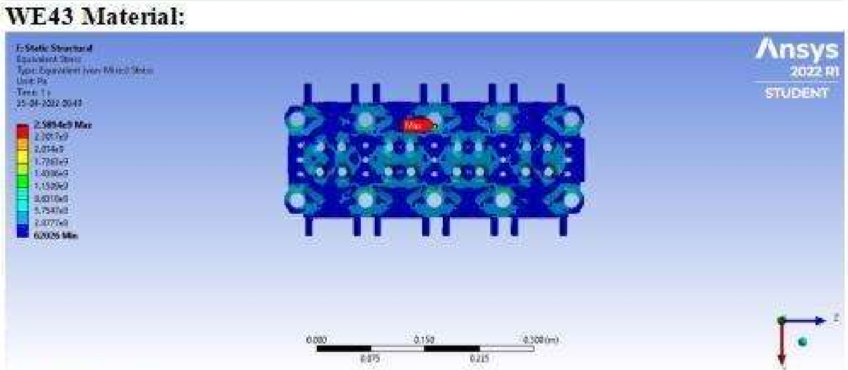
Table 3.1. Total Deformation Results.

Von-Mises Stress results of all the three materials:

A-356 Material:



WE43 Material:



WE54 Material:

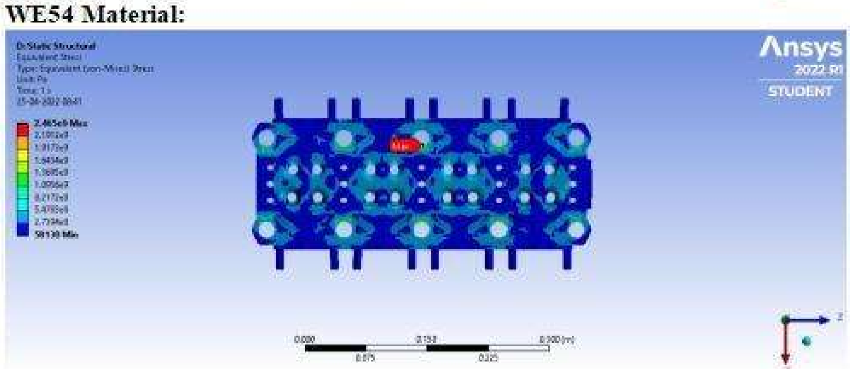


Figure 3.6. Equivalents (von-Mises) Stress Results

Sr.No.	Material	Equivalent(von-Mises) Stress (MPa)
1.	A-356	59.472
2.	WE43	59.52
3.	WE54	59.472

Table 3.2. Equivalent (von-Mises) Stress results table

For Steady-State Thermal analysis the parameters that are to given are the temperatures the materials are to be exposed and the surface of convection along with the convection values.

In this project we have considered the convection to be on the surface of the cylinder head and the coolants convection and oil convection has not been considered. The selection of surface for convection has been shown in figure…

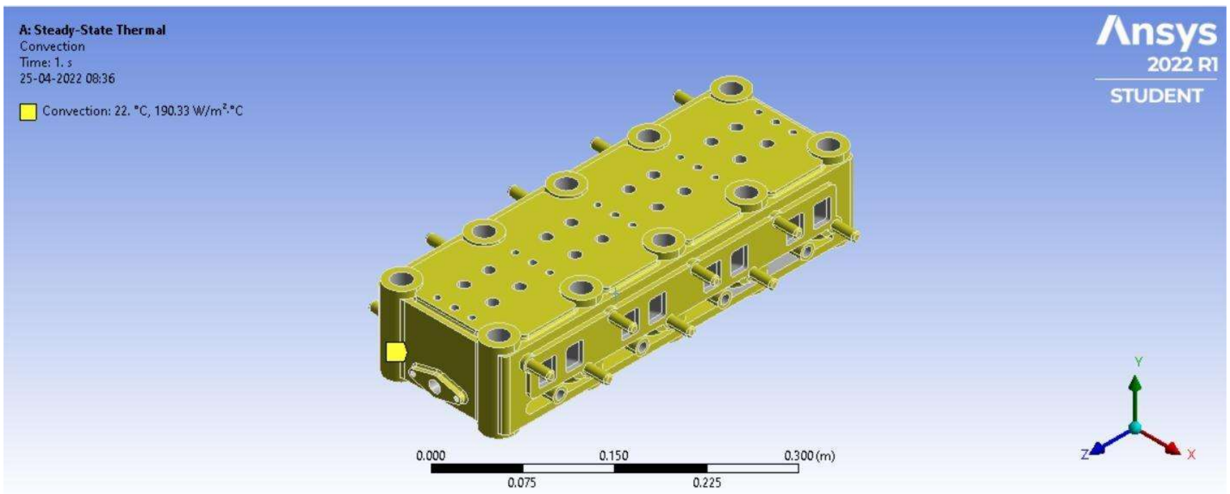
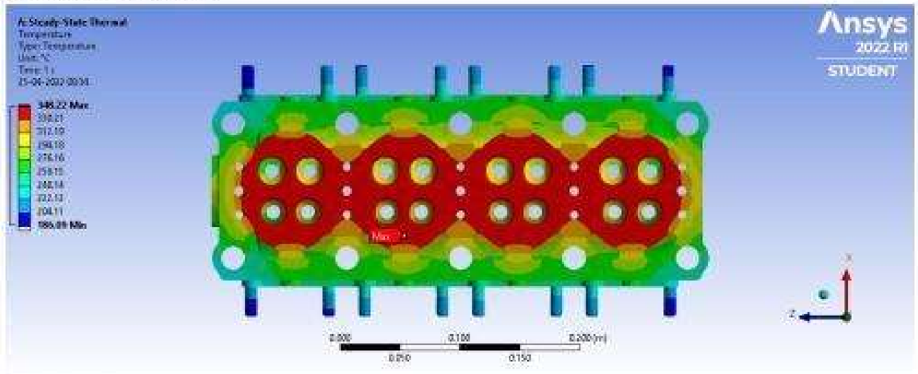


Figure 3.7. Convection surface

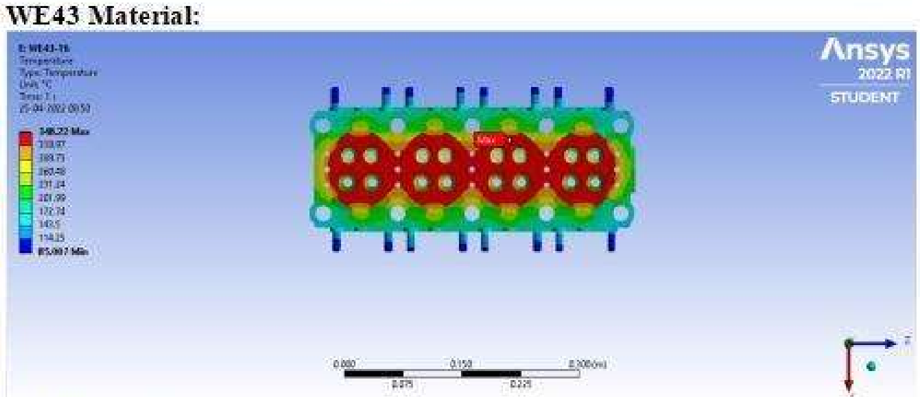
Since we have not considered the coolant convection and the oil convection in the respectively provided passages, the thermal loading stress has been over the limit and causing a failure. The solution to the issue has been addressed in the conclusions and the future scope chapter.

Temperatures on the bottom surface of the Cylinder Head:

A-356 Material:3



WE43 Material:



WE54 Material:

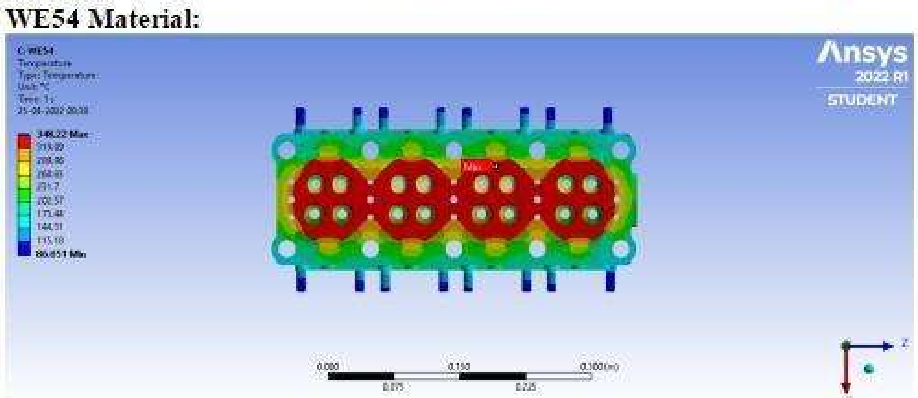


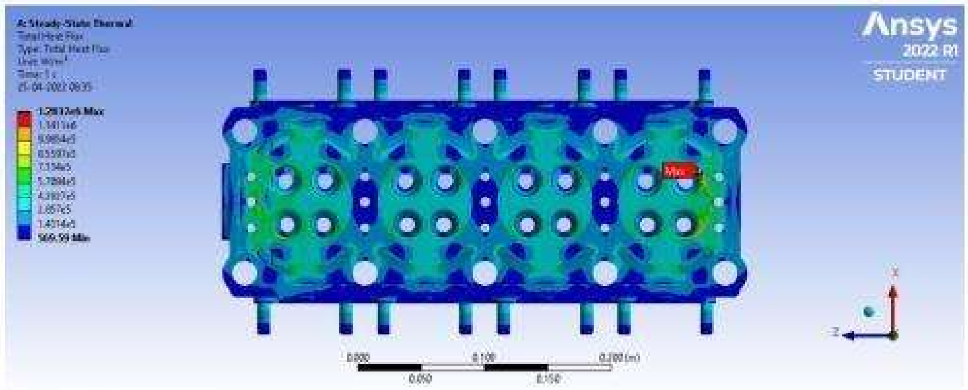
Figure 3.8. Temperature Distribution Results.

Sr. No.	Material	Temperature (°C)
1.	A-356	348.22
2.	WE43	348.22
3.	WE54	348.22

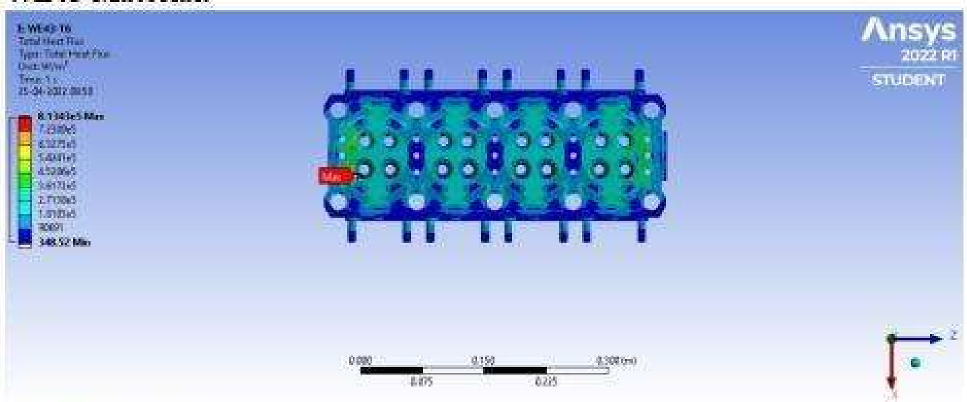
Table 3.3. Temperature Distribution Results Table.

Heat Flux Results in all three materials:

A-356 Material:



WE43 Material:



WE54 Material:

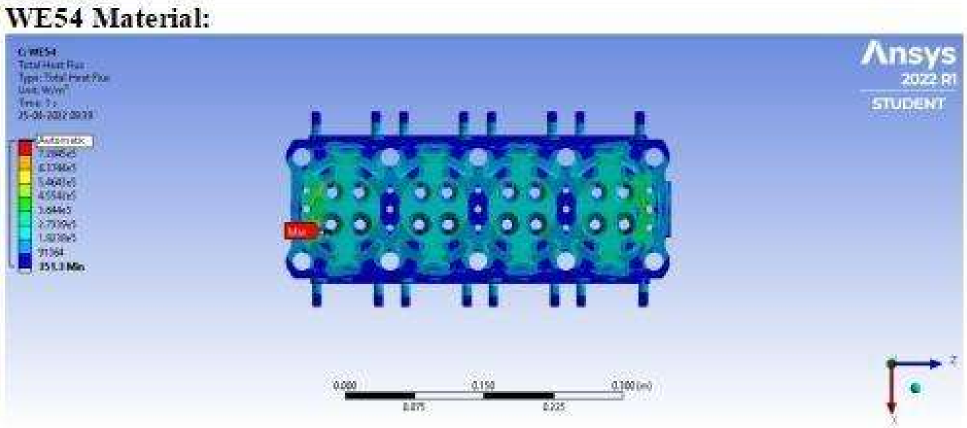


Figure 3.9. Heat Flux Result.

Sr.No.	Materials	Heat Flux (W/m²)
1.	A-356	1.2837×10^6
2.	WE43	8.1343×10^5
3.	WE54	8.1947×10^5

Table 3.4. Heat Flux Results Table.

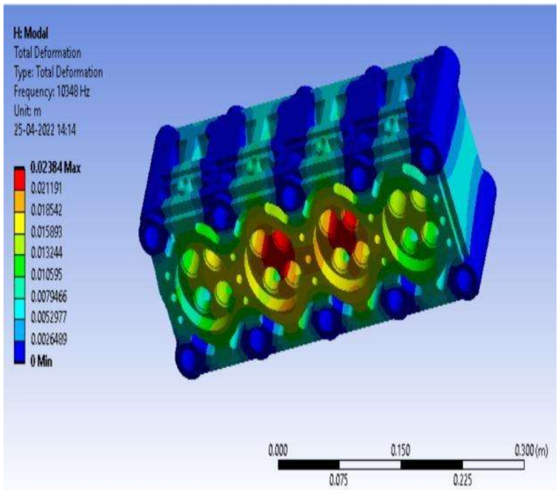
Vibrations Analysis

For vibrations analysis we simulated the modal analysis and Random Vibration analysis, for the modal analysis we have considered 20 nodes and their respective frequencies from the harmonic analysis done prior to this simulations. The modes and their corresponding frequencies have been shown in the figure

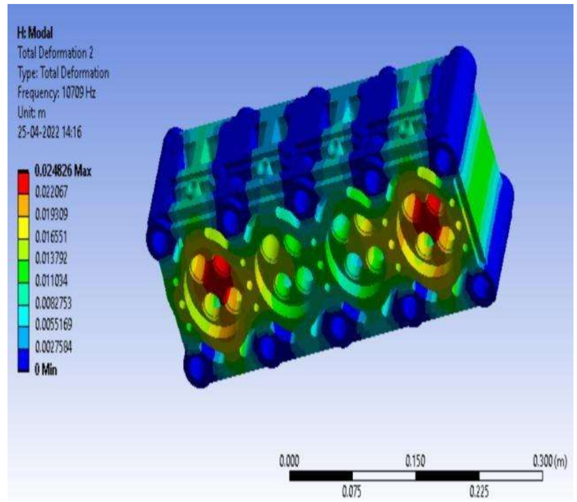
Mode	Frequency [Hz]
1	10348
2	10709
3	11381
4	12049
5	12437
6	12797
7	13805
8	13975
9	14020
10	14282
11	14366
12	14429
13	14516
14	14565
15	14850
16	15204
17	15327
18	15811
19	15891
20	15936

Table 3.5. Modes and their corresponding Frequencies.

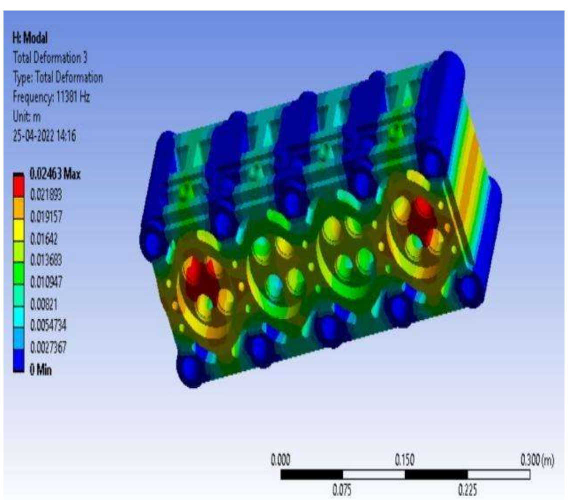
For every mode and it's respective frequencies a total deformation test is performed and the maximum deformation is tabulated, The results are shown in the figure.



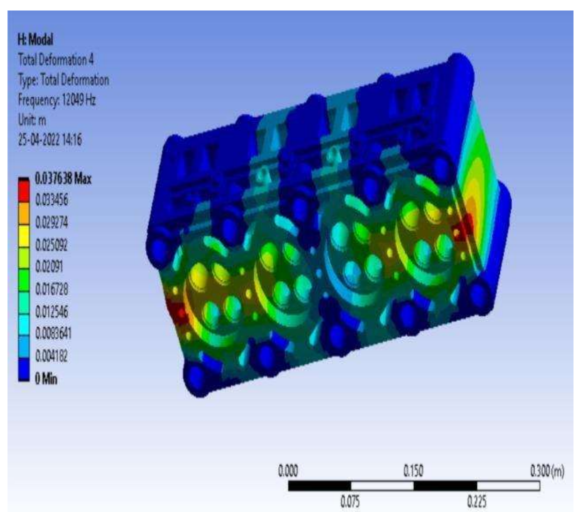
MODE 1



MODE 2

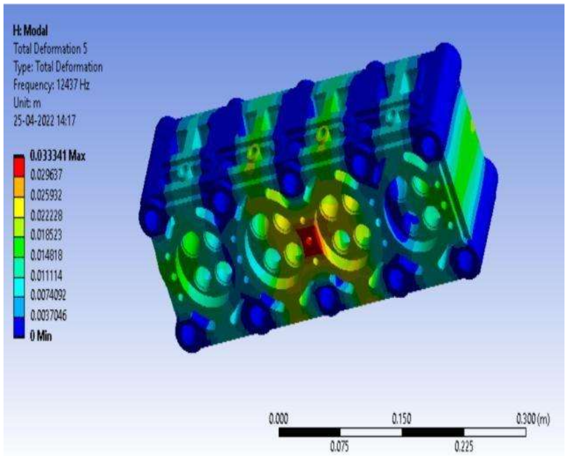


MODE 3

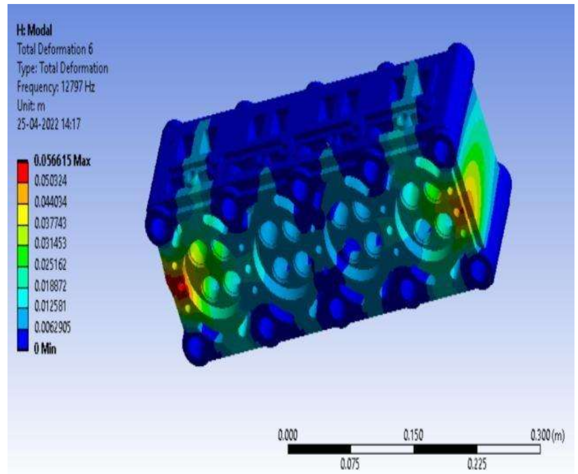


MODE 4

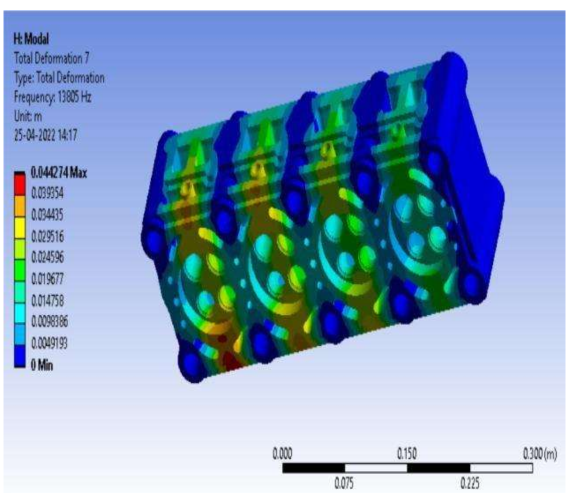
Table 3.6. Total Deformation of Mode 1-4.



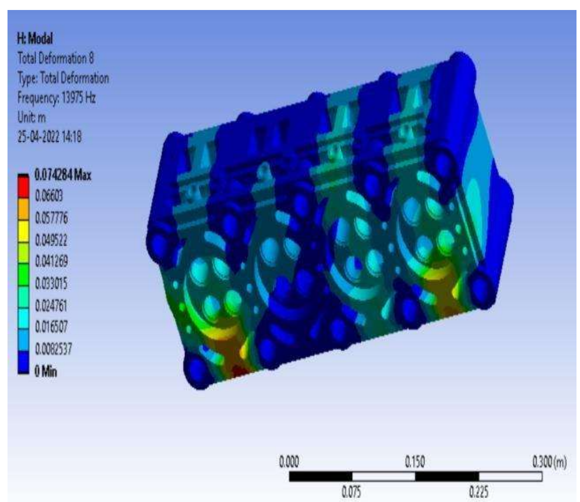
MODE 5



MODE 6



MODE 7



MODE 8

Table 3.7. Total deformation of mode 5-8.

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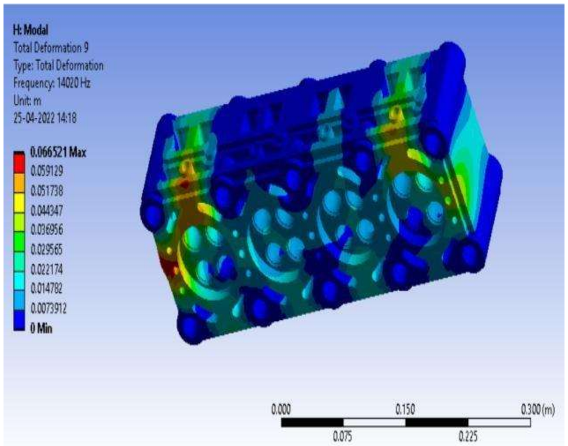
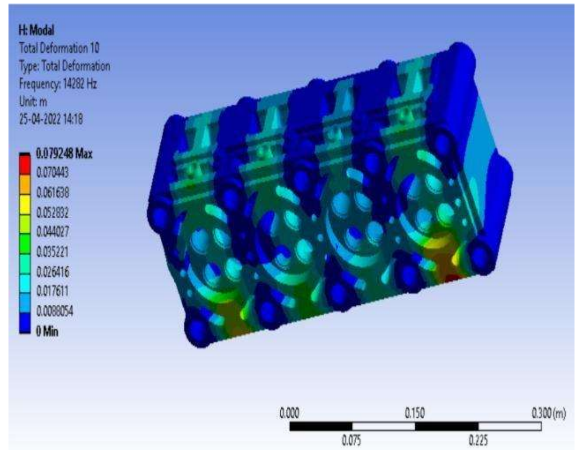
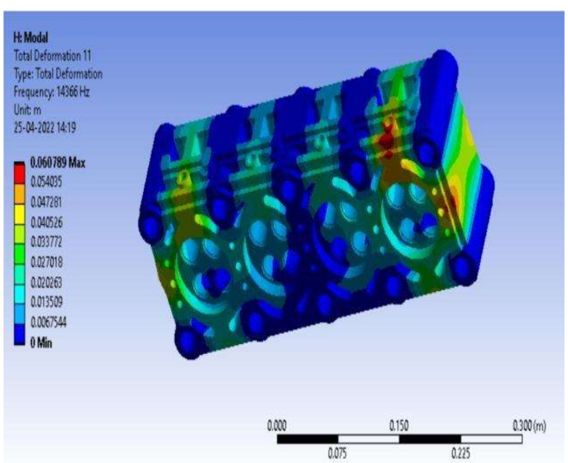
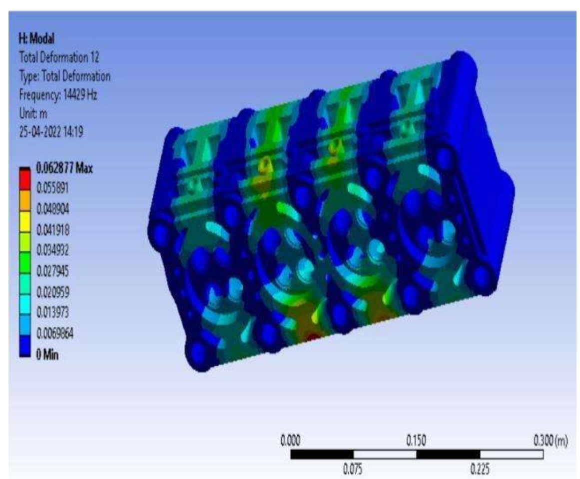
<td>

MODE 9</td>
<td>

MODE 10</td>
</tr>
<tr>
<td>

MODE 11</td>
<td>

MODE 12</td>
</tr>
</table>

Table 3.8. Total Deformation of mode 9-12.

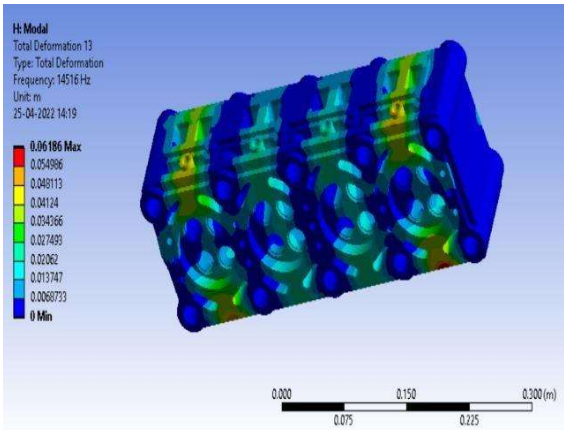
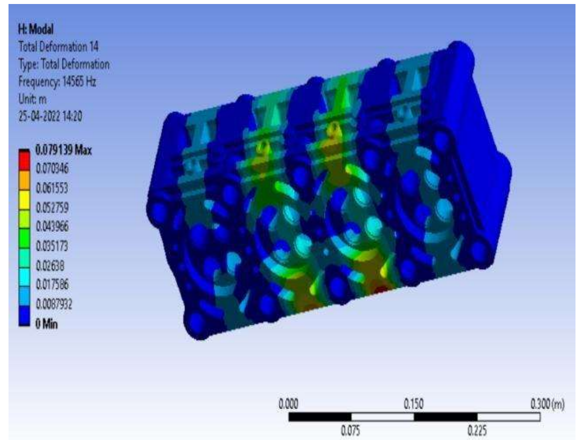
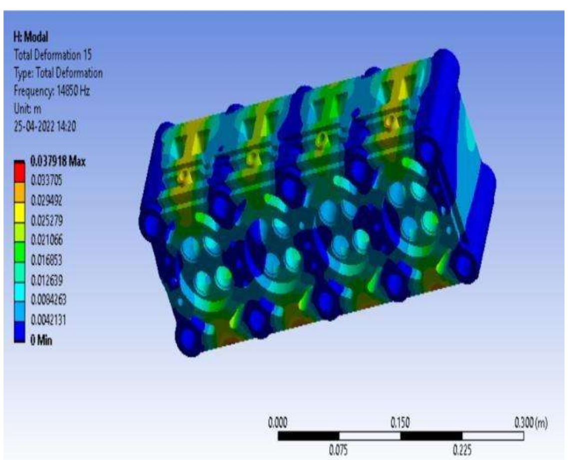
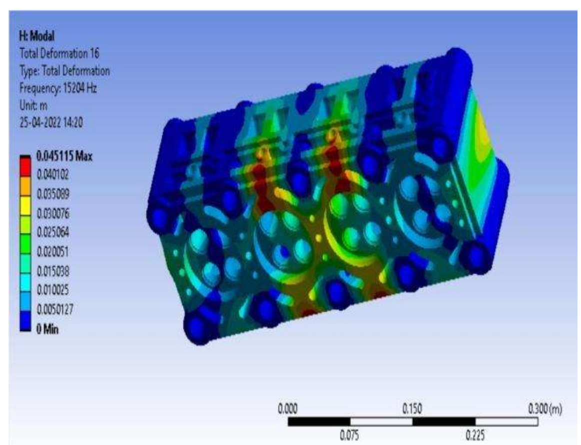
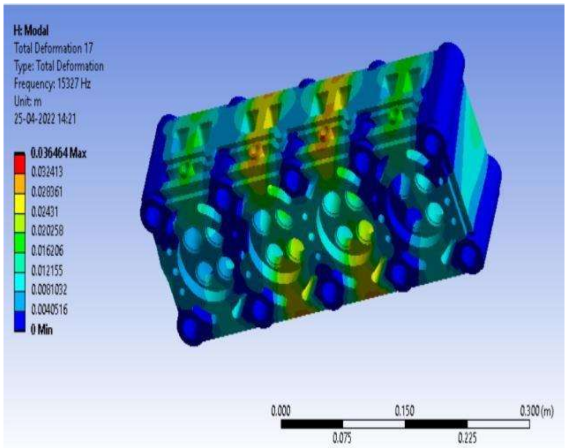
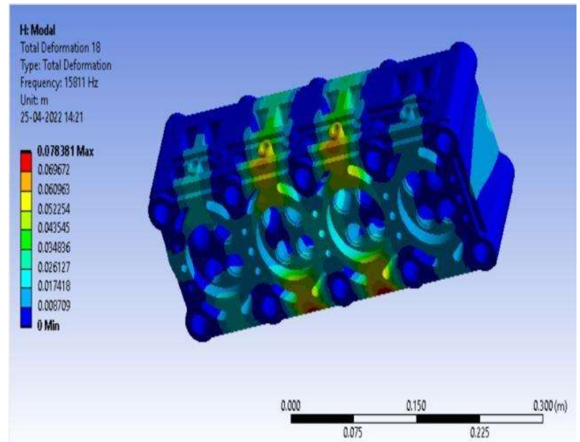
 **MODE 13**	 **MODE 14**
 **MODE 15**	 **MODE 16**

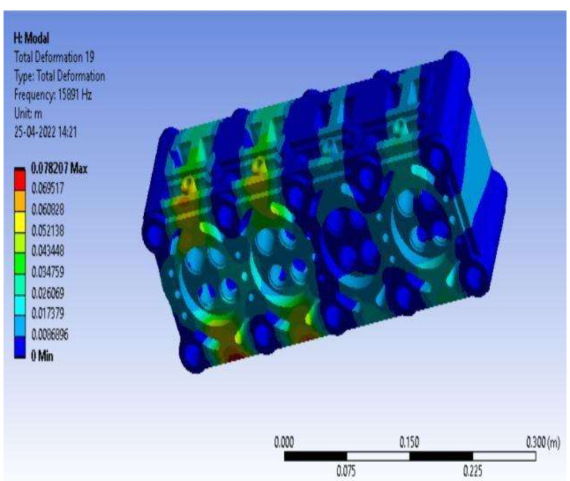
Table 3.9. Total Deformation of mode 13-16.



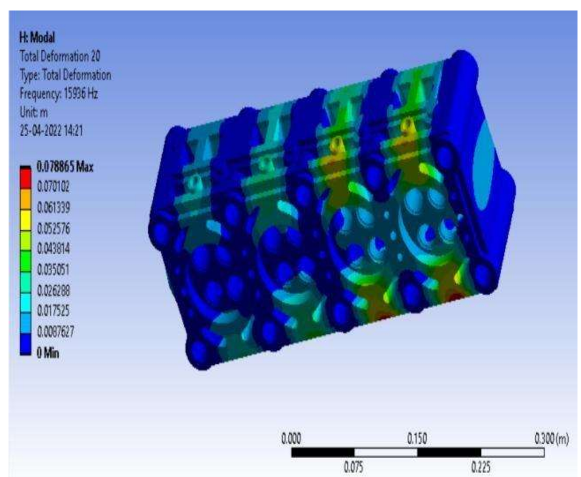
MODE 17



MODE 18



MODE 19



MODE 20

Table 3.10. Total Deformation of mode 17-20.

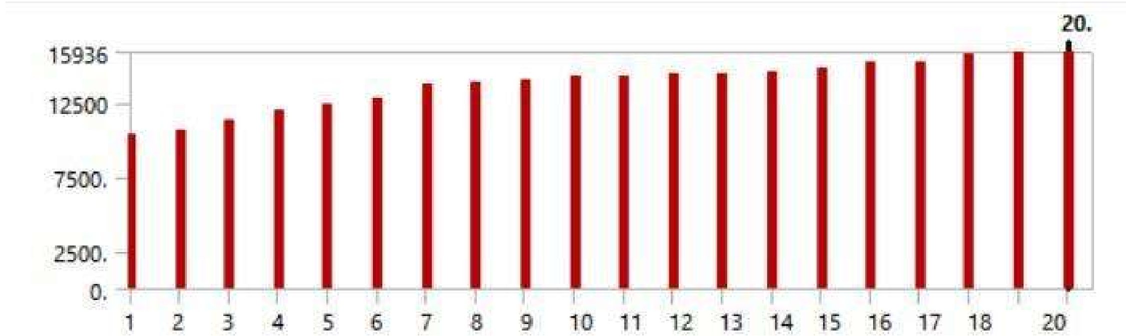


Figure 3.10. Graph plotted for Modes vs Frequency.

For Vibration analysis unlike the previous analysis only one material is considered among the magnesium alloys for simulation because, this particular analysis depends on the mass of the component. Since the density are similar and the Volume of the component remains the same irrespective of the material change the analysis was performed only on a single magnesium alloy and the results have been generalized.

Also in random vibration analysis only the Y-axis directional velocity and acceleration have been simulated because the pressure or force will only be applied in the Y-axis direction. Therefore only the Y-axis directional tests have been performed and the results have been derived.

Random Vibration Analysis

In this analysis we have done Directional Velocity, Directional Acceleration & Equivalent stresses tests are done. PSD acceleration data is fed into the simulation software as the initial value as 10,000Hz to final value as 16,000Hz with a 1000Hz interval.

	Frequency [Hz]	G Acceleration [G^2/Hz]
1	10000	9.6236e-003
2	11000	8.75e-003
3	12000	8.02e-003
4	13000	7.403e-003
5	14000	6.874e-003
6	15000	6.416e-003
7	16000	6.014e-003

Figure 3.11 G Acceleration for PSD Analysis.

PSD acceleration graph plotted against frequency.

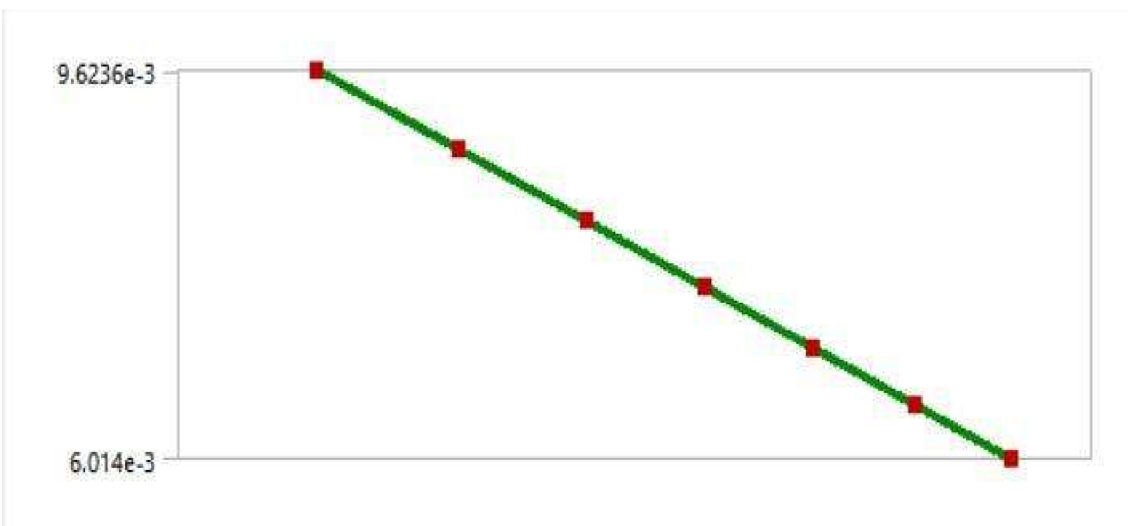


Figure 3.12. No. Of Frequencies vs G acceleration.

3.2 DISCUSSION

From all the analysis performed and results obtained the discussion proceeds to the compatibility of the magnesium alloys for usage in engine cylinder head. In total three kinds of analysis were performed and the performance of the WE43 & WE54 magnesium alloys were similar to the aluminium alloy A-356 that was analyzed similarly with the desired magnesium alloys.

In Static Structural Analysis it is found at some points of the component the stress was par above the safety limit, later when analyzed it was proven to b singularity errors and thus can be ignored. When all the stresses were added the thermal loading stress was found to be significantly higher and was effecting the structural integrity of the component. This is because of no cooling systems were considered in the design and in simulation.

Apart from thermal loading stress, the stresses caused due to structural loading and vibrations were found to be well within the industry standards. Therefore in future it is advisable to include the cooling system for a non defective component.

CHAPTER 4
CONCLUSIONS

4.1 CONTRIBUTIONS TO THE LITERATURE

The usage of the magnesium alloys as a material at higher elevated temperatures such as implementation in engine cylinder head. As the analysis have provided the insights into the applications and benefits the alloys carry with them. Magnesium alloys as the material for dual fuel engines can become an added benefit as the load on the engine decreases and the light-load fuel can be used longer reducing the cost of usage along with the reduction in emissions of pollutants from the vehicle.

4.2 SCOPE FOR FUTURE WORK

As observed in the results the thermal stresses are exceeding the industry standards of safety and thus future scope of the work can be to provide a water cooled or oil cooled system through radiator to solve the thermal issues and decrease the stresses in the component. This would help in drastically reducing the thermal stress in the component.

Also, for lower pressure engines other creep resistant magnesium alloys with comparably lower tensile strength can be tested and the advantages of the alloys can be utilized. As they posses even more weight reduction capability due to their low tensile strength.

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