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Modelling, Static and Thermal Analysis of multi Cylinder Head

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ABSTRACT

Cylinder head is a critical part of an I C engines cylinder head is used to seal the working ends of the cylinder and accommodates combustion chamber in its cavity, spark plug and valves.The main aim of this work is to predict the performance based on the stress/strain and thermal behavior of multi cylinder head of an metal alloy compared to non-alloy material. The effects of engine operating conditions such as combustion gas maximum internal pressure, temperature on the cylinder head have been analyzed. The analysis was carried out for different materials using a finite element analysis (FEA)software package, which is use to simulate and predict the Von-Misses stress and stain pattern and thermal distribution of the multi cylinder head structure. The heat generated in combustion chamber is highly dynamic and allows very little time (few micro seconds) to transfer the heat if not distributed will lead to squeezing of piston due to overheating. Hence an effective waste heat distribution through cylinder head plays a very important role in smooth function of I C engine. Heat Transfer through cylinder head consists of conduction through walls and convective heat transfer due to surrounding air flow. As the shape of cylinder head is complex and temperature within the combustion chamber is still fairly unknown. Conventional methods of evaluating heat transfer are very complex. The geometrical modelling was carried out using SOLIDWORKS and analysis is done on ANSYS software. The steady state finite element method (FEM) stress analysis can play a very effective role in the rapid prototyping of the multi cylinder head. The results of the thermo-mechanical analysis shows that when the engine is running the stress in the region is compressive, caused by thermal loading and combustion pressure. When the engine is shut off, the compressive stress turns into tensile stress because of assembly loads. Analysis of this cylinder head will be carried by using different materials such as Aluminum alloy and grey castiron.

KEYWORDS: *Multicylinder Head, Otto cycle, Diesel cycle, Solid Works, Ansys*

I. INTRODUCTION

A cylinder head is a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod.The development of modern engines leads to further forcing of its operation process, thus causing more thermal stress of their main parts, forming the combustion chamber. The design and, especially, the engine development necessitate conducting of comprehensive and thorough assessments of quality, reliability and performance of all systems and engine parts, comprising the piston

–cylinder group (further parts of the group operate under significantly high temperatures and in chemically active medium. Secondly, simultaneous impact of thermal and mechanical stresses, which are different During the cycle due to inconstant gas pressure, has high influence on the cylinder's durability. The heat flux, varying significantly during the cycle and reaching the values up to 10^6 W/m^2 and higher, is also irregular througheach surface of the group.

II. CYCLES OF RECIPROCATING INTERNAL COMBUSTION ENGINES

As can be seen from its name, an internal combustion engine is a heat engine in which fuel combustion inside the engine transfers heat to the working medium. In these engines during the first and second stroke, the working medium is air or a mixture of air and an easily inflammable liquid or gaseous fuel. During the third stroke, the products of combustion of this liquid or gas fuel (gasoline, kerosene, solar oil, etc.) represent the working medium. In gas engines, the working medium is under comparably low pressures and its temperatures are well above the critical temperature, thus, it allows us to consider the working medium as ideal gas and, thereby, significantly simplifying the thermodynamic analysis of thecycle.

III. OTTO CYCLE

The schematic diagram of the Otto –cycle –operating engine and the indicator diagram of this engine are shown in Fig.1

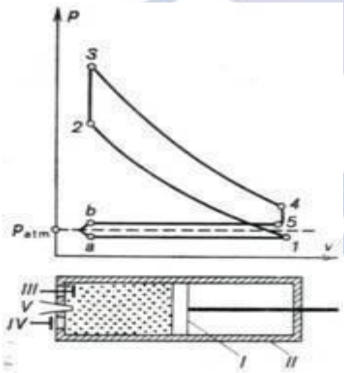

FIG 1 OTTO CYCLE

A piston (*I*) is placed in a cylinder (*II*) with an inlet (*III*) and exhaust (*IV*) valves. The piston moving from top dead canter to bottom dead canter (process *a-I*) creates a rarity inside. Preliminary prepared combustible mixture of air and vaporized gasoline is injected into the cylinder after the inlet valve opening. The inlet valve closes when the piston reaches BTC, thus, terminating a fuel supply. The piston moving in the opposite direction compresses the mixture and causes a pressure rise (process *1-2*). After the pressure of the fuel mixture is compressed to a certain pressure value, corresponding to point *2* on the indicator diagram, the fuel mixture is ignited with the aid of spark plug (*V*). The process of combustion is assumed to be at constant volume, because the combustion of the fuel mixture is nearly instantaneous and the piston almost makes nomovement. Combustion is accompanied by the heat release and heat transfer to the working medium inside the cylinder. Consequently, its pressure rises to a value, corresponding to point *3*on the indicator diagram (process*2-3*). The pressure boost forces the piston to move again from TDC to BDC and perform work of expansion which is transferred to an external consumer (process *3-4*). After the piston has reached the BDC, exhaust valve *IV* opens and the cylinder pressure reduces to a value somewhat exceeding atmospheric pressure (process *4-5),* with a fraction of the gas leaving the cylinder. The piston then travels again from BDC to TDC, ejecting the remaining part of the exhaust gas into the atmosphere, followed by initiation of a newscycle.

IV. DIESEL CYCLE

One way to enhance the compression ratio is to compress only pure air not a fuel mixture and inject the fuel into the engine cylinder when the piston is about to reach the TDC. The Diesel cycle is based on that principle.

The schematic diagram of the Diesel –cycle operating engine and the indicator diagram are presented at Fig.2

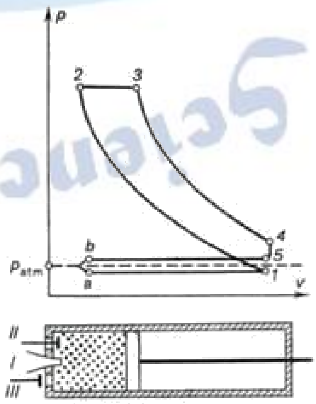

FIG 2 DIESEL CYCLE

Similarly, to the Otto cycle, the piston travels to the BDC making a rarity inside the cylinder during the process *a–1*, but an atmospheric air instead of fuel mixture is drawn into it. Further

compression is carried out until the air reaches pressure $p2$. Commonly, Diesel engines operate with a compression ratio ranging between 15 and 16).

In the beginning of air expansion, the fuel is injected to the cylinder with the aid of special fuel injection valve. High temperature of compressed air causes the fuel ignition, which burns

at constant pressure following with gas expansion from $v2$to $v3$.

After the process of fuel injection is over, further expansion of working fluid follows the adiabatic curve *3–4*. When the piston reaches BDC (point *4*), the exhaust valve opens reducing the cylinder pressure to atmospheric at constant volume.

With several assumptions made similar to the Otto process, the Diesel cycle is simplified and represented with thermodynamically equivalent ideal closed cycle implemented with pure air

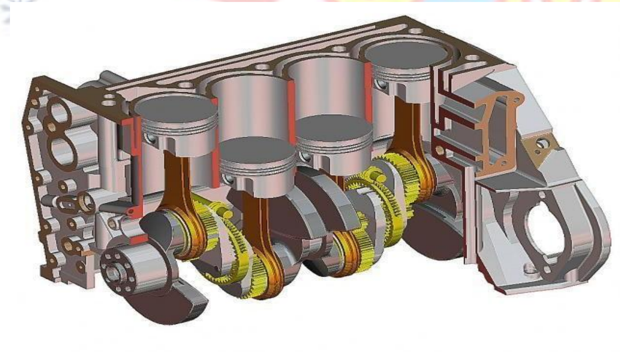

FIG 3 LOCATION OF PISTON IN 4 STROKE AND 6 STROKE ENGINE

V. INTRODUCTON TO SOLID WORKS

The SOLIDWORKS® CAD software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings.

SolidWorks is a modern computer aided design (CAD) program. It enables designers to create a mathematically correct solid model of an object that can be stored in a database. When the mathematical model of a part or assembly is associated with the properties of the materials used, we get a solid model that can be used to simulate and predict the behavior of the part or model with finite element and other simulation software. The same solid model can be used to manufacture the object and also contains the information necessary to inspect and assemble the product. The marketing organization can produce sales brochures and videos that introduce the product to potential customers. SolidWorks and similar CAD programs have made possible concurrent engineering, where all the groups that contribute to the product development process can share informationreal-time

VI. INTRODUCTION TO ANSYS

Ansys is general purpose finite element analysis software package. Finite element numerical method of a deconstructing a complex system into very small pieces (user designated size) called element. The software implements equations that governs the behavior of these elements and solver them all; creating a comprehensive explanation of how the system acts as a whole. These results than can be presented in tabulate or graphical forms. This type of analysis is typically used for the designed and optimization of system for too complex to analyze by hand. Systems that make fir into this category are too complex due to their geometry, or governingequations.

Ansys is the standard teaching tool within the engineering department at many colleges. Ansys is also used in civil and Electrical engineering, as well as physics and chemistry department.

Ansys provide a cost-effective way to explore the performance of the products and processes in a virtual environment. This type of product development is termed as virtual Prototyping. With virtual prototyping techniques users can iterate various scenarios to optimize the product long before manufacturing is started. This enables a reduction in level of risk, And in the cost of ineffective designs. The multifaceted nature of Ansys also provides a means of ensure that users are able to see the effect of designs on the whole behavior of the product, be it electromagnetic, thermal, mechanical etc.

Like solving any problem analytically, you need to define (1) your solution domain,

(2) the physical model, (3) boundary conditions and (4) the physical properties. You then solve the problem and present theresults.

In numerical methods, the main difference in an extra step called mesh generation. This is the step that divides the complex model in to small elements that become soluble in an otherwise too complex situation. Below describes the process in terminology. Slightly more attune too the software.

BUILD GEOMETRY Construct a 2 or 3 –D representation of the object to be modeled and tested using the work plane coordinates system in Ansys.

DEFINE MATERIAL PROPERTIES Now that the part exists, define a library of necessary materials that composed an object (or project) being modelled. This includes thermal and mechanicalproperties.

GENERATE MESH At this point Ansys understands the makeup of the part. Now define how the model system should be broken down into finite pieces.

APPLY PRESSURE Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions.

OBTAIN SOLUTION This is actually a step because Ansys need to understand within what state (steady state, transient… etc.) The problem must be solved.

PRESENT THE RESULTS After the solution has been obtained there are many ways to present Ansys results, Choose from many options such as tables, graphs and contour Plots.

VII. LITERATURE REVIEW

By harnessing the pros and cons of combustion chamber temperatures, internal combustion engines are developed. Here temperature difference puts a major impact on efficiency. If the gas energy is utilized to an utmost level the efficiency could be improved. To provide the same researches preferred limited cooled diesel engine. This provides a clear understanding of how to improve efficiency, which is enhanced by diminishing heatlosses.

After thorough study of literature and analyzing brainstorming sessions the following report is made.

Myers et al., [2] had worked on properties which in turn effect on the transfer of heat and also on various efficiencies related to the IC engines and this marks first of its kind effort on adiabatic engines after 25 years of Kirloskar's research. He clearly mentioned the pros and cons of his research. This is very much useful for researchers for further developments

One of the earliest investigations on the low heat rejection concept was conducted by Griffiths [10]. In his thermodynamic simulation model, he increased the combustion chamber wall temperature and studied its effects on thermal efficiency and heat rejection. In his analysis he found that only 25% of the reduction in heat rejection is recovered as work. About 61% of this reduction appears in the exhaust and 14% is lost inintercooler.

Adiabatic engine research was disseminated to the world when the Cummins engine Co. collaborated with the US Army tank in 1978, - Tank-automotive and Armaments Command (TACOM) in pursuing the adiabatic engine concept. In one of their earliest attempts, Kamo et al., [12] had reported using Hot Pressed Silicon Nitride (HPSN) and Lithium Alumina Silicate (LAS) as the insulating material. The main disadvantage of using LAS is its low material strength. Although HPSN has good high temperature strength, the conductivity has left much to bedesired.

After careful study of literature research work is much focused on four-stroke compression ignition engines. Valland et al., [33] had proved divergence from four strokes maximizes the benefits and also they clearly cited two stroke engines entail maximum efficiency. They have shown that there is a 9% increase in exhaust energy for the two-stroke cycle and 6% increase for the four-stroke cycle.

Dalvi et al., [42-44] had described the effect of adding various stabilizers (CaO,MgO,

Y_2O_3) on sintering and stabilization of zirconia. They had found out, from their experiments, that for uncalcined mixtures the sintered bulk density was higher when $CaO$is used as a stabilizer. But, when the mixture was calcined at 1600^{0}C, Y_2O_3 stabilized zirconia is far more superior. Hence, for high temperature applications, as required in internalcombustion engines, Y_2O_3 stabilized zirconia is preferred.

In their paper in 1983, Kamo et al., [46] had leveraged maximum benefits with the use of Partially Stabilized Zirconia (PSZ). The PSZ powder was deposited on the engine components by the plasma spraying technique. Experiments were carried out on a 450 HP turbo compound reported a specific fuel consumption of 228 gms/ bhp-hr. With this research they showed that greenhouse gases are reduced in line with smoke emissionlevels.

Tovell [55] came forward with his idea of computer-simulated model, which showcased effects of heat losses in the performance of the diesel engine. He prototyped the model, by comparing the engine, with and without insulation on direct injection diesel engine. Hereported a 7.5 % reduction in fuel consumption on eliminating cooling system completely. He has found that the largest reduction in fuel consumption can be obtained by insulating the piston crown or cylinder head. He has also reported a drop in hydrocarbons, particulate and smoke emissions and rise in NO_X emissions and exhaust temperature and a reduction in engine noise.

Wallace et al., [57] had reported the use of heat resisting materials on the adiabatic engine concept. At the University of Bath, they replaced the standard piston crown by heat resisting crown made of nimonic material with air gap to derive maximum benefits from heat loss. The aluminum piston skirt and crown are joined together with the help of spacer ring, which is interchangeable. They also developed a finite element analysis for calculating the heat flows, temperature distribution and stress analysis. The analysis made clear evidence of increase in piston temperature to 400 ^{o}C.

Alkyds et al., [61] had also reported some research work on the air-gap insulated piston. In their design, the piston crown was made of Inconel, which has high temperature strength and relatively low thermal conductivity. The crown was attached by four bolts with disk springs to maintain a sufficient clamping load despite dimensional changes due to thermal expansion. The effective thickness of the air gap was about 4 mm. The diameter of the air gap was made as large as possible to minimize the heat flowarea.

In their paper published in 1984, Kamo et al., [62] focused their research in attaining full- fledged volumetric efficiency with effective heat resisting ceramic materials. They concluded this research session by noting the material requirements to be implemented for adiabatic engines. Due to limitations of lubricating oil failures, they turned out their research importance to friction losses, which put up to50%.

French [64] had conducted an extensive literature review on the subject of adiabatic engine. He has developed a simple model for this survey, based on air cycle, which describes the reduction in coolant heat loss as a function of the ceramic dimensions and engine operating conditions. He even compared the results of his model with experimental results published in the literature. In his analysis he found that increasing the insulating material thickness follows the law of diminishing returns (i.e. a 2 mm layer of zirconia will reduce heat loss by 48%anda8mmthickzirconialayerisrequiretoreducetheheatlossby78%).Wadeetal.,

[74] had concentrated much on the area of the combustion chamber above the piston rings. Their research was focused on insulated steel piston for the development of limited cooled engine. They made significant efforts to study the pollution impact on diesel engines and fuel consumption at part load operating conditions. The major pollutants namely hydrocarbons and particulate matter have been reduced to 7%. They also faced problems like lubricating oil failure at elevated temperatures and drop in volumetric efficiency due to change indensities.

They also reported impacts made due to nitrogen oxide emissions, Lumby et al., [81] had reported the development of a new ceramic material syalon (Si-Al-O-N) for engine applications. Though this material was superior to zirconia in many aspects such as rupture modulus, tensile strength, compressive strength, young's modulus, hardness, the coefficient of thermal expansion and thermal conductivity left much to be desired. Hence syalon can be used for high temperature applications but not as an insulatingmaterial.

Morel et al., [82] had formulated strategy to work considering the structural parameters related to diesel engines and these embark a new correlation [83] regarding heat transfer and proper mixing of charge inside the engine cylinder as well as combustion gas velocities. They focused on the effects of different insulation approaches and insulating materials placed at several positions within the combustion compartment.

In their analysis they found that the piston and head receive about 81% of the total heat transferred. Hence insulating the piston and head should be given first priority. In the liner, the top portion (i.e. 1/6th of the total liner length) receives most of the heat transferred through the liner. Hence insulating the top portion of liner is recommended because insulating the whole liner increases the liner temperature, which in turn reduces the volumetric efficiency.

Arunachalam et al., [122] had conducted several experiments on the performance of limited cooled engine with diesel as fuel. He has also conducted tests to see whether the high temperatures encountered in an insulated engine allowed the use of low cetane number fuels. In his experiments, he found that with full insulation, fuels with 25 as cetane number could beused. With partial insulation, fuels having 35 as cetane number can be used, above which the engine h started missing.

Engine tests were conducted by Pawar et al., [208] on the ceramic-coated engine components. Experiments were carried out on a comet (VCT-10) type, 10 HP, 1500 rpm water cooled twin cylinder, diesel engine with fully instrumented for the measurement of engine output, speed, fuel consumption, air flow rate, heat transfer rate to the coolant, exhaust gas temperature and smoke density. Engine tests were conducted with the ceramic-coated engine components. The piston top with stainless steel bowl press fitted into the combustion chamber with two mm air gap insulation thermal barrier and valves were coated with materials namely Calcia Stabilized Zirconia (CSZ) by the use of plasma spray techniques. They noticed suppression in smoke emissions in limited cooled compression ignition engines. Maximum reduction in smoke density was found in 80% to 100% load range. They also reported that the turbo compound system was essential for taking full diesel advantage of insulated semi adiabaticengine.

Researcher by name Mirari et al., [215] in latest experimentation report showed 7% improvement in brake specific fuel consumption using single cylinder DI diesel engine with necessary insulation in combustion chamber. The study showed useful results compared to metallic engine in terms of better combustion and fuel efficiency.

The study report from Domingo et al., [223] showed that cylinder heat rejection reduction causes temperature increase in insulated engine in line with convective heat transfer.

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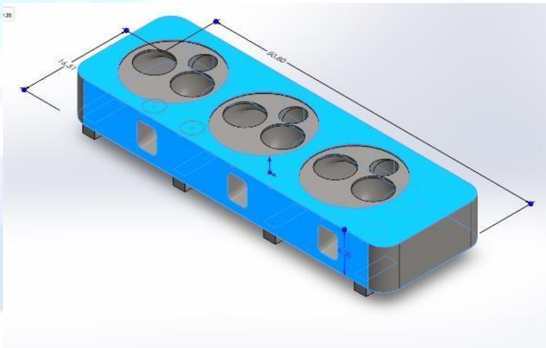
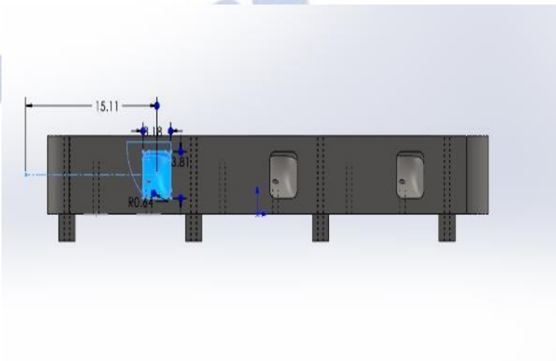
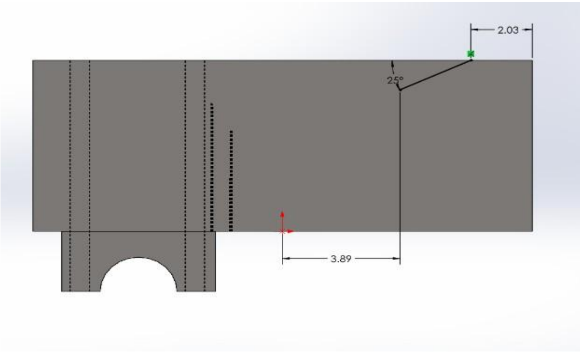
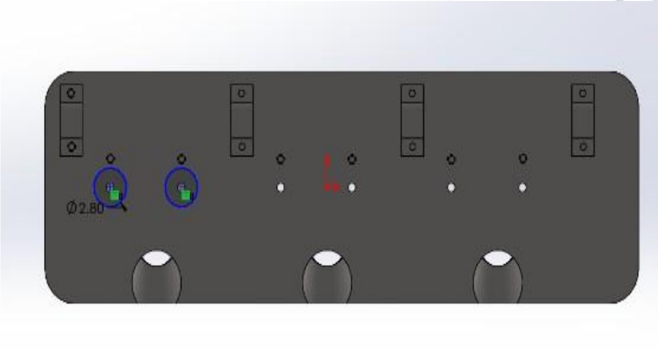
Authors of rejected papers may revise and resubmit them to the journal again.

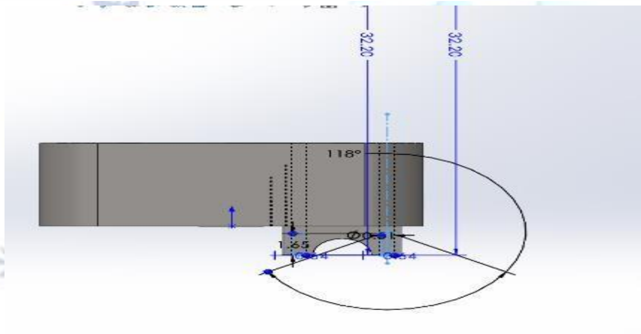
VIII. MODELLING OF MULTI CYLINDER HEAD USING SOLIDWORKS

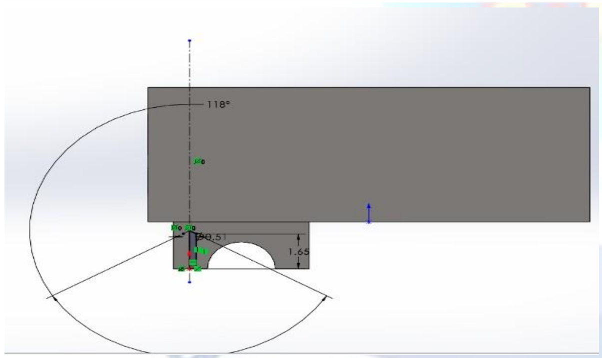


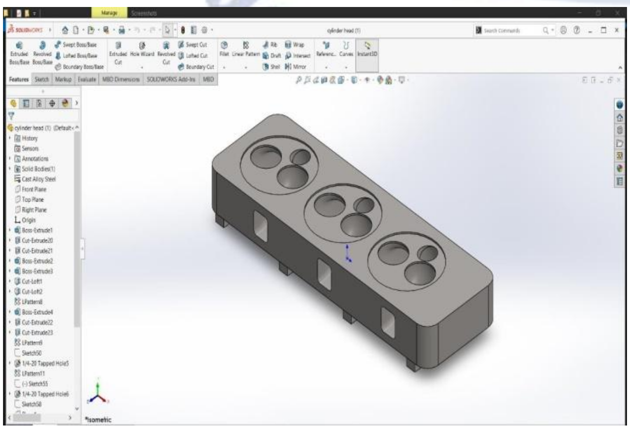












ISOMETRIC VIEW OF MULTI CYLINDER HEAD

IX. INTRODUCTION TO FEA

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variation calculation to obtain approximate solution to vibration systems. Shortly thereafter, a paper published in 1956 by M.J Turner, R.W Claough, H.C Martin and L.J Top, Established a broader definition of a numerical analysis. The paper centered on the "Stiffness and deflection of complex structures".

By the earlier 70"s, FEA was limited to expensive mainframe Computers, generally owned by Aeronautics, Automotive, Defense and nuclear industries. Since the rapid decline in the cost of the computers and the phenomenal increase in compute ring power, FEA have been developed to an incredible precision. Present day super computers are now able to produce accurate results for all kind ofparameters.

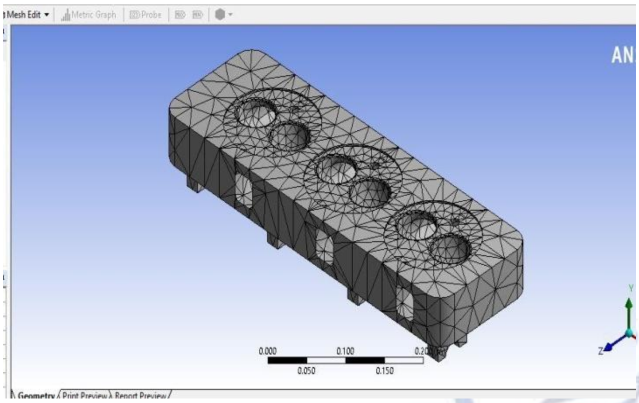
FEA consists of a computer model of material or design i.e.stressed and analyzed for specific results. It is used in new product design and existing product refinement. Accompany is able to verify a proposed design will be able to perform the client's specification prior to the manufacturing or construction. Modifying an existing product for structure is utilized to qualify the product or structure for a new service condition. In case of structure failure FEA may be used to help determine the design modifications to meet the newconditions.

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

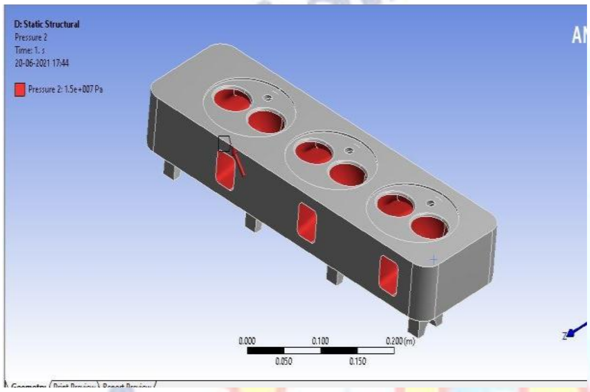
X. STATIC ANALYSIS OF ALUMINIUM ALLOY AND GREY CAST IRON MULTICYLINDER HEAD

1. ***Aluminum A360 Alloy:***

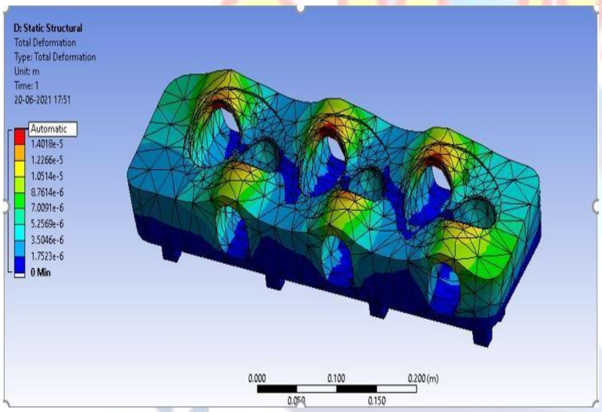
Density-2.65g/cm3
Ultimate Tensile strength -300MPa
Yield tensile strength -180MPa
Modulus of elasticity -71GPa
Poissonratio -0.33
Specificheat-963J/kg-K
Thermal conductivity-113W/m-K



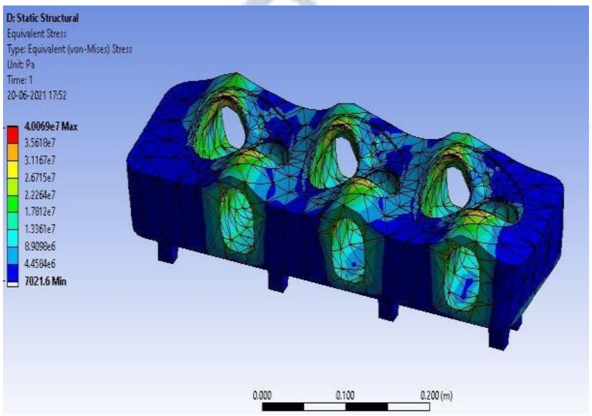
meshed model of multi cylinder head



applied pressure



TOTAL DEFORMATION



EQVIVALENT STRESS

2. *Grey Cast Iron:*

Density-7.35g/cm3

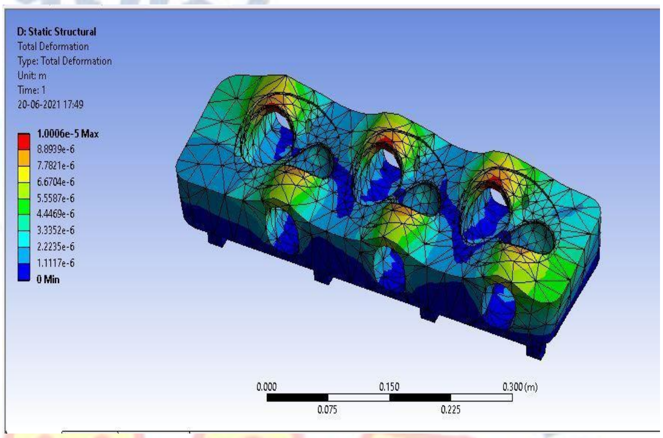
Ultimate Tensile strength -450 MPa

Modulus of elasticity -340MPa

Poissonratio-0.265

Specificheat-370 J/kg-K

Thermal conductivity-55 W/m-K



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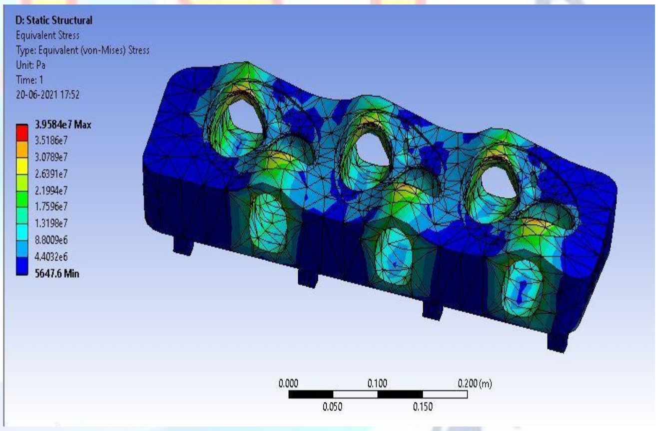
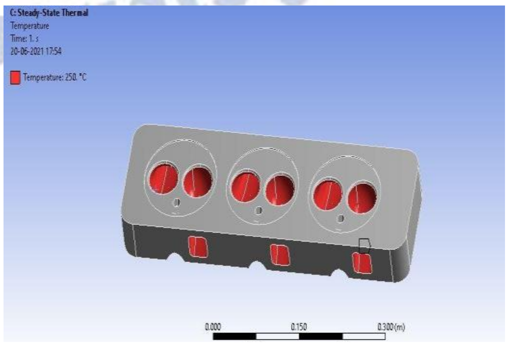


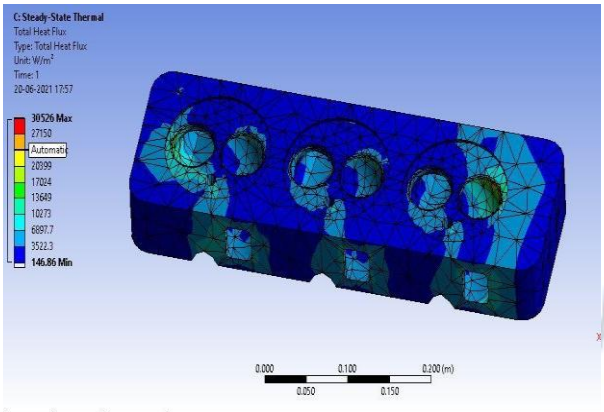
EQUIVALENT STRESS

XI. THERMAL ANALYSIS OF ALUMINIUM ALLOY AND GREY CAST IRON MULTI CYLINDER HEAD

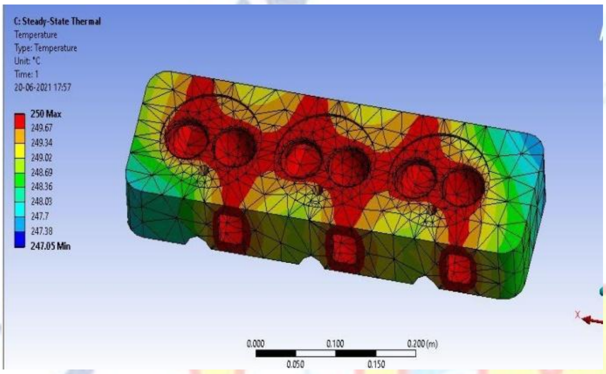
1. *Aluminum A360 Alloy:*



APPLIED TEMPERATURE

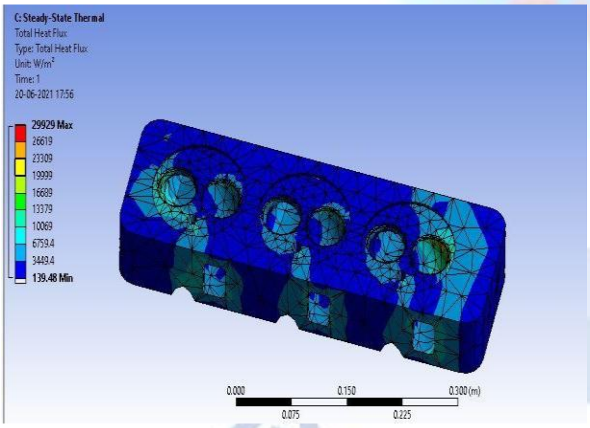


TOTAL HEAT FLUX

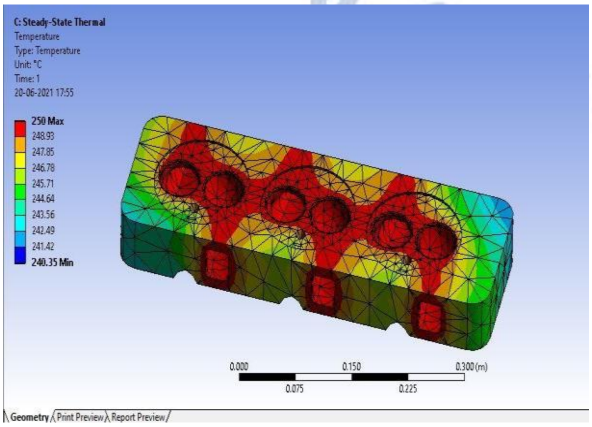


TEMPERATURE DISTRIBUTION

2. *Grey Cast Iron:*



TOTAL HEAT FLUX



TEMPERATURE DISTRIBUTION

XII. RESULTS

Material / output	Aluminum Alloy	Grey cast iron
Equivalent stress	4.0069e7 pa	3.9584e7 pa
Total Deformation	1.0003e-5 m	1.0006e-5 m
Total Heat Flux	30526 W/m2	29929 W/m2

XIII. CONCLUSION

In this project we have done a 3D Modelling of Multi-cylinder head using SOLIDWORKS and finite element analysis using ANSYS. The materials we conserved are Aluminum alloy and Grey cast iron.

In static structural analysis we applied same pressure to both the materials i.e.,1.5e+007pa i.e.,15Mpa to find the equivalent (von-misses) stresses and also Total deformation. We observed that in Aluminum alloy the total deformation is 1.0003e-5 m which is lower than the Grey cast iron i.e.,1.0006e-5 m indicating that Aluminum alloy can withstand heavy loads and also for longer life. And also, we observed that for Aluminum alloy the equivalent stresses are 4.0069e7 which is more than the Grey cast iron i.e., 3.9584e7 indicating Aluminum can take more pressure on it causing lessdeformation.

In Thermal analysis we applied same temperature to both the materials i.e., 250 degree centigrade to find out the total heat flux through both the materials. We observed that in Aluminum alloy the total heat flux is 30526 w/m2 which is more compared to the Grey cast iron material i.e., 29929w/m2 indicating that the rate of heat passing through the surface of aluminum alloy is more. So, it can resist more heat from the cylinder and can attain more efficiency and life period.

So, after all the comparisons done to the both materials i.e., Aluminum alloy and Grey cast iron, we can conclude that Aluminum alloy is preferable for cylinder head in terms of safety, efficiency, resistivity and strength.

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XIV. ACKNOWLEDGEMENT

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