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Transient Thermal Analysis of Exhaust Manifold for Multi Cylinder Engine

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Abstract: *Exhaust manifold is an automotive component generally made up of cast iron. It collects combustion gases from multiple cylinders and directs them into the collector exhaust system. Due to complex loading i.e., mechanical load and thermal loading, it becomes necessary to find out stresses in the component. The thermal cycle load includes cold start when the vehicle is starting, at full load and a cooling when engine has stopped. Any circumstance that produces an isothermal loading led to failure of the component. The thermostatic analysis of the structure has been performed on the single runner of the exhaust manifold to check the high temperature strength. In simulation, exhaust gas temperature is implemented for the model as thermal boundary condition and pressure is applied. Stresses and temperature distribution of grey cast iron and stainless steel have compared with each other. The aim of the work is to analyze the performance of the engine exhaust manifold. Because the engine exhaust manifold is a significant factor in the engine performance. In this work the manifold design is prepared with the help of CAD software and it is analyzed by the ANSYS.*

Keywords: Exhaust Manifold, ANSYS, Mechanical Load and Thermal Loading, etc.

I. INTRODUCTION

The mounted exhaust manifolds on top of the cylinder head of the engine collect the gas exhausted from the engine, and sends it to a catalyst converter. The performance of the Engine depends upon the design of the exhaust manifold. Principally, the efficiency of the emission and fuel utilization are strongly related with the exhaust manifold. The rising and falling temperature causes fatigue due to less thermal efficiency of manifold leading to the fracture. A thorough attention has been determined on the low cycle thermal fatigue by accelerated laboratory tests and by FEM or analytical methods for evaluating life performance of the exhaust manifold under a cyclic thermal loading. Designs that do not add to a smooth flow were very typical in early on. The reverse force built up was a large amount greater than before the work done by the redesigned piston at the exhaust stroke.

Huge number of remaining gases stay in the compression chamber and, as a consequence, the temperature increases. Sometimes when working tough the manifold glow red-hot. The materials used like asbestos, a highly heat withstand able fibrous silicate mineral, to guard paintwork. Now, exhaust manifold designs have been distorted totally to get better in comparing with previous configurations, designers have move towards up with altered designs that decrease the flow opposition by using a lot enhanced pipe layout and increasing the average exhaust velocity of the gases, which improve the power output.

The exhaust manifold is very essential component of an engine in the field of automobile mounted on the cylinder of internal consumption engine. The gases coming from the cylinder head at different exhaust strokes are collected with minimum back pressure for smooth exhaust.

The gases coming from one cylinder at a particular stroke need to discharge smoothly before the gases from other strokes. From multiple pipes gases were supplied into a common pipe before entering into the muffler. The performance of an IC engine depends upon the design of the manifold and effective emission of combustion products.

The exhaust gases coming out of the engine cylinder has a temperature in the range of 800°C with pressure range from 100kPa to 500kPa and manifold surface experiences 250°C-300°C temperature.

Therefore, the manifold due to temperature gradients exerts thermal load on the material and causes displacement of the material from the mounted position with the cylinder head. When this thermal load is mapped along with the structural load due to bolt pretension the stresses will be results both on the manifold as well as bolt materials. These stresses should be within the limit for safe design. There it is necessary to do the thermo-mechanical analysis during initial stage of the design

- Thermal analysis of manifold is required to get the nodal temperature as thermal load.
- Mapping of the thermal load against bolt pre tension for thermo-mechanical analysis to obtain deformation and stress.

Exhaust manifold always subjected to intense thermal and mechanical loads. Due to thermal cyclic load, in long run, leads to failure of the component by low cycle thermal fatigue. The exhaust regulations for heavy-duty vehicles are continuously becoming more restricted in order to limit the environmental effects from exhaust gases and particles. By increasing the specific power output of diesel engines, the fuel efficiency is improved and emissions reduced. However, a drawback is that it leads to increased exhaust-gas temperatures putting higher demands on the materials for the exhaust manifolds. The gas temperature is expected to reached as high as 1000 Degree. The influencing factors on exhaust manifold are e.g., Loadings, working temperatures, material characteristics including heat treatment, microstructure, anisotropy and Environmental effects. Thermo- static analysis is considered in the designing many structures such as exhaust manifold. For the simulation, the mechanical and thermal boundary conditions are pressure and temperature respectively applied on both grey cast iron and steel material and compared their stresses and temperature distribution. The exhaust system can mainly be divided into 2 sections based on the working temperature. The hot end [temperature above 600 which starts from the manifold till the catalytic converter, and the cold end [temperatures below 600 which extends from the pre-muffler till the tail pipe. For 4 Stroke SI engine, temperature lies in the range of 400 to 600. Normally, ferrous alloys are used in the manufacturing of exhaust system. These include cast iron.

Problem Definition

It is observed that manifold material requires high strength at high temperature applications. Most commonly used materials are cast iron. The manifold material undergoes thermal fatigue cycle from no load to full load during engine operation. A manifold made of these materials undergoes more deformations and stresses with respect to fixed positions due their more weight under high temperature applications. There is scope of analyzing the manifold under temperature gradient. Mapping of these thermal load in structural analysis to get deformations and d stresses against the bolt pretention. The induced deformations and stresses in aluminum alloy, Stainless steel & titanium alloy manifold are compared with cast iron manifold to check the feasibility of aluminum alloy, Stainless steel & titanium alloy material with cast iron to achieve high strength to weight ratio for the same boundary conditions.

Objectives

- To study the working of exhaust manifold & determine the stress acting on it.
- To analyze the thermo- mechanical behavior of exhaust manifold in Ansys with temperature of 1000 Degree -Celsius to find the stress & thermal distribution in it.
- To compared the structure and thermal behavior of cast iron, stainless steel, aluminum alloy & titanium alloy.

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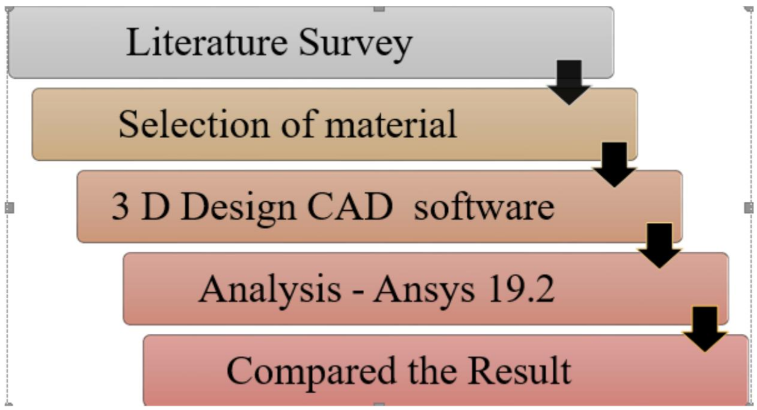
Methodology



II. LITERATURE SURVEY

[1]. Gocmez et al.

Developed a model that Exhaust manifold crack beginning Thermo mechanical Fatigue (TMF) are frequently seen on extremely loaded engines due to rising marketplace difficulty for presentation and emissions. Due to at most gas temperatures that in a quantity of instance are already above 1000°C. A variety of studies are published more than the last few decades concerning the recognition of these critical areas, which comprise taking into account kinematic and isotropic hardening, creep in material modeling and deliberation of plasticity, creep and oxidation in life span modeling. Deger et al. [1]

[2]. Yasar Deger et al.

Have analyzed the fast advance in simulation technology making it possible to model complex geometrical shapes by using CAD and material behavior and load cases to analyze the connected deformations and stresses [2]

[3]. Abhijit Londhe et al.

Have analyzed the fast advance in simulation technology making it possible to model complex geometrical shapes by using CAD and material behavior and load cases to analyze the connected deformations and stresses [3]

[4]. Henrik Ekholm et al.

The research article deals with a new method to deal with an Exhaust manifold failure during physical testing on an engine test bed. Rezaei et al. [4]

[5]. Razeai et al

Has analyzed most of internal combustion engines have multiple heat shields that have been installed on the exhaust manifold to keep away from the heat transfer to upper engine parts, such as the valve cover. In some engines, this part fails due to the fracture and causes engine noise and other failure. In this research the heat shield failure occurs due to engine vibration loads has been analyzed by using experimental and FE technique. The results of the optimized heat shield in this field show two of the primary resonance frequencies of heat shield. [5]

[6]. Bin Zou et al.

Has analysed the contact of temperature significance on exhaust manifold modal analysis is analyzed in his study. First, the temperature field data are taken from the CFD software and then heat transference process is analyzed in FEM software with the boundary conditions of temperature field. The incident among vibration mode and cold and thermal models are classified and the results are predicted. The manifold design is influenced by temp. to a greater extent. [6]

[7]. Mohammad A. S. et al

D5S is the alloy used for exhaust manifold. Fracture toughness was determined by doing structural analysis. Crack failure analyzed by using FEM at the first mode (KI) under thermal mechanical load. According to ASTM standard, 4 compact test (CT) specimen with different notch lengths used for tension test and then simulated in ABAQUS software. The critical fracture toughness (KIC) was gained by using the fracture analysis in simulation then KI and KIC were compared. Finally, using the fracture forces, critical fracture intensity factor was determined. Maximum normal stress occurs on the exhaust manifold confluence, where the exhaust ports join together. The temp. in the internal surface and external surface were 940 and 750, respectively. Mechanical boundary conditions include the preload of exhaust manifold bolts to the cylinder head, exhaust manifold bolts to the turbocharger, turbocharger bolts to the catalyst, and catalyst bolts to its bracket. Preloading the exhaust manifold bolts to the cylinder head is 16.5 kN. Bolt tightening torque is measured by torque meter.

[8]. G M Castro et al.

The left exhaust manifold of Y block engine was used for analysis. The failed component contained two fracture surfaces: the first one was located the fifth runner (Runner Fracture) and the second one was situated in the transversal pipe, between the sixth and seventh runners (Transversal Fracture). The specification of the SAE J431 G1800 grey cast iron was used in the manufacturing of exhaust manifold. The hardness of the exhaust manifold, evaluated on both inner and outer surface of the component. Visual inspection was done on the component. Two different scenarios were taken into consideration for finite element modeling.

First of all, the loads imposed by the normal operation of the engine at the maximum torque speed were estimated using an uncoupled thermal – mechanical simulation, implemented in the Fluent and Mechanical Workbench packages of Ansys 14. Then, several cases of bending loading were assessed to find out if one of these configurations was responsible for the propagation of the transversal fracture. The failure of the exhaust manifold was produced by two different situations. On one hand, the runner fracture was caused by thermal fatigue, which formed a crack that grew during many years of operation, until the load bearing capacity of the component was exceeded. On the other hand, the transversal fracture was caused by a bending load imposed when the exhaust manifold was improperly fixed to the cylinder head.

[9]. Simone Sissa et al.

This paper focused on the estimating the low-cycle and high-cycle fatigue life of a turbocharged diesel engine exhaust manifold. Vibrational loading was applied to the exhaust manifold in order to do dynamic harmonic analysis. 1D CFD simulation of combustion process has been applied to the engine head. The thermos – mechanical quasi static finite element model was prepared. The paper proposed the numerical method for low and high cycle fatigue life. Several areas in which plasticity occurred they have detected and related with low cycle fatigue life. Results have shown that vibrational effect cannot be neglected.

[10]. Hyun and Kim et al.

Put two CT specimens under 2394 N and 1960 N load and measured crack elongation based on time. Specimens were built according to the ASTM standard.

[11]. R.M. Hazim et al.

Developed a transient nonlinear FEA to simulate inelastic deformation, and estimate the thermo-mechanical fatigue life of cast iron and cast steel exhaust manifolds under Dynamo meter test condition. Transient heat transfer FE analysis was applied to simulate the thermal loads on the exhaust manifold. The results showed that the creep deformation is the most effective factor on the inelastic deformation for cast iron manifold ratcheting, gasket sealing, and crack initiation. The predicted transient temperature field and manifold deformation of the FEA model were in good agreement with two experimental tests. Further, the model could predict the crack initiation site in all cases.

[12]. Simulia-Dassault et al.

Presented a CT simulation analysis as a sample which can be an appropriate example in crack failure FE simulation. In their work, a displacement was exerted to the specimen and based on this displacement the J-integral was calculated in ABAQUS software and was compared with the ASTM standard results. In addition, ABAQU Scalability and accuracy in fracture analysis were evaluated in this study.

[13]. Wen and Yue et al.

Prepared a CT specimen for investigating Nickel based super alloyed fracture behavior and crack propagation path. They concluded that crack propagation path is completely dependent on the type of material seed formation at the low temperature (lower than 100 °C). However, at a higher temperature, they are not related to each other. The kind of material seeds and temperature are two impressive factors playing a role in crack initiation and propagation. They plotted the fracture intensity factor diagrams at 760□, 850□, and 950□ based on the amount of crack tip opening displacement and stress diagrams based on the tension force.

[14]. Kendal and Ceylon Kublai et al

Studied the microstructural change and crack formation mechanism on exhaust manifolds manufactured by using Si Mo ductile iron. The microstructure of these cast irons Consists of carbides dispersed within the ferrite matrix. Chemical analyses, as well as optical and scanning electron microscope Studies were conducted in this study. They concluded that solidification and cooling conditions play a significant role in the microstructure of cast irons. The M1 manifold with 0.5% Mo and 4% Si failed during the 200-hours exhaust manifold crack test.

[15]. C. Delprete et al

Due to complexity in exhaust manifold geometry, stresses and strains field became multi-axial and worsening the fatigue resistance. Several damage models were applied and compared. A complete thermos – structural FE analysis has been run and results were post processed by numerical code. Solid works CAD software was used for building component model. In the structural analysis also, the friction contact between bolts, manifold, gasket and cylinder head has been taken into account. Contact between bolts, manifold, gasket and cylinder head has been taken into account.

III. DESIGN AND ANALYSIS

CAD:

In the project we are creating 3D CAD Model Drawn in the SOLID WORKS software show in the figure 1.

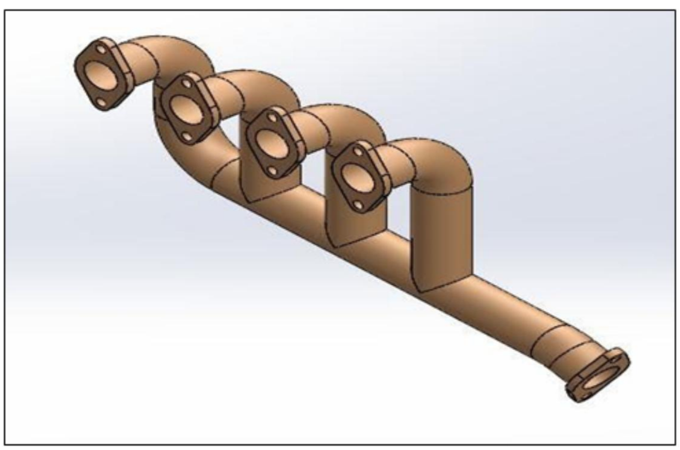


Figure 2: Exhaust Manifold Model in Solid works

The figure 1 show that 3D CAD model of pipe after completing the 3D model we moved for the drafting of the component. Computer-aided design (CAD) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. Its use in designing electronic systems is known as electronic design automation (EDA).

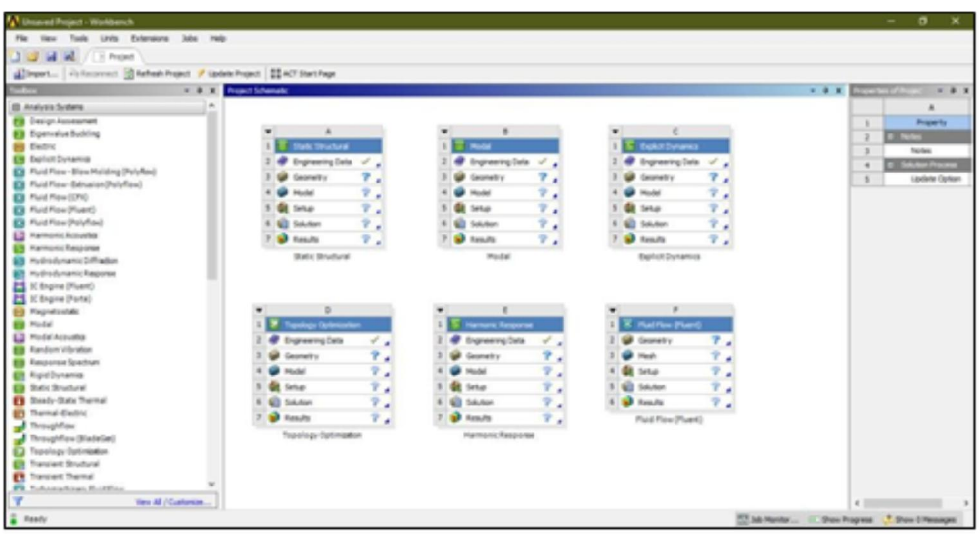
In mechanical design it is known as mechanical design automation (MDA) or computer-aided drafting (CAD), which includes the process of creating a with the use of computer software. CAD software for mechanical design uses either vector-based graphics to depict the objects of traditional drafting, or may also produce graphics showing the overall appearance of designed objects.
However, manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions. CAD may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in three-dimensional (3D) space. CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding and aerospace industry industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals, often called DCC digital content creation.
The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, CAD has been a major driving force for research in computational geometry, computer graphics (both hardware and software), and discrete differential geometry. The design of geometric models for object shapes, in particular, is occasionally called computer-aided geometric design (CAGD)

FEA (Finite Element Analysis):

- A set of algebraic equations for steady state problems.
- A set of ordinary differential equations for transient problems.

In present research for analysis ANSYS (Analysis System) software is used. Basically, its present FEM method to solve any problem. Following are steps in detail

1 Geometry
2 Discretization (Meshing)
3 Boundary condition
4 Solve (Solution)
5 Interpretation of result



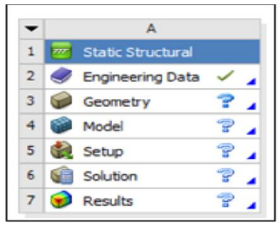


Figure 3: Ansys Work flow

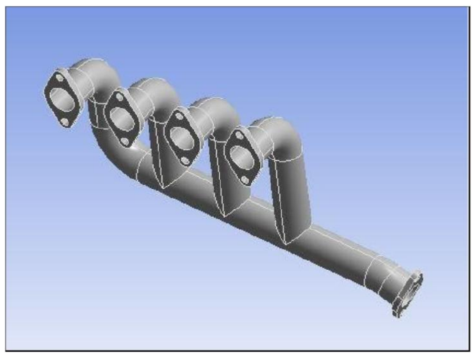


Figure 4: Geometry of Pipe imported in ANSYS

Properties of Outline Row 3: Gray Cast Iron

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7200	kg m^-3		
4	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
7	Derive from	Young's Modulus...			
8	Young's Modulus	1.1E+11	Pa		
9	Poisson's Ratio	0.28			
10	Bulk Modulus	8.3333E+10	Pa		
11	Shear Modulus	4.2969E+10	Pa		
12	Tensile Yield Strength	0	Pa		
13	Compressive Yield Strength	0	Pa		
14	Tensile Ultimate Strength	2.4E+08	Pa		
15	Compressive Ultimate Strength	8.2E+08	Pa		
16	Isotropic Thermal Conductivity	52	W m^-1 C^-1		
17	Specific Heat, C_p	447	J kg^-1 C^-1		

Figure 5: Details of Grey Cast Iron material

MESH:

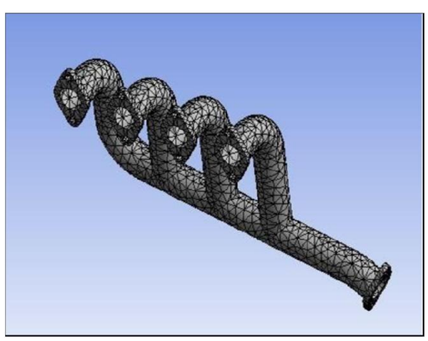


Figure 6: Meshing

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Statistics	
Nodes	17961
Elements	8829

Figure 7: Meshing Details of stainless-steel material

Boundary Condition:

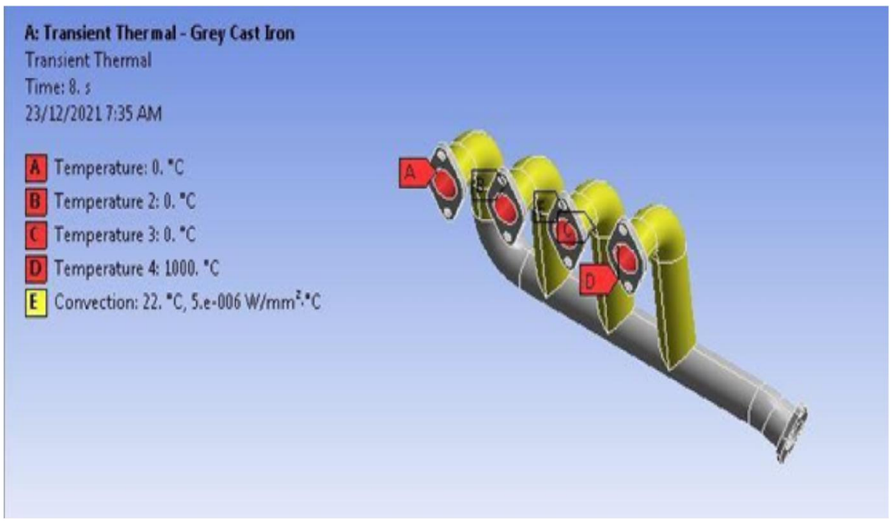

Figure 8: Boundary condition – Temperature

	Steps	Time [s]	Temperature [°C]
1	1	0.	22.
2	1	1.	1000.
3	1	2.	1000.
4	1	3.	0.
5	1	8.	0.

	Steps	Time [s]	Temperature [°C]
1	1	0.	= 22.
2	1	1.	22.
3	1	2.	22.
4	1	3.	1000.
5	1	4.	1000.
6	1	8.	0.

	Steps	Time [s]	Temperature [°C]
1	1	0.	= 22.
2	1	1.	22.
3	1	2.	22.
4	1	3.	22.
5	1	4.	22.
6	1	5.	1000.
7	1	6.	1000.
8	1	8.	0.

	Steps	Time [s]	Temperature [°
2	1	1.	22.
3	1	2.	22.
4	1	3.	22.
5	1	4.	22.
6	1	5.	22.
7	1	6.	22.
8	1	7.	1000.
9	1	8.	1000.

Figure 9: Details of Boundary condition

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IV. FEA RESULT OF GREY CAST IRON – THERMAL PARAMETERS

Temperature:

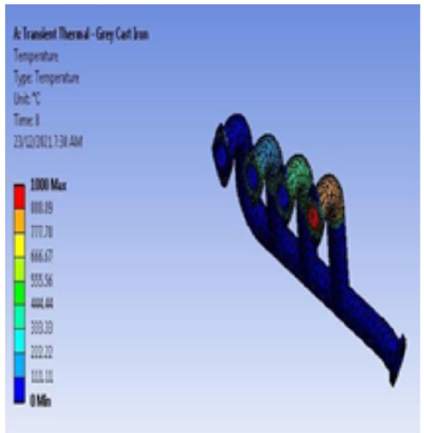

Figure 10: Details of Temperature for Grey Cast Iron

Total Heat Flux:

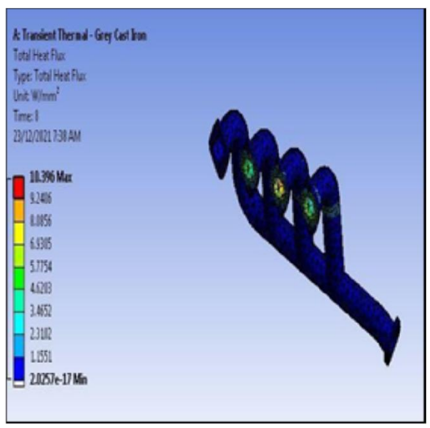

Figure 11: Details of Total Heat Flux for Grey Cast Iron

FEA Result of Grey Cast Iron – Static Structure Parameters

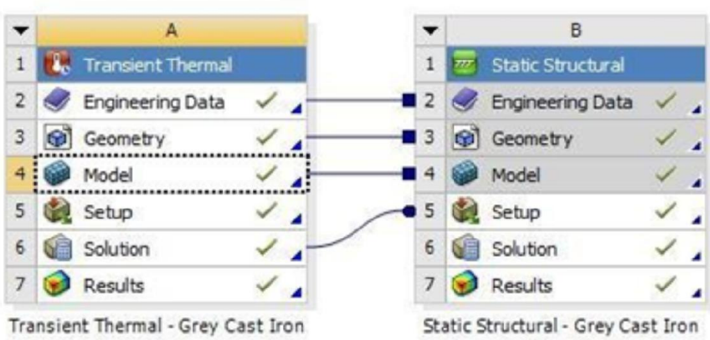

Figure 12: Data transfer from thermal to static structure analysis

Deformation

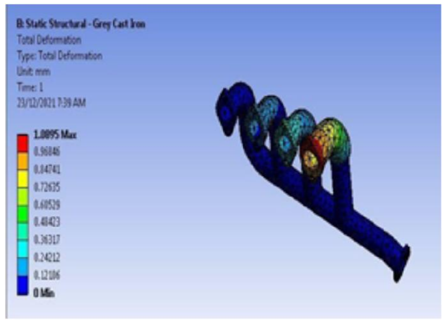

Figure 13: Deformation for Grey cast Iron

Stress

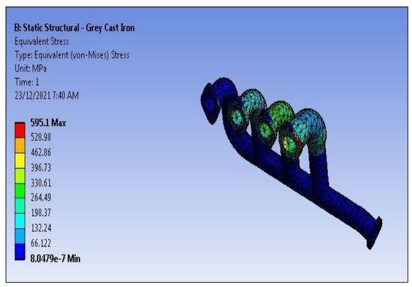

Figure 14: Stress for Grey cast Iron

Strain

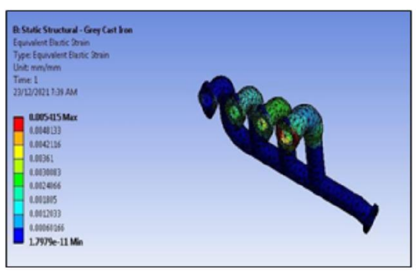

Figure 15: Strain for Grey cast Iron

FEA Result of Aluminum Alloy

Temperature

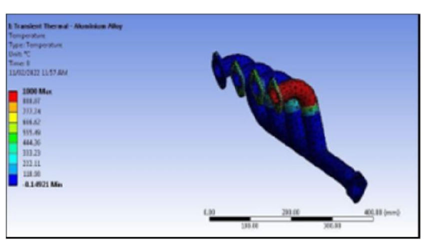

Figure 16: Temperature for Al Alloy

Temperature Distribution of Aluminium Alloy with the max temperature 1000 degree Celsius which we are applying in our Boundary condition.

Total Heat Flux

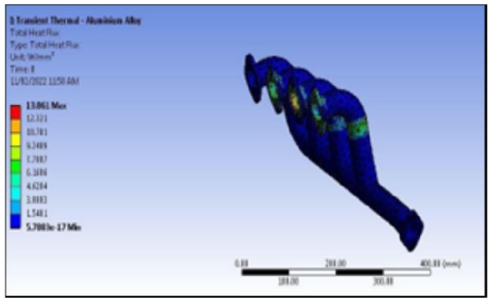

Figure 17: Heat Flux for Al Alloy

In the boundary condition of the manifold, we can apply the 1000degree Celsius due to this temperature the total heat flux is 13.86 W/mm^2.

Deformation

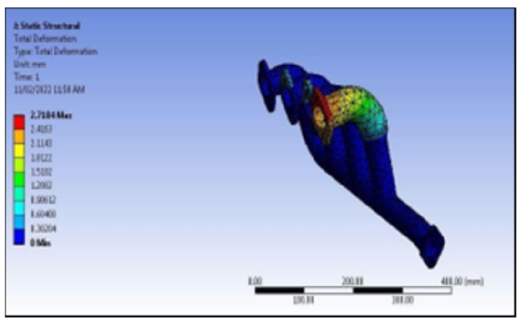

Figure 18: Deformation for Al Alloy

Temperature Distribution of Al Alloy with the max temperature 1000 degree Celsius which we are applying in our Boundary condition total max deformation is 2.71 mm.

Stress

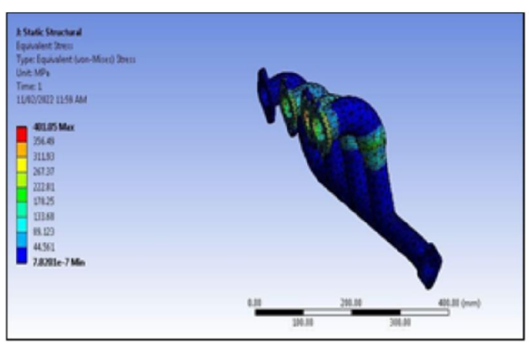

Figure 19: Strain for Al Alloy

In the boundary condition of the Al alloy, we can apply 1000 Degree/Celsius due to which stress generate is 401.05 Mpa

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Strain

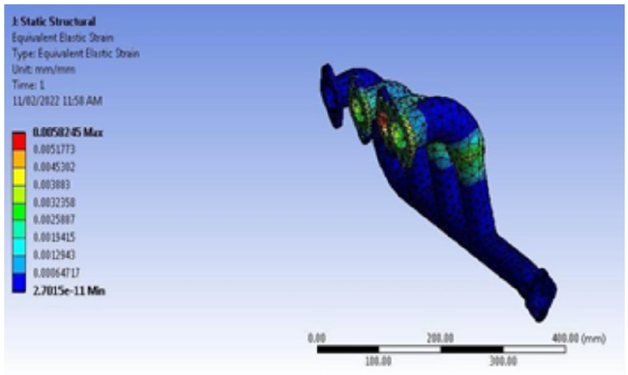

Figure 20: Strain for Al Alloy

In the boundary condition of the Al alloy, we can apply 1000 Degree /Celsius due to which strain value is 0.0058 mm

FEA Result of Stainless Steel

Temperature

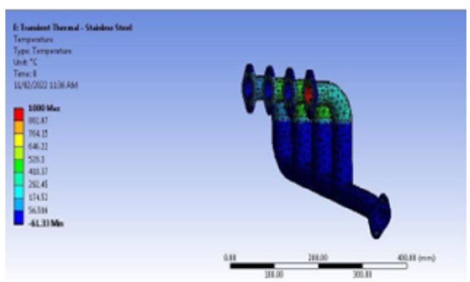

Figure 21: Temperature for Stainless Steel

Temperature Distribution of Stainless Steel with the max temperature 1000 degree Celsius which we are applying in our Boundary condition

Total Heat Flux

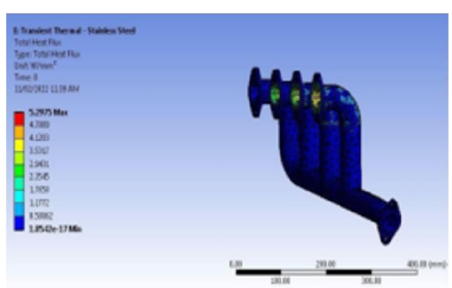

Figure 22: Heat Flux for Stainless Steel

In the boundary condition of the manifold, we can apply the 1000degree Celsius due to this temperature the total heat flux is 5.29 W/mm^2.

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Deformation

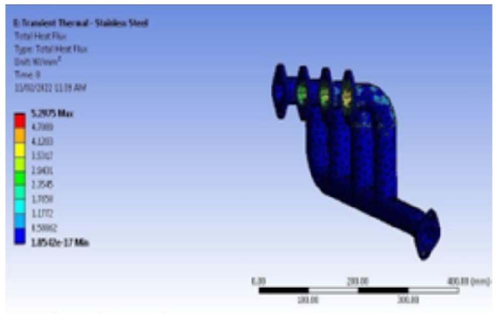

Figure 23: Deformation for Stainless Steel

Temperature Distribution of Stainless Steel with the max temperature 1000 degree Celsius which we are applying in our Boundary condition total max deformation is 0.970 mm.

Stress

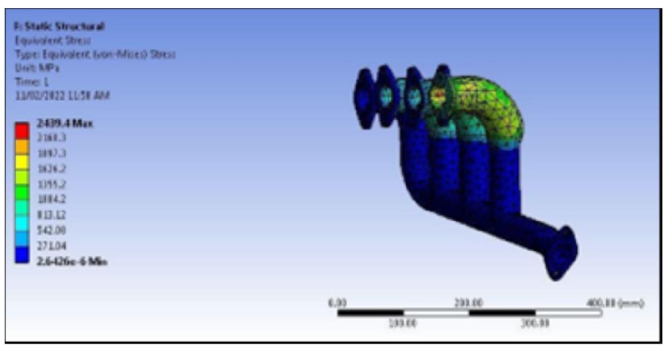

Figure 24: Stress for Stainless Steel

In the boundary condition of the Al alloy, we can apply 1000 Degree/Celsius due to which stress generate is 2439.4 Mpa.

Strain

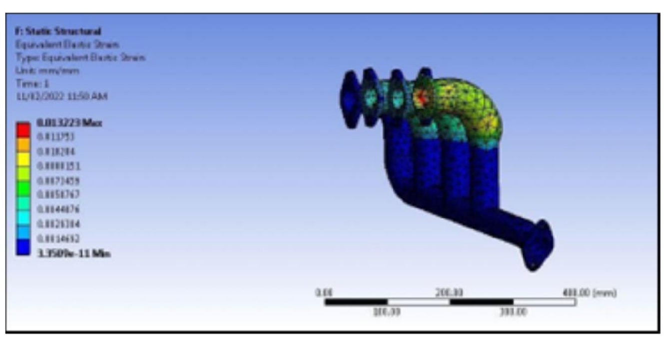

Figure 25: Strain for Stainless Steel

In the boundary condition of the Stainless Steel we can apply 1000 Degree /Celsius due to which strain value is 0.013 mm.

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FEA Result of Structure Steel

Temperature

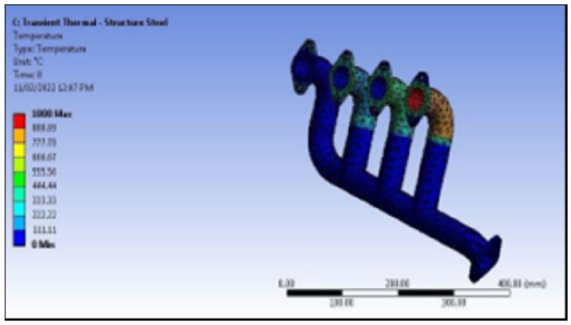

Figure 26: Temperature for Structure Steel

Temperature Distribution of Structure Steel with the max temperature 1000 degree Celsius which we are applying in our Boundary condition

Total Heat Flux

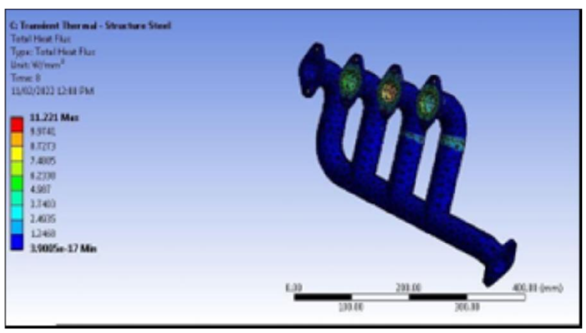

Figure 27: Heat Flux for Structure Steel

In the boundary condition of the manifold, we can apply the 1000degree Celsius due to this temperature the total heat flux is 11.22 W/mm^2.

Deformation

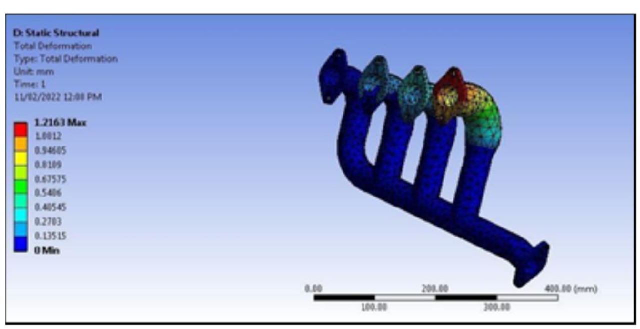

Figure 28: Deformation for Structure Steel

Temperature Distribution of Structure Steel with the max temperature 1000 degree Celsius which we are applying in our Boundary condition total max deformation is 1.21 mm.

Stress

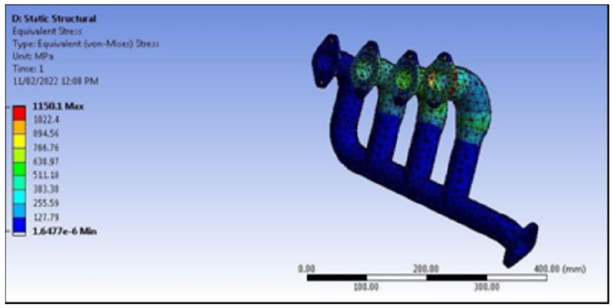

Figure 29: Stress for Structure Steel

In the boundary condition of the Structure Steelwe can applied 1000 Degree/Celsius due to which stress generate is 1150.1 Mpa.

Strain

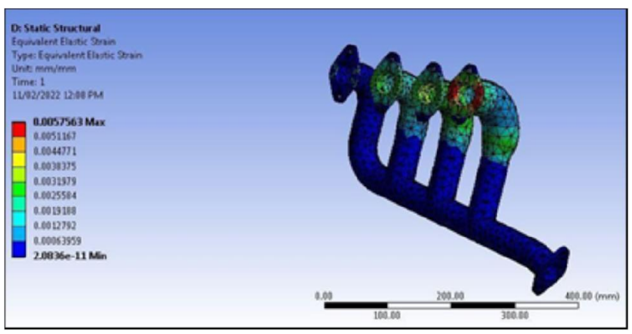

Figure 30: Strain for Structure Steel

In the boundary condition of the Structure Steel, we can apply 1000 Degree /Celsius due to which strain value is 0.0057 mm.

FEA Result of Titanium Alloy

Temperature

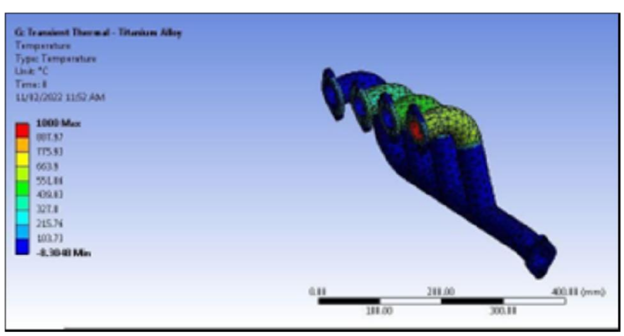

Figure 31: Temperature for Ti Alloy

Temperature Distribution of Ti Alloy with the max temperature 1000 degree Celsius which we are applying in our Boundary condition.

Total Heat Flux

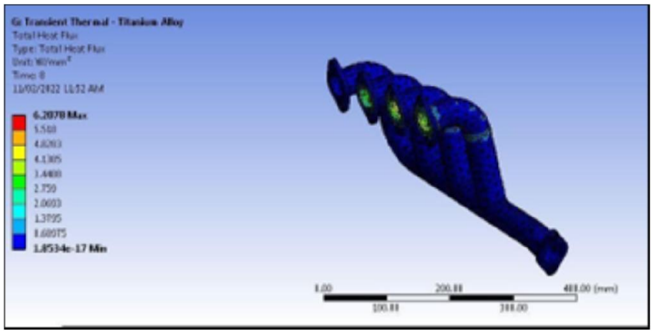

Figure 32: Heat Flux for Ti Alloy

In the boundary condition of the manifold, we can apply the 1000degree Celsius due to this temperature the total heat flux is 6.20 W/mm^2.

Deformation

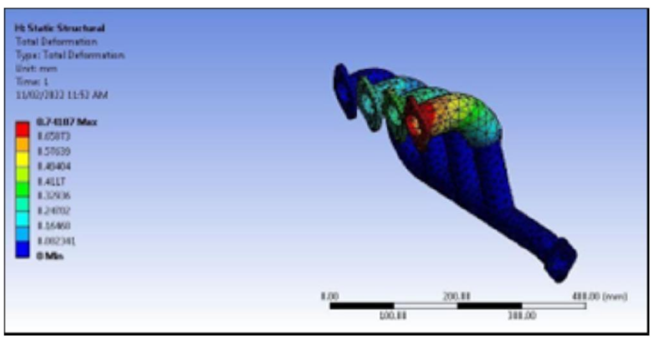

Figure 33: Deformation for Ti Alloy

Temperature Distribution of Ti Alloy with the max temperature 1000 degree Celsius which we are applying in our Boundary condition total max deformation is 0.74 mm.

Stress

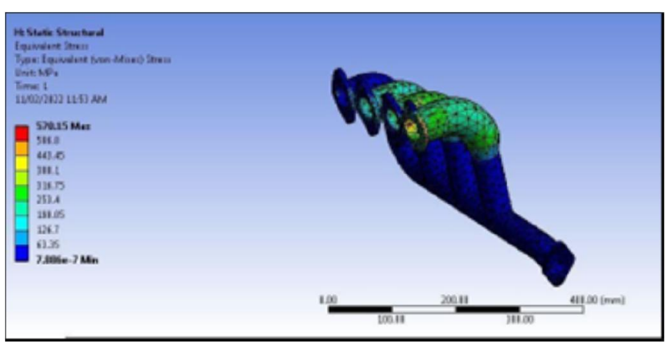

Figure 34: Stress for Ti Alloy

In the boundary condition of the Ti Alloy, we can apply 1000 Degree/Celsius due to which stress generate is 570.15 Mpa.

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Volume 2, Issue 8, June 2022

Strain

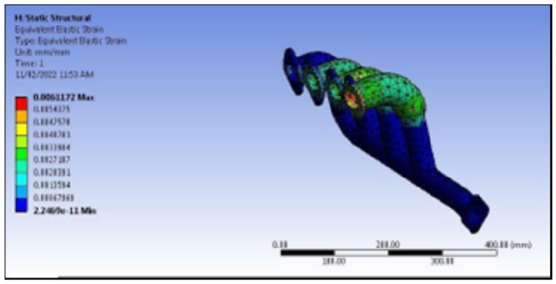
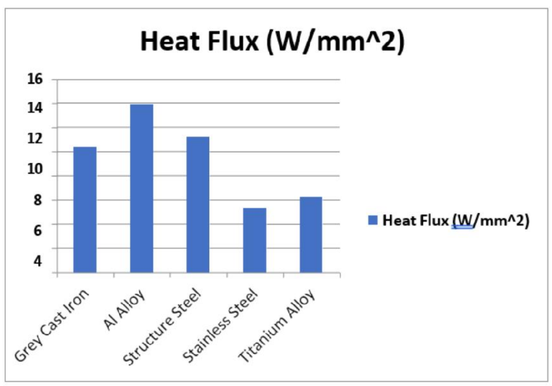


Figure 35: Strain for Ti Alloy

In the boundary condition of the Ti Alloy, we can apply 1000 Degree /Celsius due to which strain value is 0.006 mm,

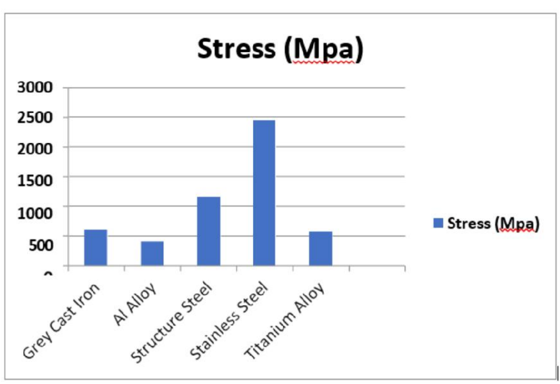
V. RESULT & DISCUSSION:

In the research we are considered different material in manifold and find out the result with stress, strain, displacement & Total heat flux.



Graph.1: Total heat flux Comparison

In the total heat flux comparison, we can see that the maximum heat flux occurred in Aluminum Alloy material and minimum heat flux occurred in stainless steel.



Graph.2: Stress Comparison

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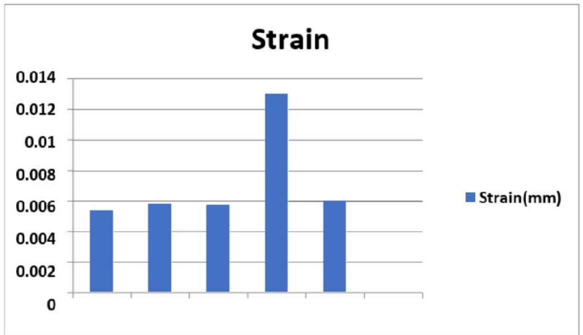
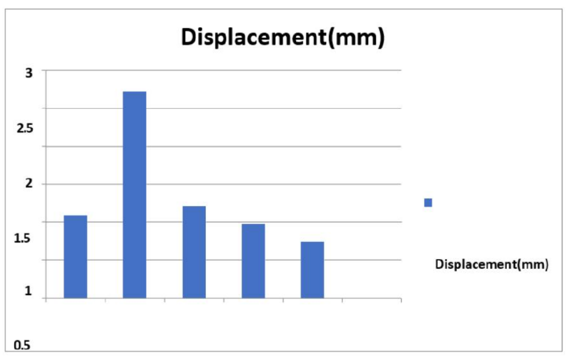
In the stress comparison we can see that the maximum stress generates in Stainless Steel material and minimum stress generate in aluminum Alloy.



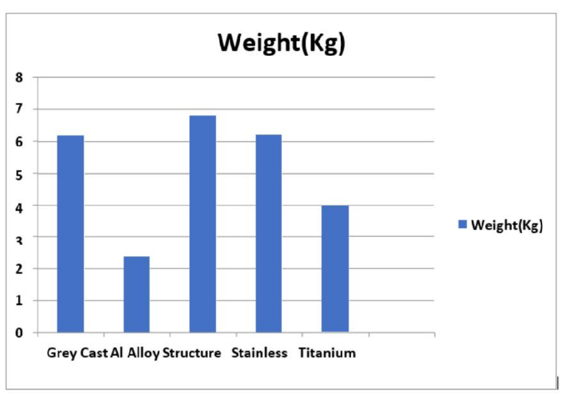
Graph.3: Strain Comparison

In the strain comparison we can see that the maximum strain generates in Stainless Steel material and minimum strain generate in grey cast Iron.



Graph.4: Displacement Comparison

In the Displacement comparison we can see that the maximum Displacement generate in Aluminum Ally material and minimum Displacement generate in Titanium alloy.



Graph.5: Displacement Comparison

In the Weight comparison we can see that the maximum weight Structure steel material and minimum weight in Aluminum alloy.

VI. CONCLUSION

1. In present investigation with boundary condition applied to the existing material to determine stress, strain energy Displacement, total temperature distribution & Total heat flux.
2. With the Reference of FEA Result we are concluded that titanium alloy shows the better result than grey cast iron which is our existing material.
3. The amount of weight reduced by titanium alloy is 21% compared to the existing material also in thermal consideration heat flux reduced 25% compared to the existing material.
4. In structure parameter also titanium alloy deformed 20% less deformed compared to the existing material.
5. Hence, we have successfully completed the project by achieving the all objective.

Future Scope

1. This model could further be improved to a certain extent to make it a complete solution for any other modification such as a peak pressure. This improvement that could be made to this model and tested. This model can be analyzed by computational analysis of this modification.
2. Analysis of various parameters such as pressure, temperature, Velocity.
3. Analysis of new modified design.
4. Applying some other modification.

From those analyses, the exhaust manifold was thoroughly analyzed and peak pressure and back pressure effects were minimized

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