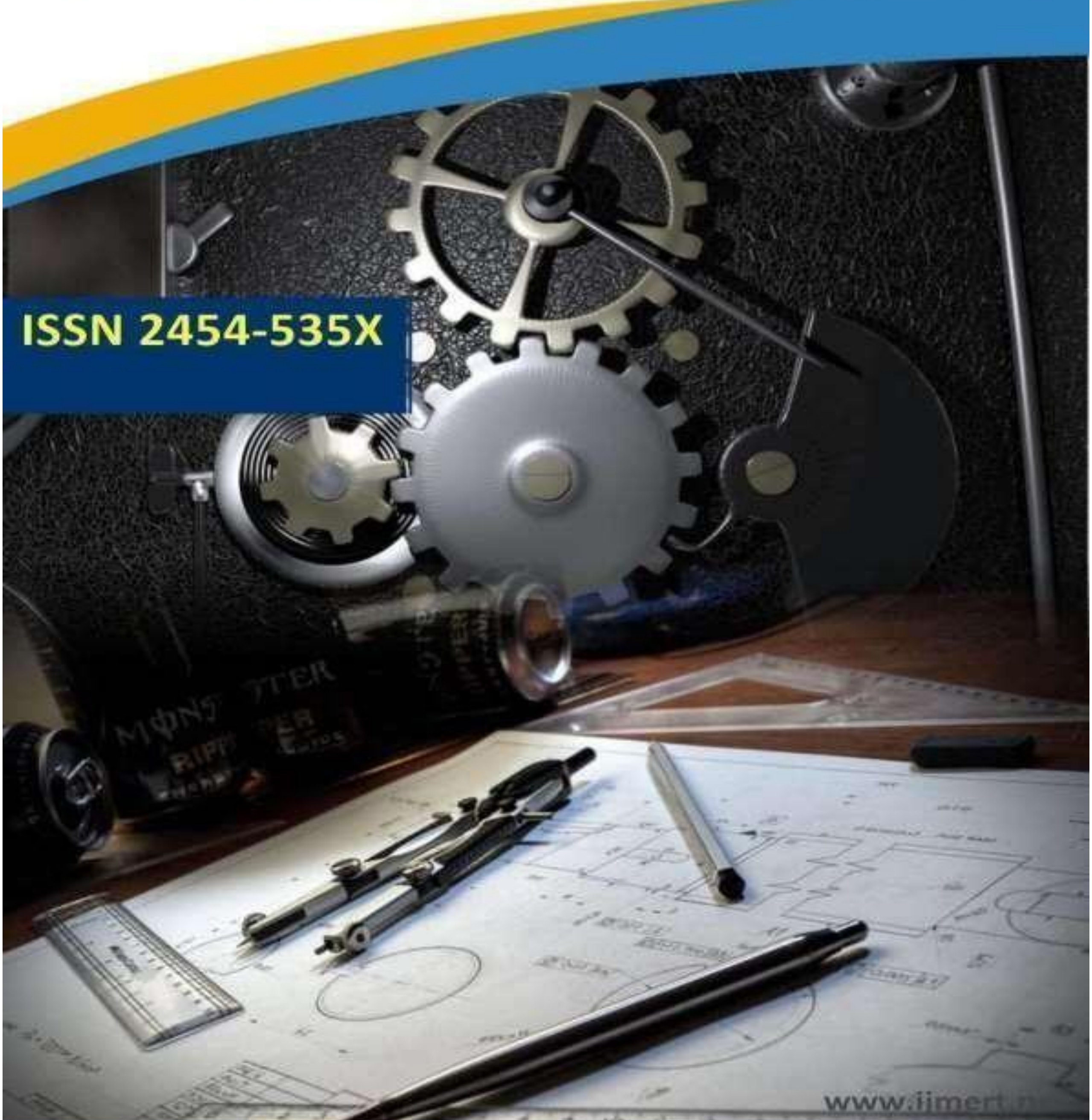
International Journal of
Mechanical Engineering Research and Technology

ISSN 2454-535X



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ISSN 2454 – 535X
http://www.ijmert.com
Vol.16 Issue 2, 2024

DESIGN AND ANALYSIS OF EXHAUST MANIFOLD OF MULTI-CYLINDER SI ENGINE USING FINITE ELEMENT METHOD

Mr.M.Srinivasa Rao H.O.D & Associate Professor, Department Of MECH, SICET ,Hyderabad
Padakanty Durgaprasad, Janapareddy Durga Vara Prasad, Shaik Enayath Ansari, Vulepe Mohan Chandra
Department Of MECH, SICET, Hyderabad

Abstract:

Manifold is one in every of the important elements of IC engines for improving the volumetrically efficiency. In burning engine, volumetrically efficiency is one in every of the factor in crucial how much quantity of power output will generate as compared to its capability. The volumetrically efficiency of the engine is magnified by reducing the back pressure within the manifold. In this paper, an existing model of an engine Exhaust manifold is modeled in 3D modeling software. The design of the exhaust manifold is changed. In existing model the bend radius of 48mm and exhaust is at the centre of the header, the models are modeled in CATIA. Thermal analysis is done for both the models using different materials copper, manganese, nickel and stainless steel. After thermal analysis CFD analysis is done for both models at different mass flow rates. Hence, it is concluded manifold model is better.

INTRODUCTION:

The exhaust manifold of a vehicle motor is constantly presented to hot gasses. Cast iron has been being used for the generation of exhaust systems generally. The fundamental qualities required for the exhaust manifold material incorporate warm weariness quality required to withstand the high temperature deplete gasses, oxidation resistance, great manufacture properties and low warm ability to upgrade the reactant work. Ferrite stainless steel displays every one of these properties and offers huge weight lessening too.

The advancements in vacuum throwing process has helped in the manufacture of stainless steel complex with segment thickness of 2-5mm. Higher requests in contamination control will rise the fumes temperatures as well and in this manner, ferrite stainless steel will be in real use for fumes framework producing. Ferrite stainless steel displays enhances warm weariness attributes when prepared by strong arrangement reinforcing with molybdenum or niobium. This procedure likewise enhances the oxidation resistance and micro structural security. Ferrite stainless steel additionally has fetched points of interest due to the nonattendance of nickel in its creation. Another variation called the austenite stainless steel is utilized where ferrite stainless steel is unacceptable. Austenite stainless steel can improve its properties when enough carbon is added to it.

EXHAUST MANIFOLD DESIGN CONSIDERATIONS AND CRITERIONS

Present day engines are required to have more engine power and are also required to meet the strict pollution standards. To improve exhaust system performance, many design specifications are required. The Exhaust Manifold of an automobile engine is always exposed to hot gases. The main characteristics required for the exhaust manifold material include thermal fatigue strength required to withstand the high temperature exhaust gases, oxidation resistance, good fabrication properties and low thermal capacity to enhance the catalytic function.

ISSN 2454 – 535X
http://www.ijmert.com
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Proper material section for components exposed to elevated temperature service is complex. Although operating temperature and peak skin temperatures are the major factors limiting materials that can be used, many other variables contribute to the proper selection. In addition to operating working temperatures, mechanical and thermal loading conditions in the component's working environment are also considered.

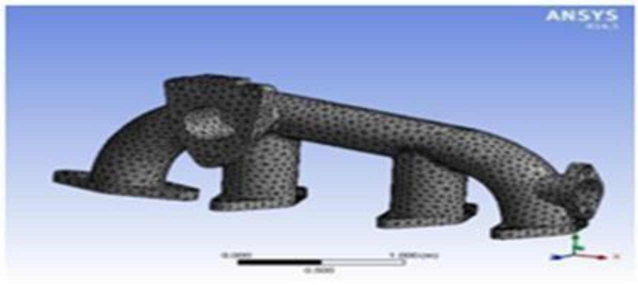
Figure 1: Top view of the exhaust manifold

Methodology:

The Dimensions and Exhaust temperature are noted using experimental studies on the manifold. The geometric model of exhaust manifold created using Creo Parametric 2.0 is saved with STEP (.stp) format so that it can be imported and accessed in ANSYS Workbench 14.5. Steady State Static Structural and Transient Thermal Module are coupled. Fine Mesh model is created using Model wizard. Materials are assigned using the Engineering Data Wizard. Structural forces and exhaust thermal conditions are applied in the set up wizard. Results of the analysis are obtained in the form of Total Deformation, Equivalent (von-Mises) Stress and Temperature Distribution, Maximum Deflection and Stresses are obtained for the results. Reports are generated for three different materials and these results are analyzed.

FINITE ELEMENT ANALYSIS CONSIDERATIONS

The Finite Element Analysis (FEA) is a numerical analysis technique for finding approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into simpler parts, called finite elements, and various methods from the calculus of variations to analyze and solve the problem by minimizing an associated error function. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEA encompasses methods for analyzing many simple element equations over many small sub domains, named finite elements, to approximate a more complex equation over a larger domain.



Mesh is a very important step required for FEA of Exhaust manifold, an optimized mesh has been developed using Model wizard in ANSYS Workbench 14.5, a proper setting have been executed in order to use smaller element on proximities and curvature for the model. The number of tetrahedral elements used for the exhaust manifold mesh model is 12509 while the number of nodes is 25077.

THERMAL ANALYSIS

Thermal analysis calculates the temperature distribution; amount of heat gained or lost, thermal gradients and thermal fluxes.

TYPES OF THERMAL ANALYSIS

Steady-state thermal analysis is done to determine the temperature distribution and other thermal quantities. The loading conditions are steady-state, wherein the temperature changes over time period is not considered. Transient thermal analysis is done to determine the temperature distribution and other thermal quantities under conditions that vary over a period of time.

COUPLE FIELD ANALYSIS:

Coupled field analysis is done for thermal-structural, wherein the result values obtained of one analysis is used for doing another analysis. The entire model will have single set of nodes.

International Journal of Mechanical Engineering Research and Technology
ISSN 2454 – 535X
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The geometry created for the first analysis is used for the coupled analysis also. The geometry is kept constant throughout. Create the geometry in the Thermal Environment, where the thermal effects will be applied. The geometry must remain constant, but the element types can change. Thermal elements are required for a thermal analysis while structural elements are required to determine the stress in the structure. A coupled-field analysis can use matrix-coupled ANSYS elements, or sequential load-vector coupling between separate simulations of each phenomenon.

DYNAMIC ANALYSIS:

Exhaust manifold is analyzed for dynamic loading conditions. To check the structure response for resonance condition, modal analysis is performed on exhaust manifold. The natural frequencies occurring in the operating range is calculated.

MODAL ANALYSIS:

The vibration characteristics such as natural frequencies and mode shapes in the frequency range are found out from Modal analysis. The output serves as a starting point for doing further dynamic analysis such as transient dynamic analysis, harmonic response analysis, etc.

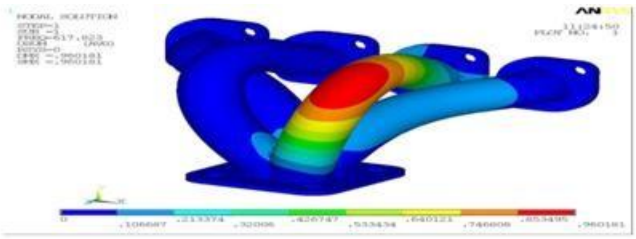
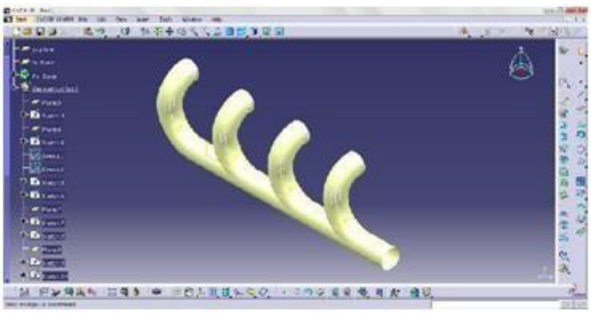
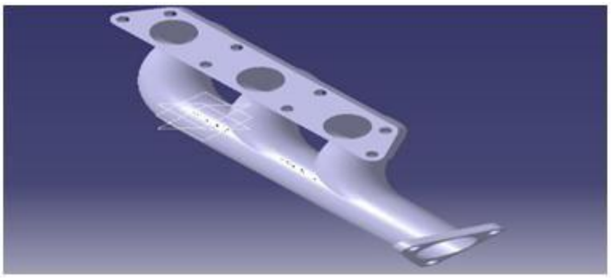


Figure 2: Mode shape for exhaust manifold





Purpose

The Purpose of CFD Lab 2 is to simulate turbulent airfoil flows following "CFD process" by an interactive step-by-step approach and conduct verifications using CFD Educational Interface (FlowLab 1.2). Students will have "hands-on" experiences using FlowLab to conduct verification and validation for lift coefficient and pressure coefficient distributions, including effect of numerical scheme. Students will manually generate the "O" type and "C" type meshes and investigate the effect of domain size and effect of angle of attack on simulation results. Comparisons between inviscid and viscous flows will also be conducted. Students will analyze the differences between CFD and EFD, analyze possible source of errors, and present results in the CFD Lab report.

Table 2 shows the densities and viscosities of air, water and honey.

Substance	Air (18°C)	Water (20°C)	Honey (20°C)
Density (kg/m^3)	1.275	1000	1446
Viscosity (P)	1.82e-4	1.002e-2	190

Boundary Conditions:

To solve the equation system, we also need boundary conditions. The typical boundary conditions in CFD are No-slip boundary condition, Axisymmetric boundary condition, Inlet, outlet boundary condition and Periodic boundary condition. For example, fig is a pipe, the fluid flows from left to right. We can use inlet at left side, which means we can set the velocity manually.

At the right side, we use outlet boundary condition to

International Journal of Mechanical Engineering Research and Technology
ISSN 2454 – 535X
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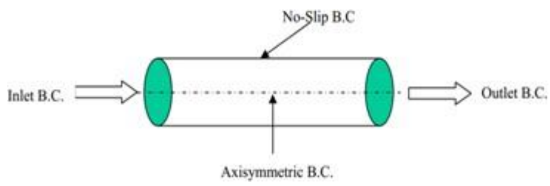
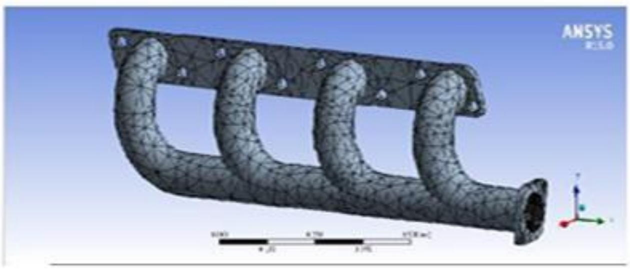
keep all the properties constant, which means all the gradients are zero. At the wall of pipe, we can set the velocity to zero. This is no-slip boundary condition. At the center of pipe, we can use axisymmetric boundary condition.



Boundary Conditions of Pipe Flow: ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behavior of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

Input Model Of Exhaust Manifold



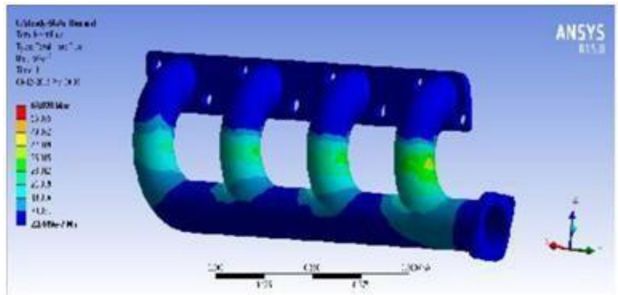


Figure 3: Outer plots of Total Heat Flux

Thermal Analysis of Exhaust Manifold Made Of Cast Iron Coated With Zinc Oxide

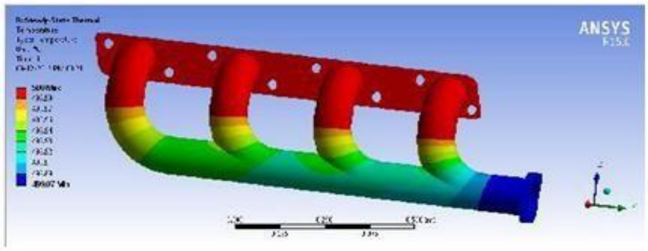


Figure 4: Counterplots of Temperature Distribution

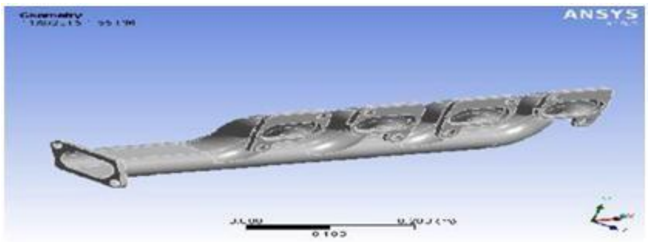
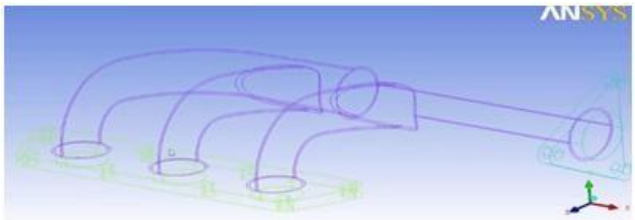


Figure 5: Thermal Analysis of Exhaust Manifold Using Zinc Oxide

CFD ANALYSIS OF EXHAUST MANIFOLD

Imported manifold to CFD module



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ISSN 2454 – 535X
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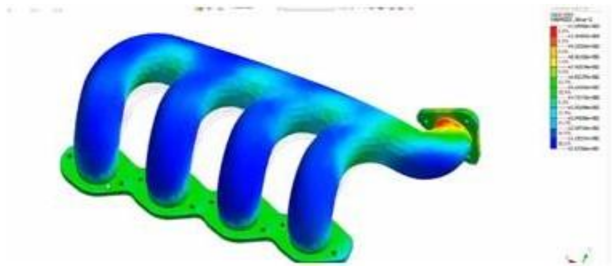
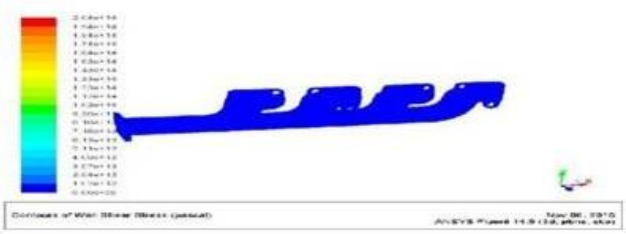


Temperature

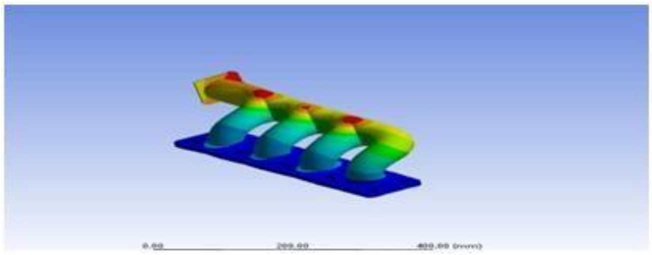


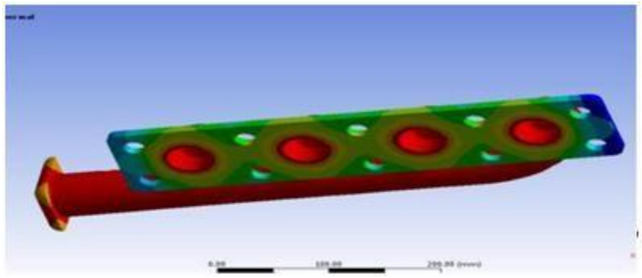
FINITE ELEMENT ANALYSIS (FEA)

The major thought in FEA is that the body or structure might be isolated into more diminutive segments of limited estimations called "Limited Elements". The first body or the structure is then considered as a variety of these parts related at a set number of joints called "center points". Clear limits are approximated the evacuations over every constrained segment. Such acknowledged limits are called "shape limits". This will imply the development inside the segments similar to the movement at the centers of the segments. The Finite Element technique is a logical device for settling customary and incomplete differential correlation in light of the reality it is a numerical device, it can deal with the unpredictable issue that can be meant in differential scientific proclamation from. The utilization of FEM is boundless as regards the course of action of rational plan issues. In light of high cost of handling force of years cruised by, FEM has a background marked by being used to deal with complex and cost basic troubles.

Ansys Result for Structural Steel

Total deformation and Equivalent stress





Structural analysis Result

S. No	Material	Structural steel	Gray cast iron
1	Total deformation	0.0010116mm	0.0018464mm
2	Equivalent stress	1.8301e-5Mpa	3.5933Mpa

Thermal analysis result

S.No	Material	Structural steel	Gray cast iron
1	Temperature distribution	800.01°c	800.01°c
2	Heat flux	0.026119W/mm2	0.026079W/mm2

Boundary Conditions

Thermal Analysis

1. Ambient Temperature: 40 degrees
2. Inside of the pipes: 1073 K
3. Operating Temperature: 900 degrees.
4. Convection on External surface.
5. Film Coefficient: 0.422 J/Kg-K

Structural Analysis

1. Bolts arrested in all Dof (Fixed).
2. Exhaust Gas Pressure Range – 100 to 500 KPa
3. Temperature distribution applied as thermal loads.

Normal Force:

100N (Point force of outer surfaces of the Manifold).

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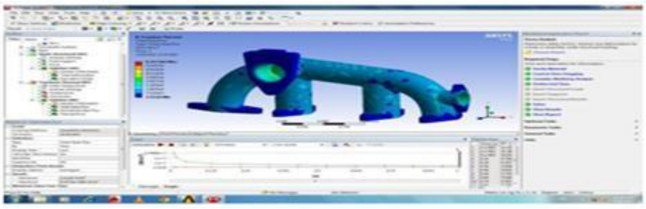
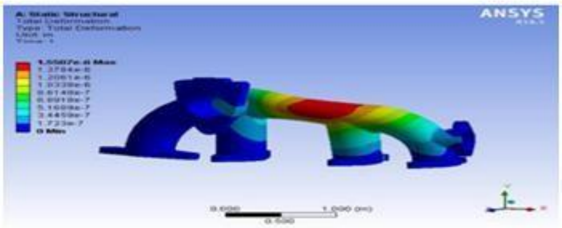
Results obtained after analysis equated in the form of following parameters are

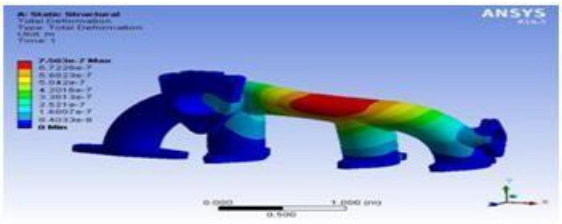
1. Total Deformation
2. Total Heat Flux
3. Equivalent (von-Mises) Stress



Mechanical Module



Total Deformation of Manganese



Comparison

Parameters	Manganese	Stainless Steel	Copper
Total Deformation	1.5507e-006 m	7.563e-007 m	1.0073e-006 m
Total Heat Flux	7.8333e+006 W/m²	6.3174e+006 W/m²	1.3067e+005 W/m²
Equivalent (von-Mises) Stress	1.2081e+005 Pa	1.1901e+005 Pa	1.1728e+005 Pa
Manifold Weight	15.43 Kg	17.34 Kg	8.87 Kg

From the above investigated result of Coupled Thermal - Structural FE analysis, we observed that the critical area of thermal stress concentration and deformation on all three the materials are similar.

The Results shows that all studied material, Grey Cast Iron, Ferritic Stainless Steel and Titanium Alloy are appropriate for the investigated Exhaust Manifold TATA Safari Dicor 2.2L vehicle diesel engine. Of the three materials, Titanium Alloy shows better results than the other two and also its light weight can reduces the overall weight of the vehicle and thus raises the efficiency. Cost of Titanium Alloy is high as compared to currently used Grey Cast Iron but future developments will surly solve this problem.

CONCLUSION:

In this study we design an exhaust manifold with different high temperature resistant materials and we test it with Finite Element Methodology, both temperature distribution and thermal stress concentrations are calculated using Finite Element Methodology. Here after design we have imported it into the Ansys and first Thermal analysis is done on it using the materials-cast iron, silicon nitride, zinc oxide. By using these materials the results are obtained and when they are compared with each other we can conclude that cast iron has the best ability to dissipate heat but it will get effected by the heat very soon, even though silicon nitride and zinc oxide are poor conductors, we should consider there insulation property's as when manifold gets heated up it will act as a heat source to the cylinder head on which it is mounted.

More over these materials won't chip in course of time so clogging of exhaust system is also avoided, which also prevents back pressure conditions. Now even CFD analysis is done to the best output material here and the results obtained are plotted in a tubular form. As per the results obtained totally we can conclude that the exhaust manifold with and zinc oxide are the best suited materials with better life. Basic examination and Thermal investigation has been performed on the ventilation system to discover the deformities in the arrangement of ventilation system. Examination was finished by considering the two unique materials structural steel and gray cast iron.

ISSN 2454 – 535X
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Gray cast iron has observed to have more twisting while contrasted with others. Structural steel is great material for this design. We can also reduce the cost of the manifold if we use these materials as coatings on the manifold.

1. The 3 materials Gray Cast Iron, Ferrite Stainless Steel and Titanium Alloy were analyzed over similar structural and thermal conditions.
2. The result of FE simulations of temperature distributions on Grey Cast Iron, Ferritic Stainless Steel and Titanium Alloy with ambient temperature 40°C were validated with experimental data.
3. The result of FE Simulations of Static Structural and Transient Thermal Analysis are mentioned in a tabulated form

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