International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 03 | Mar 2020 www.irjet.net p-ISSN: 2395-0072

Thermo- Structural Analysis of Runner of Exhaust Manifold

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Abstract - *Exhaust manifold is 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 vehicle is starting, at full load and a cooling when engine has stopped. Any of the circumstance produces an-isothermal loading leads to failure of the component. The thermostatic analysis of the structure has 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.*

Key Words: Thermal and mechanical loading, Thermostatic analysis, Grey cast iron and Steel

1. INTRODUCTION

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. [3] The gas temperature is expected to reach as high as 1000˚C in the near future making it impossible to use commonly found material like cast iron because temperature is limited to 750˚C.

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.

Fig -1: Engine - exhaust manifold assembly

The exhaust system can mainly be divided into 2 sections based on the working temperature. The hot end [temperature above 600°C] which starts from the manifold till the catalytic converter, and the cold end [temperatures below 600°C] which extends from the pre-muffler till the tail pipe. For 4 Stroke SI engine, temperature lies in the range of 400 °C to 600°C. Normally, ferrous alloys are used in the manufacturing of exhaust system. These include carbon steel, stainless steel, alloy steels and cast iron.

Fig -2: Crack development on runner

1.1 Objectives

1. To study the working of exhaust manifold and determine the forces acting on it.
2. To analyze the thermo –mechanical behaviour of runner of exhaust manifold in Ansys for 50 kPa pressure and temperature of 700̊C and to find the stresses and temperature distribution within it.
3. To compare the structural and thermal behaviour of cast iron and stainless steel.

2. LITERATURE REVIEW

Engine exhaust manifold failure is mainly due to thermo-structural fatigue.

Mohammad A. S. et al [1], 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 temperatures in the internal surface and external surface were 940°C and 750°C, 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.

G M Castro et al [2], the left exhaust manifold of Y block engine was used for analysis. The failed component contained two fracture surfaces: the first one was located on 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.

M. Ekstrom et al [3], In this paper 7 different materials were used for heavy duty diesel engines and they were tested in air from 20 to 1000°c. High temperature tensile testing were done on the component. Coffin- Manson equation was used to analyze strain and fatigue life. The fractions of elastic and plastic strain were calculated and plotted. The percentage of ductile fracture increases with temperature and at 700°C it is completely ductile. Cross-section examinations could not reveal any pore formation around the graphite nodules. The 7 materials were used to calculate low cycle fatigue life. They were compared with other in correspondence to temperature at which fracture occurred. Material properties related to composition of various materials were deeply studied.

Simone Sissa et al [4], this paper focused on the estimating the low-cycle and high-cycle fatigue life of a turbocharged diesel engine exhaust manifold. Vibrational loading were 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 thermo – mechanical quasi static finite element model were 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.

C. Delprete et al [7], 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 thermo – structural FE analysis has been run and results were post processed by numerical code. Solidworks 2009 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.

Table -1: Engine Specifications [9]

Engine	4 Stroke 4 Cylinder SI Engine
Make	Maruti-Suzuki Wagon-R
Calorific Value of Fuel	45208 KJ/KG-K
Specific Gravity of Fuel	0.7
Bore and Stroke	69.05 mm x 73.40 mm

3. THERMO - STRUCTURAL ANALYSIS OF RUNNER OF EXHAUST MANIFOLD

First of all, modeled the runner of the exhaust manifold in the Creo then it was simulated in the Ansys Workbench. Results are compared at the end.

3.1 Design of the Runner

The design of runner of exhaust manifold is shown below.

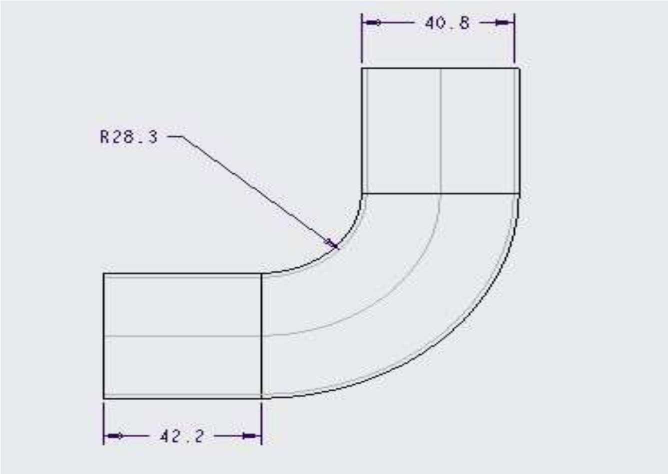

Fig -3: 2D model of runner of exhaust manifold [9]

The thickness of the runner is 6mm. [2]

3.2 Material and Boundary Conditions Used

Exhaust manifold failure occurs basically due to thermal expansion and contraction. So, thermostatic analysis is required for finding thermo- mechanical behaviour of exhaust manifold.

Material used:

For analysis cast iron and stainless steel is used as material and compared the results. Cast iron is the conventional material and stainless steel is latest material used for exhaust manifold.

Boundary conditions-

1. Gas temperature - 700̊C
2. Outlet pressure- 500 kPa [10]
3. Heat transfer coefficient for air - 100W/ m2 K [1]

Runner will be fixed at one end on the engine and another to the collector. So both flanges will be fixed.

Fig -4: Thermal boundary conditions

Fig -5: Static boundary conditions

Meshing used as follows:
Type- Hexahedral
Nodes- 100751
Elements -19770
Element size - 2mm

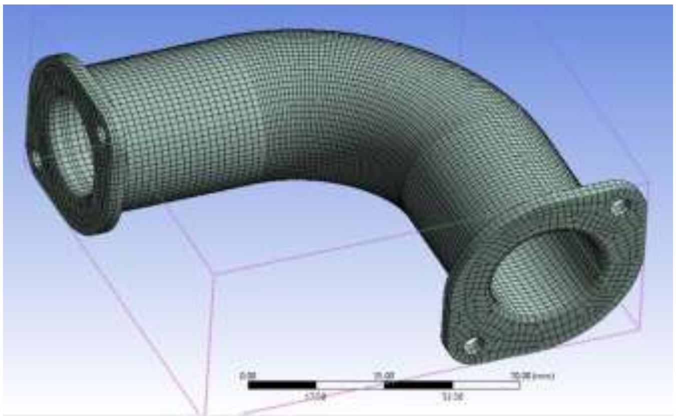

Fig -6: Meshed model of runner

3.3 Results of Analysis

1. Material - Stainless steel

Properties: Tensile ultimate strength- 586 Mpa
Tensile yield strength - 207 Mpa

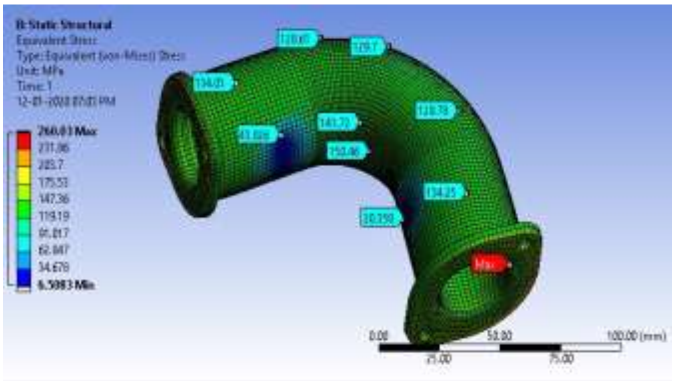

Fig -7: Stress distribution in runner made up of stainless steel

The maximum stress is at the one point of the fillet because exact fillet thickness is not known. The maximum stress on the stainless steel pipe is 150.46 Mpa which is less than tensile yield strength of the material.

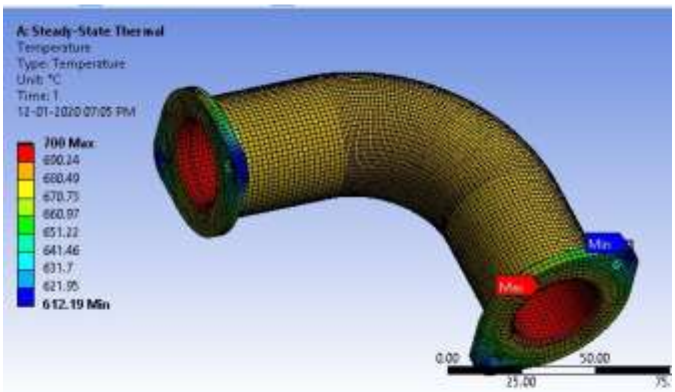

Fig -8: Temperature distribution in runner made up of Stainless steel

The maximum temperature is 700̊C which is at the inner side of the runner. The minimum temperature 612.19˚C is seen at the inlet and outlet flange edges of the runner.

2. Material- Grey cast iron

Properties: Compressive Ultimate Strength - 820 Mpa
Tensile ultimate strength -240 Mpa

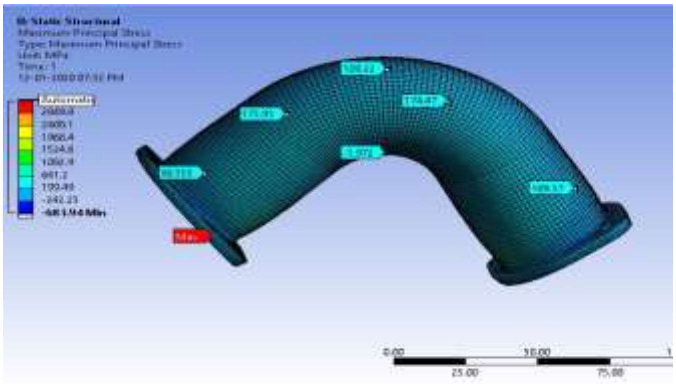

Fig -9: Stress distribution in runner made up of grey cast iron.

The maximum stress produced in the runner is 174.47 MPa which is higher than the stainless steel. But lower than the ultimate tensile strength of the grey cast iron.

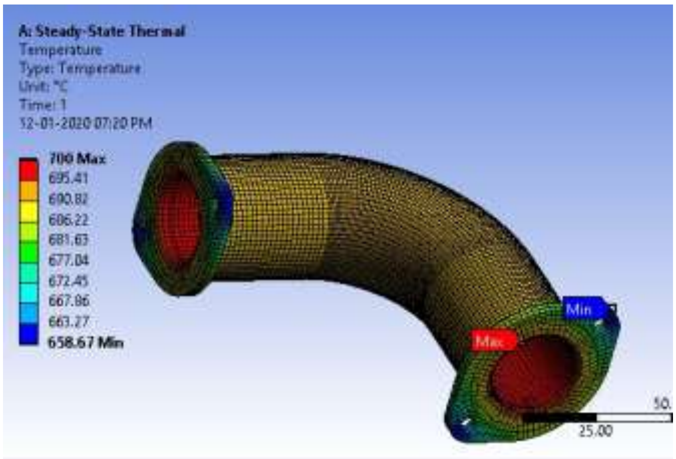

Fig -10: Temperature distribution in runner made up of grey cast iron

The minimum temperature is seen 658.67̊C which is higher than the minimum temperature of stainless steel.

3.4 Comparison between Materials

Following are the results obtained from finite element analysis:

Table -2: Comparison between Grey Cast Iron and Stainless Steel

Material		Stainless Steel	Grey cast iron
Stress (Mpa)	Max	150.46	174.47
	Min	6.5083	-683.94
Temperature (̊C)	Max	700	700
	Min	612.29	658.67

4. CONCLUSION

The runner is always failed due to thermal loads on it. So simulation is necessary to analyze the thermo-mechanical behaviour of it. The simulation of runner is done in the Ansys 19 by using pressure as structural load and temperature as thermal boundary condition.

The maximum stress produced in cast iron is greater than the stress produced in the stainless material. The stress concentration is more at the flange end. The stresses developed in the stainless steel are much lesser than the yield strength. The minimum temperature in stainless steel has seen in analysis is smaller than the minimum temperature of the cast iron.

That's why nowadays the stainless steel is the material used in the manufacturing of the exhaust manifold.

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BIOGRAHIES

PG student, Pursuing ME Design from PCCOE. Areas of interests like SOM, Vibration, modeling and simulation