iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** XI **Month of publication:** November 2020

DOI: https://doi.org/10.22214/ijraset.2020.32137

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue XI Nov 2020- Available at www.ijraset.com

Thermal Fatigue Analysis of Exhaust Manifold

Ms. Neha N. Shinde[1], Mr. A. A. Panchwadkar[2]
[1]M.E student, PCCOE Pune, India
[2]Associate Professor, PCCOE Pune, India

Abstract: The thermal cycle load incorporates cold beginning at the start of vehicle, at full load and a cooling period when vehicle has halted. Any one of activities causes the failure of the exhaust manifold.
The thermal fatigue analysis has performed on the exhaust manifold at high temperature condition. Convection and temperature are applied as thermal boundary conditions and pressure is applied as static boundary condition. Grey cast iron, stainless steel and D5S alloy are used as material. Temperature distribution, von misses stress, fatigue life and total deformation of the materials are compared with each other.
The maximum stresses are found in the grey cast iron which, lesser in D5S alloy and least in the stainless steel. Total deformation is found more in the stainless steel. The maximum as well as minimum temperature found in the stainless steel material but there is not much difference in the temperature distribution. Life for grey cast iron and stainless steel is same and life of D5S alloy is ten times lesser than other two materials.
Keywords: Thermal and mechanical loading, Thermal fatigue analysis, fatigue life

I. INTRODUCTION

The exhaust manifold is always subjected to intense thermal and mechanical loads. Thermal cyclic loads, in the long run, lead to component failure due to low cycle thermal fatigue.

Exhaust regulations for heavy duty vehicles are constantly becoming more restrictive to limit the environmental impact from exhaust gases and particles. By increasing the specific energy output of the diesel engine, fuel efficiency is improved and emissions are reduced. One drawback, however, is that it leads to an increase in exhaust-gas temperature which makes the material more demanding for exhaust manifolds. Gas temperatures are expected to rise to 1000℃ in the near future making it impossible to use commonly found materials such as cast iron as temperatures are limited to 750℃.

Factors affecting the exhaust manifold e.g. Material characteristics including loadings, working temperature, heat treatment, microstructure, anisotropy and environmental effects.

Thermo-static analysis is considered in the design of many structures such as the exhaust manifold. For the simulation, mechanical and thermal boundary conditions i.e. pressure and temperature is applied to the materials of grey cast iron and steel, respectively, and their stress and temperature distribution are compared.

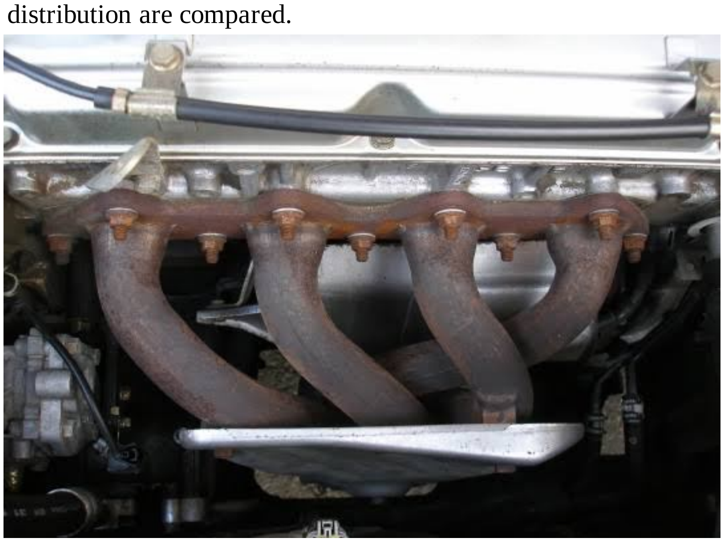


Fig.1 Engine- Exhaust manifold assembly

©IJRASET: All Rights are Reserved

Exhaust systems can be mainly divided into two sections based on the operating temperature. The hot end [temperature above 600°C] which starts from the manifold to the catalytic converter and the cold end [temperature below 600°C] which extends from the pre-muffler to the tail pipe. Temperature ranges from 400C to 800C for a 4 stroke SI engine. Commonly used in the manufacture of ferrous alloys exhaust systems. These include carbon steel, stainless steel, alloy steels and cast iron.

Fig.2 Crack development on runner

II. LITERATURE REVIEW

Two different cast iron-alloys used for exhaust manifolds to understand the corrosion fatigue. Low-cycle fatigue tests have conducted at 800 °C for argon and synthetic diesel exhaust condition and also isothermal oxidation tests in the exhaust atmosphere. The effect of corrosion on the fatigue life of two materials are compared by ∊-N (strain-life cycles) curves.

Both the materials show very different behaviors for the effect of corrosion on fatigue.

Low-cycle fatigue tests have conducted in controlled atmospheres, isothermal oxidation tests and investigations of the crack growth mechanisms in three iron-based cast alloys. Cast iron D5S shown resistance in both atmospheres due to its atmosphere-insensitive fatigue mechanism. In argon, for both cast irons, D5S and SiMo51, crack initiation occurred at surface graphite nodules through graphite matrix de-bonding. The micro crack-linkup mechanism is weakly affected by the atmosphere. [1]

CFD analysis is performed on the exhaust manifold. It is used to evaluate high temperature in manifold sections. CFD analysis evaluates the temperature peak, pace and strain distribution within Exhaust manifolds. Manifolds are the components of diesel engines subjected to crack harm. Even materials like forged alloys can be affected by high operational temperatures that can cause higher stresses and displacements. Fluid glide, temperature and strain analysis is done on the component and results are plotted for temperature, stress and speed distribution. A few hints for design improvements are provided to reduce the temperature and temperature gradients. [2]

Material used for exhaust manifold is D5S alloy. Structural analysis is performed and fracture toughness is determined by

Cracking failure is analyzed by using finite element method at the first mode using thermal mechanical load as boundary condition. According to ASTM standard, 4 compact test specimen with different notch lengths used for tension test and simulated in ABAQUS software. The critical fracture toughness (KIC) was determined by using the fracture analysis in simulation. Critical fracture intensity factor was determined by using the fracture forces. Maximum normal stress found out on the exhaust manifold confluence, where the exhaust ports join together. The temperature distribution in the internal surface and external surface were 940C and 750C respectively. Preload and torque are applied to the exhaust manifold as a boundary condition. [3]

The low-cycle and high-cycle fatigue life is estimated for exhaust manifold of turbocharged diesel engine. Vibrational load is applied to the exhaust manifold for dynamic harmonic analysis. One dimensional CFD simulation is done to the engine head. The thermo – mechanical quasi static finite element model is prepared. The numerical method is used for low and high cycle fatigue life. Several areas are detected in which plasticity found and related with low cycle fatigue life. Results have shown that vibrational effect cannot be neglected. [6]

As exhaust manifold is complex geometry stresses and strains field became multi-axial and reduce the fatigue resistance. Several damage models are applied and compared for the material. The thermo-structural finite element analysis is performed and results are post processed by numerical code. Solidworks 2009 CAD software was used for component modeling. The friction contact between bolts, manifold, gasket and cylinder head has been taken into account for structural analysis. [9]

The temperature of the wall and heat transfer coefficient of the exhaust manifold inner side of the wall were found through the thermal analysis, then modal and thermoplastic analysis were done using the finite element method. The bolt pre-tightening force and the contact relationship between flange face and cylinder head is taken into account.[10]

©IJRASET: All Rights are Reserved

III. FATIGUE ANALYSIS OF THE EXHAUST MANIFOLD

A. Design of the Exhaust Manifold

The design of exhaust manifold is shown in fig.1

The thickness of the runner of exhaust manifold is 2mm

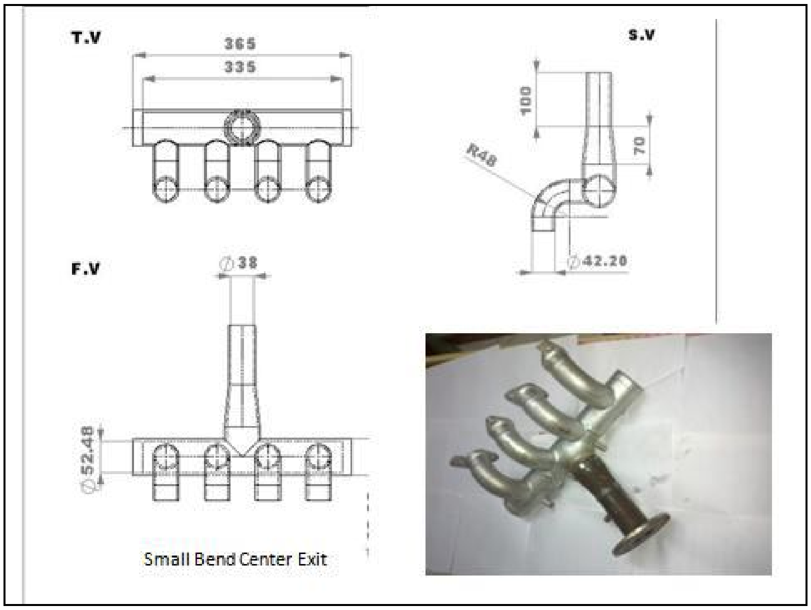


Fig.3 Design of the Exhaust Manifold []

3D model is prepared in PTC Creo as shown in fig. 2

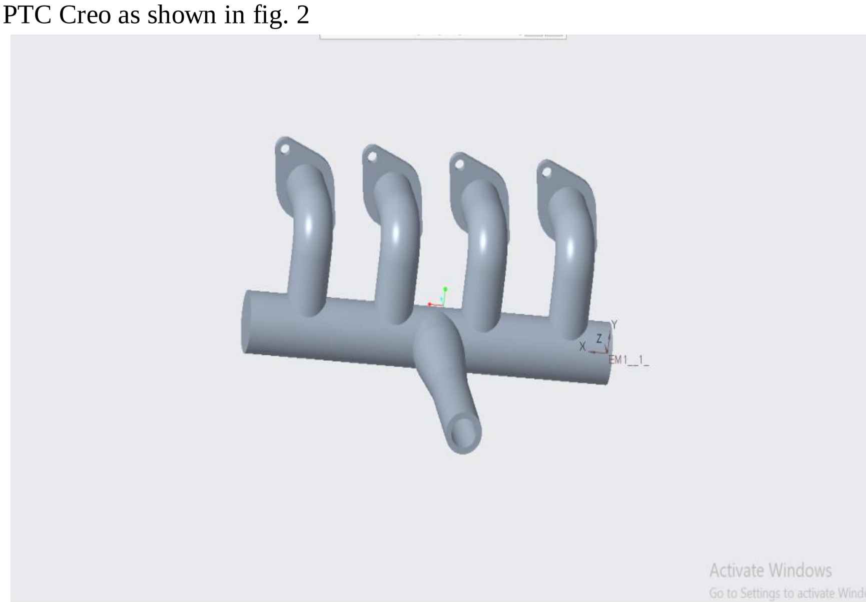


Fig. 4 3D Model of Exhaust Manifold

B. Material and Boundary Conditions Used

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

1) *Material Used:* For analysis cast iron, D5S alloy and stainless steel is used as material and compared the results with each other. Cast iron is the conventional material and stainless steel and D5S alloy are the latest material used for exhaust manifold.

©IJRASET: All Rights Reserved

2) Thermal Boundary conditions

Gas temperature - 600C

Heat transfer coefficient for ambient- 25 W/m^2 K

Heat transfer coefficient for gas temperature- 420 W/m^2 K [3]

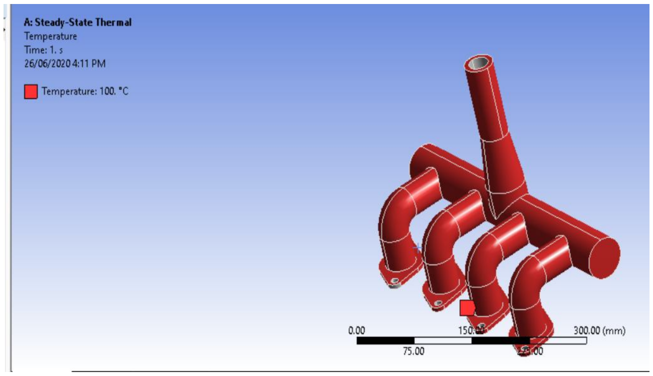


Fig.5 Temperature is applied at the exterior surface of the exhaust manifold

The temperature of 100C is applied on the outer surface of the exhaust manifold shown in above fig. 5
Exhaust gas temperature of 600C is applied on the internal surface of the exhaust manifold in fig. 6 shown below:

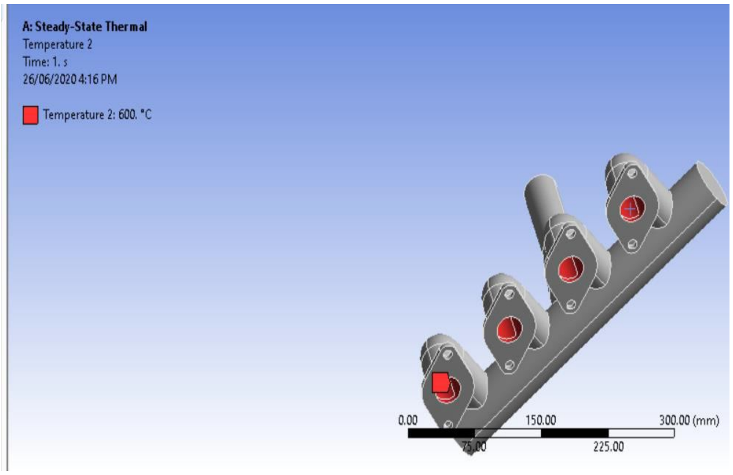


Fig.6 Exhaust gas temperature is applied to the internal surface of the exhaust manifold

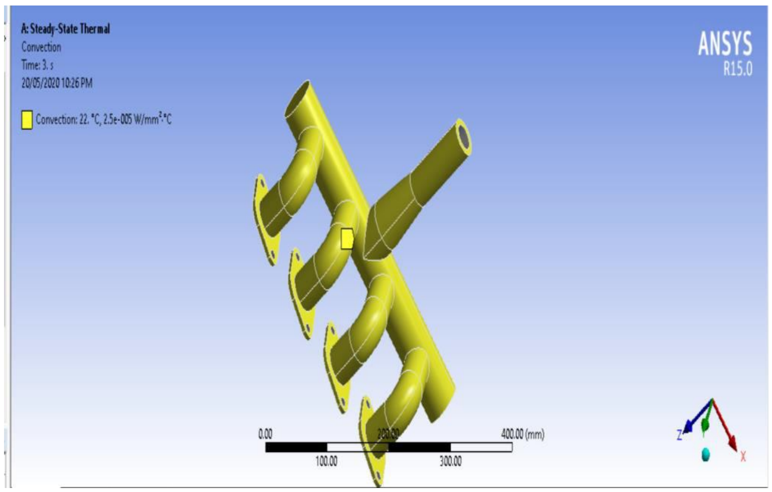


Fig.7 Air convection is applied on the external surface of the exhaust manifold.

©IJRASET: All Rights Reserved

Air convection coefficient 25 W/m^{2}K is applied on the exterior of the exhaust manifold is shown in fig7 and exhaust gas coefficient of 420 W/m^{2}K is applied on the internal surface is shown in fig.8

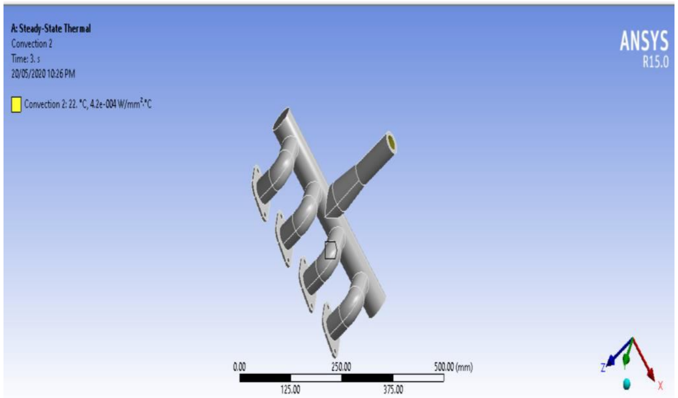


Fig.8 Exhaust gas convection is applied at the internal surface of the exhaust manifold

3) *Static Boundary Conditions:* Exhaust manifold flanges are fixed at one end on the engine and another to the collector. So both sides will be fixed and exhaust gas pressure of 500Kpa is applied on the internal surface of the exhaust manifold.

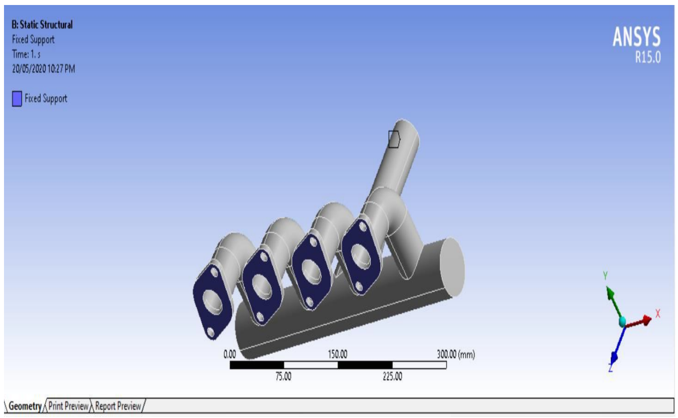


Fig.9 Exhaust manifold is fixed at the flanges and the another end

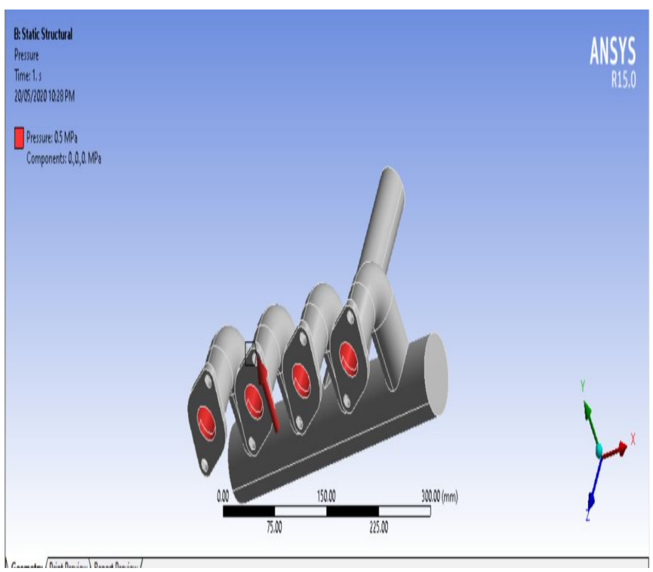


Fig.10 Exhaust gas pressure of 0.5 Mpa is applied at the internal surface of the exhaust manifold

©IJRASET: All Rights are Reserved

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue XI Nov 2020- Available at www.ijraset.com

C. Mesh Model

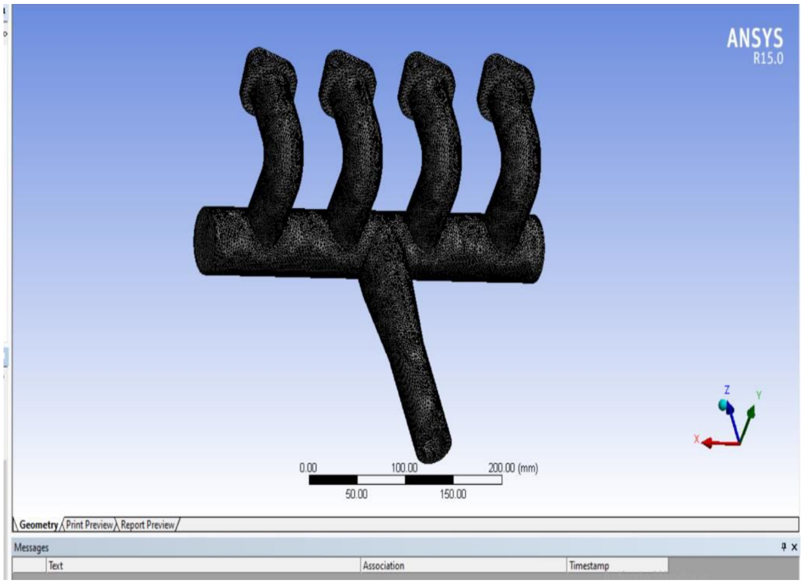


Fig.11 Meshed model of runner

1) Mesh size- 2.0mm
2) Type of element- Tetrahedral
3) Nodes - 480722
4) Elements- 272322

Mesh model of exhaust manifold assembly is shown in fig.11

IV. RESULTS OF THERMAL FATIGUE ANALYSIS

Results of three different materials are compared with each other.

A. Temperature Distribution in the material

Temperature distribution after applying for three different materials is shown in fig. 12 below:

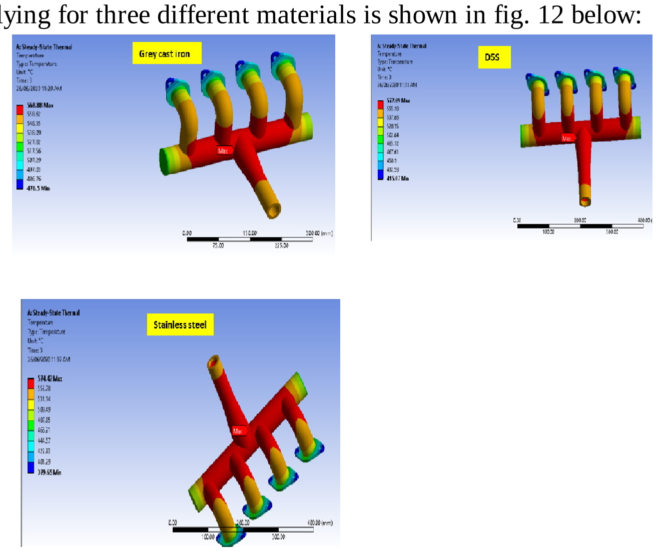


Fig.12 Temperature distribution for three materials

High temperature is seen in the stainless steel and minimum temperature is also has seen in the stainless steel. But there is no major difference in the temperature difference amongst the all elements.

©IJRASET: All Rights are Reserved

B. Von misses stress

The material properties of the material are mentioned below:

1) *Material:* Grey cast iron
   Properties: Compressive ultimate Strength - 820 Mpa
   Tensile ultimate strength -240 Mpa

2) *Material:* D5S alloy
   Properties: Tensile Ultimate Strength - 153 MPa
   Tensile yield strength- 117 Mpa

3) *Material:* Stainless steel
   Properties: Tensile ultimate strength- 586 Mpa
   Tensile yield strength - 207 Mpa

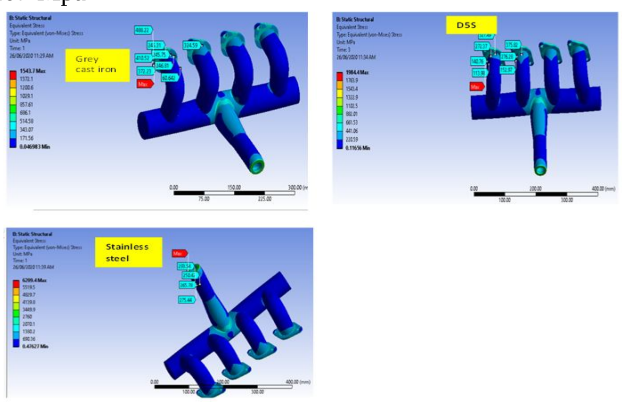


Fig.13 Von misses stress for three different materials

The stress for stainless steel is lesser than other two materials. Stress in the stainless steel is maximum at the collector side where the all runners of exhaust manifold join together. The stress is more than tensile yield strength but lesser than ultimate tensile strength. For grey cast iron and D5S alloy, the stress is maximum at the flange side where it is attached to the cylinders.

C. Total Deformation

Deformation in three materials is shown in fig14 below:

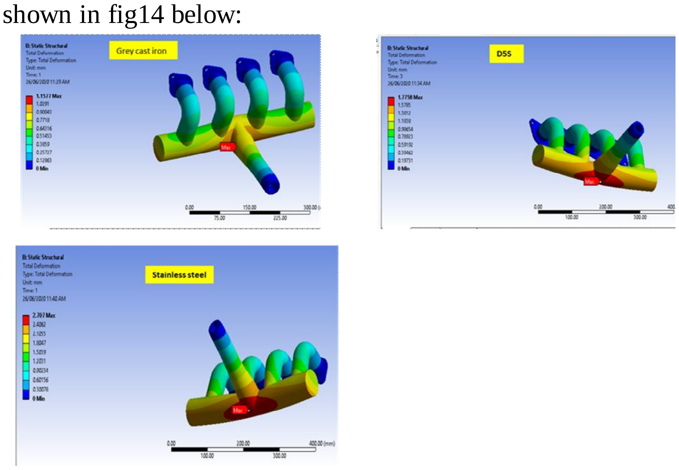


Fig.14 Total deformation in the three materials

More deformation has found in stainless steel, lesser in D5S alloy and least in gray cast iron.

©IJRASET: All Rights are Reserved

D. Fatigue life

All the thermal and static boundary conditions are applied and found out the fatigue life. Fatigue life is same for grey cast iron and stainless steel and ten times less for D5S alloy.

The predicted life is shown in fig. 15 below:

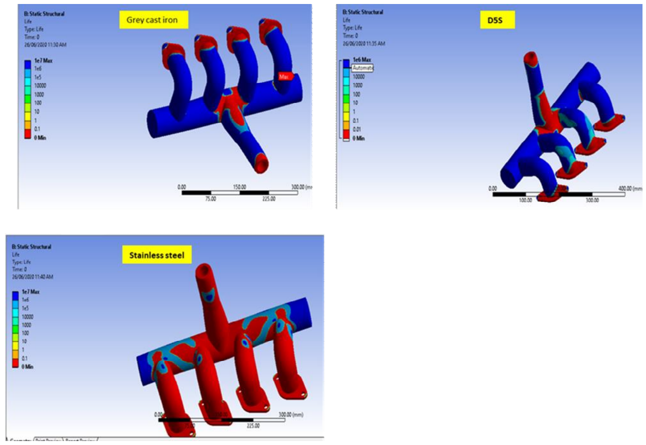


Fig.15 Fatigue life

The results of all the materials are compared with each other in the tabular form.

Table No.1 Comparison of three materials

Quantity	Material					
	Grey Cast Iron		D5S alloy		Stainless steel	
	Max	Min	Max	Min	Max	Min
Temperature Distribution (°C)	569	477	573	415	574	380
Von misses stress(Mpa)	411	-	327	-	250	-
Total deformation (mm)	1.15	-	1.76	-	2.71	-
Life(No of cycles)	1e7	-	1e6	-	1e7	-

The temperature distribution, von misses stresses, total deformation and life of three materials are compared with each other. After applying 600°C temperature in the inner surface of exhaust manifold temperature distribution is observed that maximum temperature is found in the stainless steel and minimum temperature is also found in stainless steel amongst all three materials.

Von misses stress is maximum in Grey cast iron, less in D5S alloy and least in stainless steel material. Maximum stress in grey cast iron is more than the tensile ultimate strength but lesser than the compressive ultimate strength. Maximum stress in D5S alloy is more than the tensile ultimate strength. Maximum stress in stainless steel is greater than tensile yield strength but lesser than tensile ultimate strength. The deformation is least in grey cast iron, and nearly same in the D5S alloy and stainless steel.

Life (max no of cycles) for Grey cast iron and stainless steel is same and ten times less for D5S alloy.

V. CONCLUSION

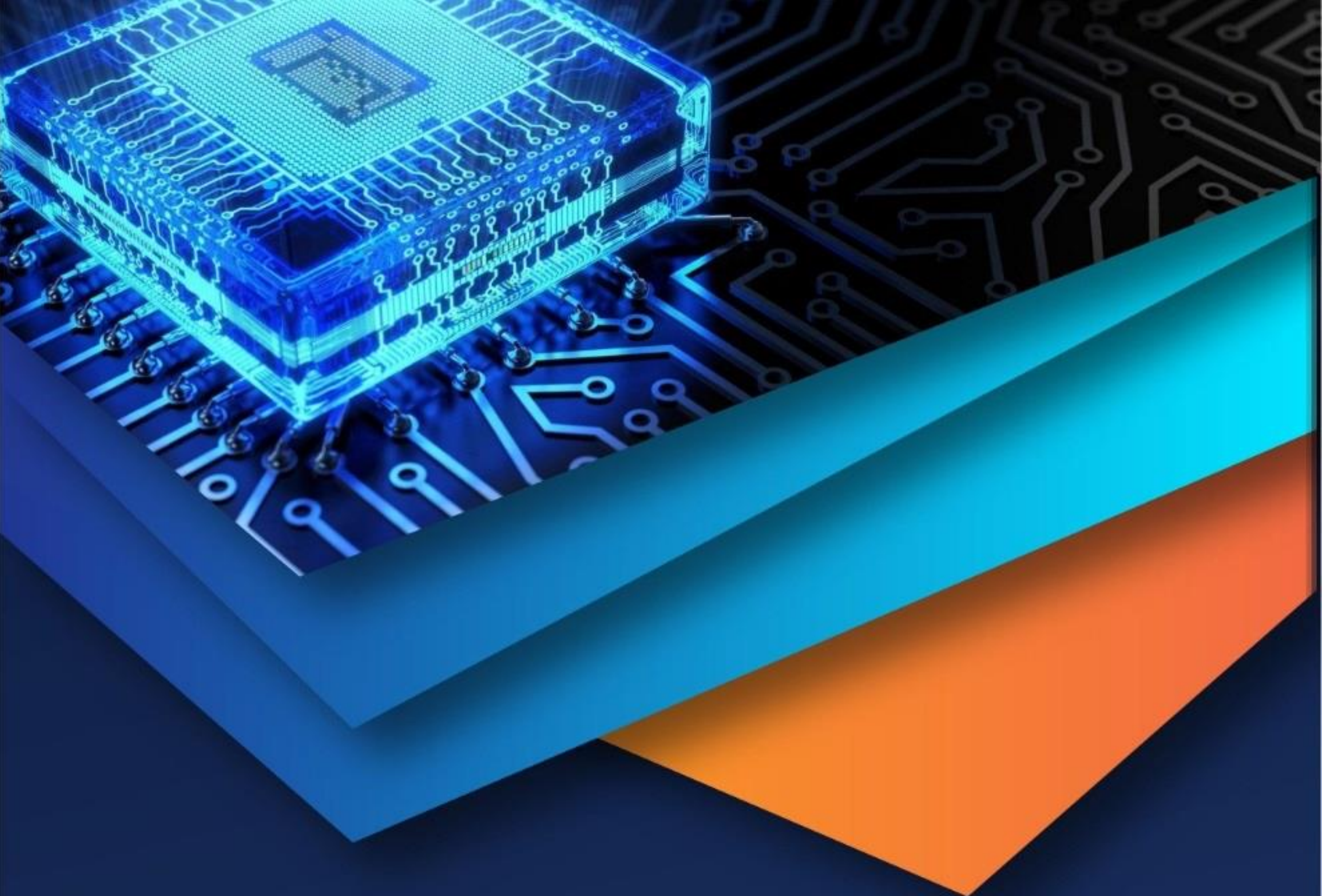
The exhaust manifold always failed due to cyclic thermal and mechanical loads on it. So simulation is necessary to analyze the thermo-mechanical behaviour of it. The simulation of the exhaust manifold is done in the Ansys 19.2 by using pressure as structural load and temperature, heat transfer coefficient as thermal boundary condition. The maximum stress produced in cast iron is greater than the stresses produced in the D5S alloy and stainless steel material. The stress concentration is more at the flange end and at the collector side. The stresses developed in the stainless steel are much lesser than the tensile ultimate strength. The minimum temperature in stainless steel has seen in analysis is smaller than the minimum temperature of the grey cast iron and D5S alloy. The fatigue life of grey cast iron and stainless steel is same but the stresses produced in the stainless steel are lesser than grey cast iron. That's why nowadays the stainless steel is the material used in the manufacturing of the exhaust manifold.

©IJRASET: All Rights Reserved

REFERENCES

[1] Shengmei Xianga, Stefan Jonssona, Baohua Zhub, Joakim Odqvista, "Corrosion fatigue of austenitic cast iron Ni-Resist D5S and austenitic cast steel HK30 in argon and synthetic diesel exhaust at 800 °C", International Journal of Fatigue, Volume 132, March 2020, 105396
[2] C. Sadhasivam, S. Murugan, J. Vairamuthu, S. Mohana Priyadharshini, "Design and analysis of two-cylinder exhaust manifold with improved performance in CFD", Innovation in Mechanical Engineering: Materials Science ,2020
[3] Mohammad Amin Salehnejada, Arash Mohammadib, Mahdi Rezaeia,Heydar Ahangaric, "Cracking failure analysis of an engine exhaust manifold at high temperatures based on critical fracture toughness and FE simulation approach", Engineering Fracture Mechanics 211 (2019) 125–136.
[4] G. M. Castro Guiza, W. Hormaza, "Bending overload and thermal fatigue fractures in cast exhaust manifold", Engineering failure analysis 82 (2017) 138-148.
[5] M. Ekstrom , S. Jonsson, "High temperature mechanical and fatigue properties of cast alloys intended for use in exhaust manifold", Material and science engineering A 616 (2014) 78-87.
[6] Simone Sissaa, Matteo Giacopinia, Roberto Rosia, "Low-Cycle Thermal Fatigue and High-Cycle Vibration Fatigue Life Estimation of a Diesel Engine Exhaust Manifold", Procedia Engineering 74 (2014) 105 – 112
[7] Ming Chen, Y. Wang, "Design of Exhaust manifold of a Turbo charged Gasoline Engine Based on a Transient Thermal Mechanical Analysis Approach", SAE International, Engines, 2014
[8] Y. Yun Long, CAO Zhan yi, "Thermal fatigue behaviour and cracking characteristics of high Si- Mo nodular cast iron for exhaust manifold", Journal of Iron and Steel Research, International 2013, 20(6) 52- 57
[9] C. Delprete, R. Sesana, "Multi-axial damage assessment and life estimation: application to automotive exhaust manifold", Procedia Engineering 2 (2010) 725-734.
[10] G. DE Angelis, "The reliability improvement of a conventional cast iron exhaust manifold for a small size gasoline engine", Combustion Engine Division October 24-27, 2004, 3341-3349
[11] Rita, "Structural and Thermal Analysis of Exhaust Manifold of a Multi-cylinder Engine", IJERT, ISSN: 2278-0181

©IJRASET: All Rights are Reserved



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089 (24*7 Support on Whatsapp)