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Thermal analysis of vehicle exhaust system

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Abstract

The Exhaust system is a type of system in which waste gases of vehicle is remove out in the atmosphere. The main purpose of this project is to design and analysis the exhaust system by considering different materials adopted for exhaust system. The optimization of exhaust system is depended on the factors like temperature, positioning of each part of the exhaust system, designing of parts etc. but the key factor is temperature which affects directly to this system, Since the design of exhaust in such a way that it can reduce air pollution as well as noise pollution. By changing the materials used for the fabrication of exhaust system we can optimize the results as per requirement. In this project for 3D modeling of exhaust system Creo 4.0 is used and ANSYS 17.1 is used for analyzing the system.

Keywords: Design, Thermal analysis, *Creo*, ANSYS Analysis

1. Introduction

The Exhaust System plays an important role for proper functioning of vehicle. It helps to improve the performance of vehicle by removing the hot flue gases from the system.

Material used for vehicle exhaust system

The most commonly used materials for vehicle exhaust system are:

1. Cast ion
2. Mild steel
3. Carbon steel
4. Stainless steel (ferritic & austenitic steels)

The additive materials are used to increase the life span of exhaust and to achieve the required mechanical, physical & chemical properties. For example:

1. Silicon
2. Molybdenum
3. Manganese
4. Chromium
5. Titanium
6. Sulphur & Phosphorous
7. Nickel etc.

The temperature is different at the different parts of the exhaust system. The temperature is high at the outlet of engine which is connected to exhaust manifold. Manifold is connected with catalytic converter through flexible coupling allow it to movement & resist vibration.

Catalytic converter connected with muffler through pipes. Catalytic converter reduces the degree of hazardness of pollutant gases and muffler is used to reduce the noise pollution. The intermediate pipe is made curved shape because the hot gases tend to go upward the and the upward curve shape provide it direction due to which less effect of temperature on that region.

Since there are numbers of experiments have already been performed for exhaust system and exhaust manifold is the main area of observation because cracking and thermal load generated more in manifold part but other parts also play a vital role to direct the hot gases by consuming its harmful properties throwing out to the atmosphere. The temperature of gasoline engine varies between 600°C to 1100°C.The selection of material in such a way that it could withstand cracking and provide strength, corrosion resistance, wear resistance to the exhaust system parts.

2. Literature Review

S. Rajadurai1, M. Afnas2, S. Ananth3, S. Surendhar4 (2014), have studied the materials required for the fabrication of exhaust system. They have compared the properties of mild steel, stainless steel & aluminized steel. The temperature is examined at the different parts of exhaust system and chemical, physical and mechanical properties are discussed for each of them separately [1].

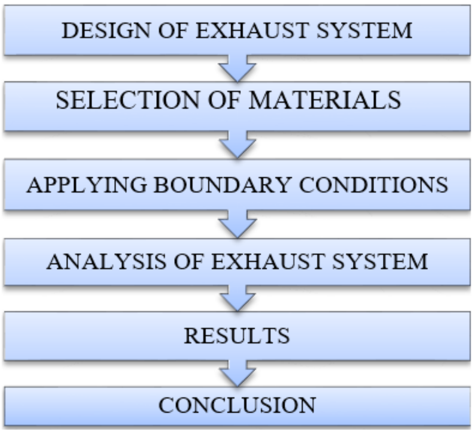
The model analysis was done by K.V.V Durga Prasad 2 Sanmala Rajasekhar and team (2015). They have chosen different coating materials for exhaust manifold and performed analysis on Ansys15.0. They have concluded that zinc oxide have better insulation property than silicon nitride and imposes good result for the durability of vehicle [2].

Mahesh S. Vasava, P. V. Jotaniya (2015) have analyze the heat transfer in automotive exhaust system. They have concluded that the better performance of automotive is achieved by controlling the temperature variation in exhaust system. The normal operating temperature can lead to increase the life span of catalytic converter, removal of corrosion, back pressure reduction and overall improve the performance of vehicle [3].

Mr. Chandan H S & Prof. Khalid Imran (2017), have investigated the thermal and model analysis of engine exhaust manifold used in TATA tipper BS-II. In this study, they analyze the manifold by using different materials like grey cast iron, carbon steel & stainless steel. They have designed the model by Creo 3.0 and for analyzing purpose ANSYS 17.0 is used. On the basis of temperature distribution, model deformation & heat flux these materials responses have recorded. They concluded that carbon steel and stainless steel has less deformation as compared to cast iron, the stainless-steel shows minimum temperature & minimum heat flux rate compared to carbon steel & cast iron. The overall observation among of these 3 materials shows that stainless steel is better than those other two materials for the exhaust system [4].

3. Methodology

For the steady state thermal analysis of the exhaust system following steps are executed:



4. Designing of exhaust system

As we discussed earlier exhaust manifold area is mainly responsible for consideration of temperature control but we could not ignore the importance of other parts of this system. Here the tail pipe is designed to observe the effects of temperature on different materials.

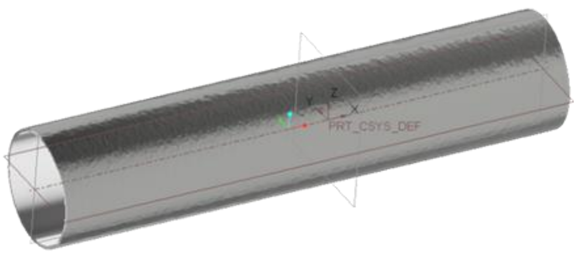


Fig 1: Model of Exhaust Pipe

5. Properties of materials

Table 1

S, No.	Properties	Cast Iron	Stainless Steel
1.	Density(Kg/m^3)	7200	7750
2.	Thermal Conductivity (W/m°C)	52	15.1
3.	Specific Heat (J/kg°C)	447	480
4.	Tensile Ultimate Strength (Pa)	2.4 x10^8	5.86 x10^8
5.	Coefficient of Thermal Expansion (/°C)	1.1 x10^{-5}	1.7 x10^{-5}
6.	Poisson's Ratio	0.28	0.31
7.	Young Modulus (Pa)	1.1 x10^{11}	1.93 x10^{11}
8.	Shear Modulus (Pa)	4.27 x10^{10}	7.37 x10^{10}
9.	Bulk Modulus (Pa)	8.33 x10^{10}	1.69 x10^{11}
10.	Melting Point (°C)	1204°C	1510°C

6. Analysis of exhaust system

The Steady state thermal analysis is performed and later structural analysis is performed to know the stress and deformation due to temperature. The analysis is done by Ansys which is used by most of the engineer in modern era gives very fast solution of complex geometry by using Numerical Method.

3 Models are prepared by CREO 4.0 to perform the experiment. Onto which 4 Boundary Conditions are applied, they are:

1. Temperature at Circular Region
2. Heat flow at one Circular face
3. Convection on the body
4. Fixed Support at one Circular face

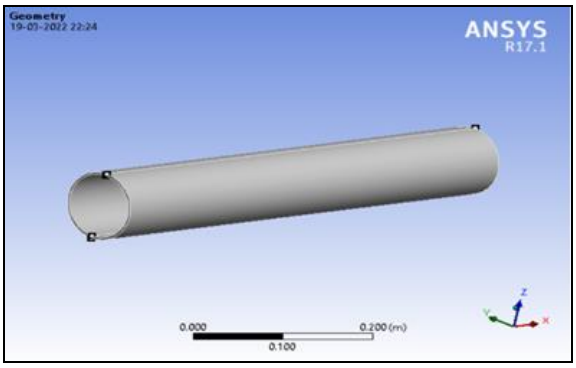


Fig 2: Exhaust Pipe Input for Analysis

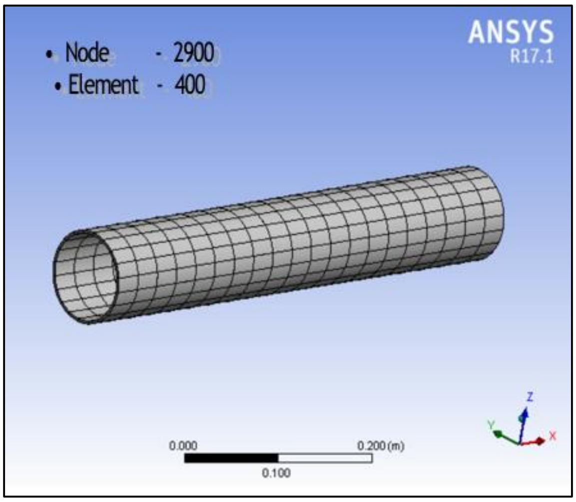


Fig 3: Meshed Exhaust Pipe

Effect of Temperature

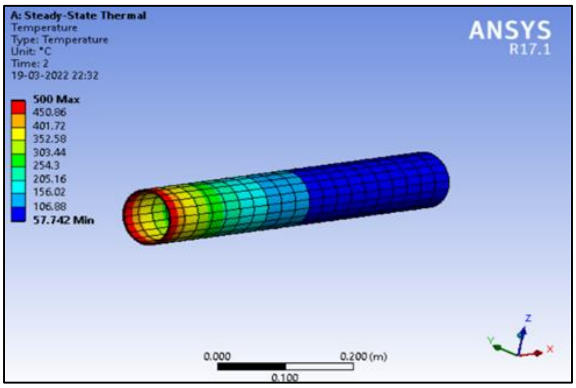


Fig 4: Temperature Effect on Cast Iron

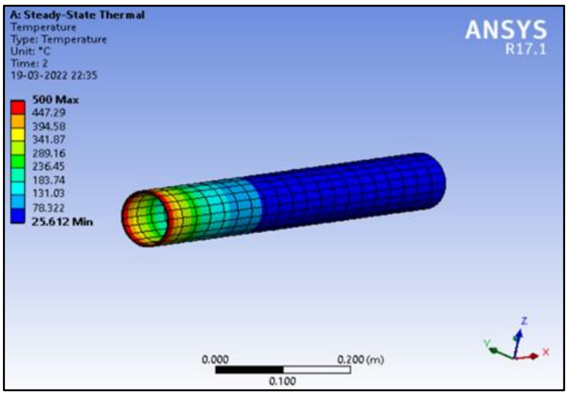


Fig 5: Temperature Effect on Stainless Steel

Effect of Heat Flux

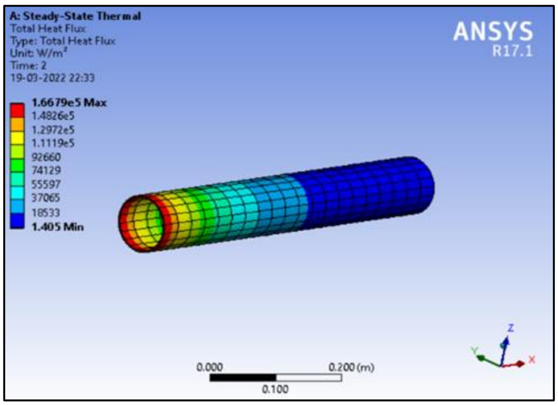


Fig 6: Heat Flux Effect on Cast Iron

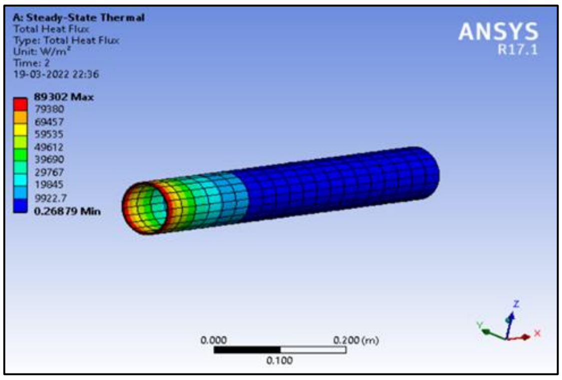


Fig 7: Heat Flux Effect on Stainless Steel

Effect of Stress

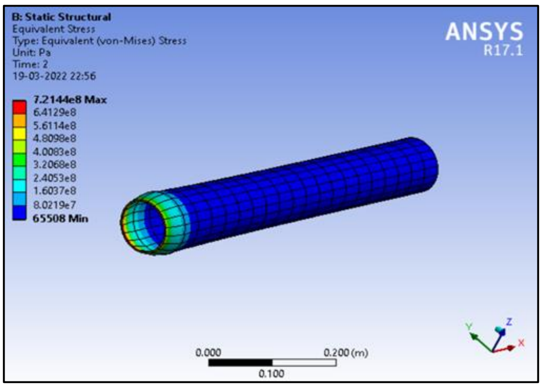


Fig 8: Thermal Stress Effect on Cast Iron

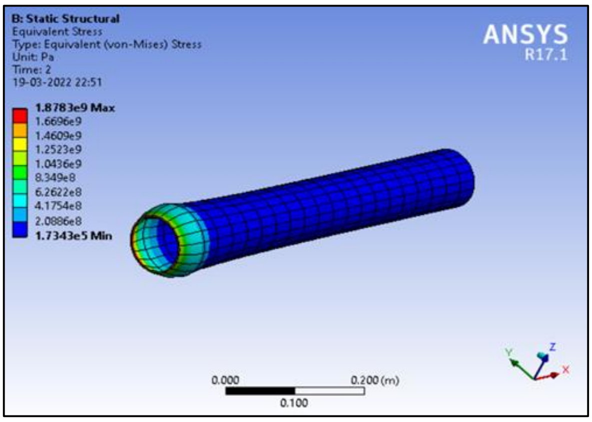


Fig 9: Thermal Stress Effect on Stainless Steel

Effect of Total Deformation

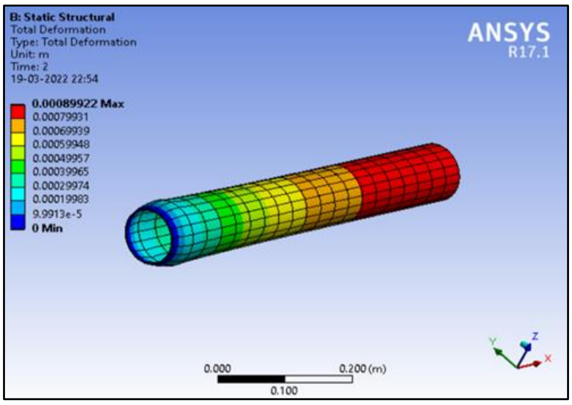


Fig 10: Deformation Effect on Cast Iron

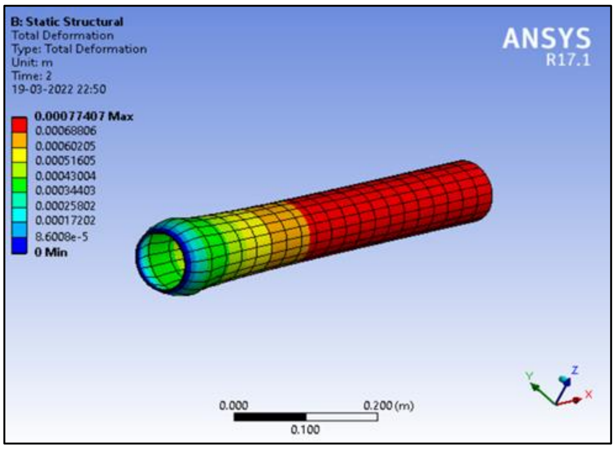


Fig 11: Deformation Effect on Stainless Steel

Effect of Thermal Strain

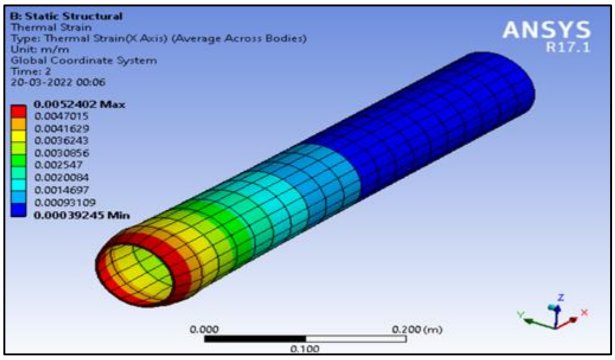


Fig 12: Thermal Strain Effect on Cast Iron

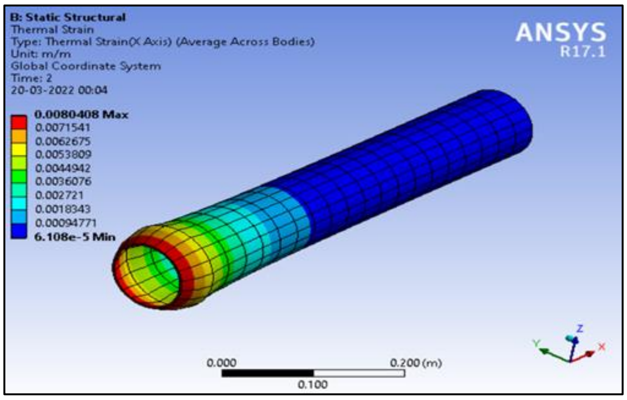


Fig 13: Thermal Strain Effect on Stainless Steel

7. Results

The Results obtained are as follows

Table 2

Temperature Analysis of Exhaust Pipe				
Heat Flow = 1000 Watt **Initial Temperature** - 22°C			**Materials**	
			MinimumTemperature(°C)	
SR. NO.	**MODEL**	**Max. Temp.**	**Cast ion**	**Stainless steel**
1	**Model 1**	500°C	57.74	25.61
	Lenth = 600mm, Diameter = 96mm Thickness = 3mm	700°C	66.84	26.54
2	**Model 2**	500°C	22.88	22.004
	Lenth = 968 mm, Diameter = 60mm Thickness = 3mm	700°C	23.116	22.005
3	**Model 3**	500°C	45.31	23.62
	Lenth = 500 mm, Diameter = 60mm Thickness = 3mm	700°C	51.214	24.04

Table 3

Heat Flux Analysis of Exhaust Pipe				
Heat Flow = 1000 Watt **Initial Temperature** - 22°C			**Cast ion**	**Stainless steel**
			Heat Flux(W/m2)	
SR. NO.	**MODEL**	**Max. Temp.**	Minimum-Maximum Range	
1	**Model 1**	500°C	1.40-1.6679e5	0.269-8.93e4
	Lenth = 600mm, Diameter = 96mm Thickness = 3mm	700°C	1.94-2.4958e5	0.342-13.3e4
2	**Model 2**	500°C	2.66-2.36e5	0.010-12.77e4
	Lenth = 968mm, Diameter = 60mm Thickness = 3mm	700°C	3.36-3.53e5	0.013-1.91e5
3	**Model 3**	500°C	79.09-2.32e5	4.81 - 1.24e5
	Lenth = 500 mm, Diameter = 60mm Thickness = 3mm	700°C	101.78-3.48e5	6.06-1.86e5

Table 4

Stress Analysis of Exhaust Pipe				
Heat Flow = 1000 Watt **Initial Temperature** - 22°C			**Cast ion**	**Stainless steel**
			Stress(Pa)	
SR. NO.	**MODEL**	**Max. Temp.**	Minimum-Maximum Range	
1	**Model 1**	500°C	6.55e4-7.21e8	1.73e5-1.87e9
	Lenth = 600mm, Diameter = 96mm Thickness = 3mm	700°C	9.18e4-10.21e8	2.45e5-2.65e9
2	**Model 2**	500°C	1.71e2-14.12e8	4.83-3.75e9
	Lenth = 968mm, Diameter = 60mm Thickness = 3mm	700°C	2.16e2-20.00e8	6.19-5.30e9
3	**Model 3**	500°C	4.27e3- 8.08e8	3.25e3-2.11e9
	Lenth = 500 mm, Diameter = 60mm Thickness = 3mm	700°C	5.31e3-11.43e8	4.35e3-2.98e9

Table 5

Deformation Analysis of Exhaust Pipe				
Heat Flow = 1000 Watt **Initial Temperature** - 22°C			**Cast ion**	**Stainless steel**
			Deformation(mm)	
SR. NO.	**MODEL**	**Max. Temp.**	Minimum-Maximum Range	
1	**Model 1**	500°C	0.099-0.89	0.086-0.77
	Lenth = 600mm, Diameter = 96mm Thickness = 3mm	700°C	0.135-1.21	0.116-1.04
2	**Model 2**	500°C	0-0.65	0-0.55
	Lenth = 968mm, Diameter = 60mm Thickness = 3mm	700°C	0-0.88	0-0.75
3	**Model 3**	500°C	0-0.61	0-0.57
	Lenth = 500 mm, Diameter = 60mm Thickness = 3mm	700°C	0-0.80	0-0.7

Table 6

Thermal Strain Analysis of Exhaust Pipe				
Heat Flow = 1000 Watt **Initial Temperature** - 22°C			**Cast ion**	**Stainless steel**
			Thermal Strain	
SR. NO.	**MODEL**	**Max. Temp.**	Maximum	
1	**Model 1**	500°C	0.0052	0.008
	Lenth = 600mm, Diameter = 96mm Thickness = 3mm	700°C	0.0074	0.011
2	**Model 2**	500°C	0.0052	0.008
	Lenth = 968mm, Diameter = 60mm Thickness = 3mm	700°C	0.0074	0.011
3	**Model 3**	500°C	0.0052	0.008
	Lenth = 500 mm, Diameter = 60mm Thickness = 3mm	700°C	0.0074	0.011

8. Conclusion

The Analysis is performed on exhaust thermal pipe by using 2 materials i.e. Cast Iron and Stainless Steel, as result obtain, we can conclude the following points

1. The rate of cooling of exhaust system is more in Stainless steel.
2. The deformation occurs more in Cast Iron.
3. The stress concentration is more in stainless steel.
4. The rate of flow of energy per unit area (Heat Flux) is more in Cast Iron.
5. There is no significant change in thermal strain of both the materials but Stainless steel have more capacity to change in shape than cast iron.
6. The rate of cooling of system depends on the area and shape of the system.

Overall, we can say that Stainless steel performance is better than the cast iron on terms of this system.

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