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Thermal and Structural Analysis of an Exhaust Manifold of a Multi Cylinder Engine

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ABSTRACT

The target of this research is to design, implement and then perform thermal and structural comparison of an EXHAUST MANIFOLD under various metals such as Stainless Steel 304, Aluminium 6063, In automotive engineering, an exhaust manifold collects the exhaust gases from multiple cylinders into one pipe. Exhaust manifolds are generally simple cast iron or stainless steel units which collect engine exhaust gas from multiple cylinders and deliver it to the exhaust pipe. Normally, ferrous alloys are used in the manufacturing of exhaust system. These include carbon steel, stainless steel, alloy steels and cast iron. The purpose of adding alloying elements is to help in solid solution strengthening of ferrite, improve the corrosion resistance and other characteristics and the cause the precipitation of alloy carbides. Mild carbon steel was extensively used for the manufacturing of exhaust systems for a considerable period of time. The operations which I have done are 2D design, 3D design, evaluation, simulation. As I mentioned earlier, I gave the detailed report of material properties, simulation, evaluation and orthographic view. At last I concluded, I chosen Aluminium 6063 is the suitable material due to the reduction of back pressure when compared to other metals which is used in this project.

KEYWORDS: 2D Drafting, 3D Designing, Evaluation, Simulation, Resulting.

1. INTRODUCTION

1.1 EXHAUST MANIFOLD

The exhaust manifold is a pipe, receives the exhaust gases from the combustion Chamber and leaves it to the atmosphere. Exhaust manifolds are mounted to the cylinder head. V- Type engines have two exhaust manifolds, and an in-line engine usually has one. When intake and exhaust manifolds are on opposite sides of an in-line engine, the head is called a cross-flow head. This design improves breathing capacity of an engine. Exhaust manifolds are typically made of cast iron or steel, although some latest-model cars use stainless steel manifolds. Cast iron is a good material for exhaust manifolds. Like the frying pan on a stove, it can tolerate fast and severe temperature changes. Exhaust gas temperature is related to the amount of load on the engine.

1.2 TYPES OF TURBO MANIFOLDS

1.2.1 Log manifold: The log type manifold is the most economical manifold on the market. They are almost bullet proof when it comes to reliability and they are the most compact manifolds available. Most manifolds you find on factory turbocharged cars are log type manifolds. This is understandable when you manufacturer are all about reliability. When it comes to performance, a log manifold will leave you wanting. All of the exhaust gases flow into a common way where they often collide with each other causing a lot of turbulence before the turbo. This hurts the turbo's performance and hurts the motors performance as well being that a log manifolds common plenum is so close to the other cylinders, it causes a lot of back flow of exhaust.

1.2.2 Tubular manifold: A tubular manifold is one that is custom made for that particular user's goal for the car. Most road racing cars will build an average runner, equal length manifold that will support great flow characteristics throughout the entire rev range. A car being set-up for drag racing will use a long runner tubular manifold, which will favour flow in the upper rev range. Tubular manifolds are very efficient when compared to a log manifold. They offer superior flow characteristics, and offer less back flow of exhaust gases back into the Motor. Now for the negative tubular manifolds are often prone to cracking causing them to lose points in the reliability column. For those focused on getting the most performance they can, a tubular manifold is a must.

1.2.3 Single scroll manifold: A single scroll manifold is one where all the exhaust runners come to a common collector where they enter the turbocharger. Also all the runners share a common waste gate to expel exhaust gases. This is the most common type of tubular manifold.

1.2.4 Twin Scroll or divided manifold: A twin scroll manifold is designed for the most ideal exhaust flow a motor can offer. These manifolds are built so that runners that come together are paired to be 180 degrees apart from each other on their firing order. This is done so that there is little chance of exhaust flow interference from another cylinders exhaust gases. This not only helps the motor to better expel its exhaust, but also helps to keep the exhaust velocity as high as possible, aiding in the turbochargers spool and the motors torque output.

A twin scroll manifold must be used with a turbo that is equipped with a twin scroll housing that keeps the exhausts divided all the way to the turbo's exhaust wheel.Factors to be considered during the design and development of exhaust manifold Runner length: This is arguably one of the most important factors. First would be to make sure that the runners are as equal length as possible. The idea being that the exhaust pulses will be spaced out evenly and arriving at the turbine wheel on the turbo at their own time in the firing order. If they arrive sooner or later, they may interfere with the exhaust pulses from the next firing cylinder. Next, a longer runner manifold will have better flow up top, while a shorter manifold can yield a faster spool, with also less transient lag. **1.2.5 Runner volume:** Runner volume needs to be considered when building a turbo manifold. While a larger runner diameter does facilitate lower exhaust backpressure for better flow on the top-end, it does cause a lower exhaust velocity. A lower exhaust velocity will cause longer spool times, and less transient response out of the turbo. **1.2.6 Collectors:** A collector's job is to tie all of the cylinder's pipes together in one common place and send them into a single exit pipe. A collector is generally a conglomeration of pipes all merged together, allowing for a smooth transition from the primaries or secondaries into the rest of the exhaust. When properly constructed, a good collector will take the low pressure waves created earlier and send them back up the primaries, thus quickening the entire evacuation process. There are two scenarios in which exiting exhaust gases will encounter once they move past the valve: low-pressure or high-pressure. Low-pressure situations within the exhaust pipes help promote better flow by allowing for increased velocity through the exhaust ports while high-pressure situations do the opposite.

1.2.7 Back pressure: Back pressure can be produced at two places, i.e., when the exhaust valve opens and cam overlap taking place shown in. Pressure measurements at the exhaust valve during the start of the exhaust stroke at bottom dead centre (BDC) to cam overlap at the end of the exhaust stroke/beginning of the intake stroke at top dead centre (TDC). Notice the positive (backpressure) spike at the far left as the exhaust valve just opens at BDC. The exhaust gases must now push against this POSITIVE (back) pressure before it can leave the combustion chamber. The pressure tracing is upwards and positive. Energy must be used up in order to overcome the initial positive (back) pressure in the exhaust system before the exhaust gas is pushed out of the combustion chamber. Further we must be able to overcome the positive back pressure. It well known that, the exhaust gas begins to travel faster and creates a NEGATIVE pressure.

In the .the pressure tracing is downward or has a negative value. When it is with a more negative pressure, then it means that, there is creation of more suction or a vacuum in the system. The system is literally sucking or pulling out exhaust gas from the combustion chamber or cylinder. This sucking or "SCAVENGING" affect not only helps to remove more exhaust gas from the cylinder. It also helps to suck more intake air and fuel mixture. Faster the exhaust gas travel more will be the vacuum creation. However, it is necessary to have much as negative pressure creation before cam overlaps.

2. LITERATURE REVIEW

The exhaust manifold of an engine is ceaselessly provided to warm gasses. Cast iron has been being utilized for the time of exhaust structures ordinarily. The fundamental attributes needed for the exhaust manifold material contain heat exhaustion great needed to look up to the high temperature drain gasses, oxidation obstruction , breath-taking assembling houses and low warm capacity to improve the reactant compositions. . Ferritic tempered steel show every such a homes and gives enormous weight reducing as well.

Progressions in vacuum tossing framework has helped inside the assembling of hardened steel confounded with fragment thickness of 2-5mm. Higher solicitations in disease oversee will up push the vapor temperatures as appropriately and thusly, ferritic treated steel might be in real use for exhaust structure delivering. Ferritic treated steel introductions upgrades warm exhaustion ascribes when arranged by means of strong affiliation building up with molybdenum or niobium. This framework moreover supplements the oxidation obstruction and microstructural assurance. Ferritic treated steel furthermore has gotten elements of interest because of the nonattendance of nickel in its creation. Another variation known as the austenite hardened steel is applied in which ferritic treated steel is inadmissible. Austenite stainless steel can improve its homes when enough carbon is brought to it. Be that as it could, the greater expense compels its utilization diverged from the ferritic variation. The comparing region in the space of the exhaust ports inside the chamber head. Some exhaust pipes have a seal between the line and the chamber head. The seals are intended to spill air/gases between the manifold head and the chambers. . Seals are normally made of copper, asbestos or paper. In various bundles, the machined surface promptly contacts the relating floor on the chamber head. The exhaust channels from each port inside the manifold are associated with the standard uncontrolled path prior to arriving at the manifold spine. The exhaust pipe is associated with the exhaust pipe spine. On a V-type motor, a header pipe is appended to every chamber head TMF breaking on exhaust manifolds is an issue that engine producers had been encountering more imperative constantly completed the latest decade. the fundamental clarification behind the TMF breaking is the out and out extending gas temperatures. Those temperatures have increase because of business focus demands for high explicit force and rules requiring low radiations. The extending fuel temperature is compared to 3 essential disillusionment parts in the exhaust manifolds Oxidation issues are overall settled using substances that have a predominant oxidation resistance. Regardless, seeing that oxidation is by and large dependant on temperature, reasonable courses of action with close by design changes (material, stacking = enduring) are incredibly problematic. Extra inconveniences lie in assessing the oxidation hurt, especially where a solid history is missing.

Studies were completed, which offer an oxidation hurt estimate show with an arranging part that has illustrated incredible associations for 1070 steel .However, to pick the structure boundaries, a tremendous variety of material tests are required and it is sketchy that the model could be considerable for various materials The fundamental point in surface decision isn't by and large to accomplish the marvelous oxidization zone under running conditions.

Fig:1 Top view of exhaust manifold

Current documentation isn't by and large solid moderately about the measure of sneak naughtiness in exhaust manifold applications. Regardless, extraordinary makers format slither deformation as the fundamental impact on broad mischief or remember gooey strain either unequivocally or positively in lifetime evaluation Testing of the exhaust manifold warm cycle involves stand time under both full burden and motoring conditions. Working the engine under full burden conditions (most limit temperature), challenge the exhaust manifold to compressive hundreds (out-of bit stacking). Under these occasions, slither hurt is seen as an assistant impact. regardless the measure of close by loosening

slither hurt is seen as an assistant impact anticipating the lifetime of the manifolds should considering the unequivocal key components of creep strain/hurt or certain consideration of the use of mean? Most weight dependence

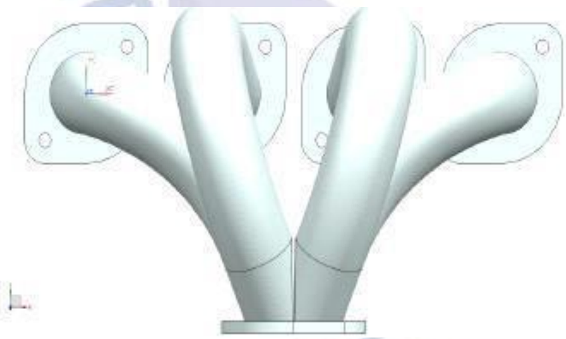


Fig:2 Log type manifold.

3. METHODOLOGY

Fizzle of exhaust manifolds are explicitly a direct result of the crazy temperature amplitudes/points the part needs to withstand. A helper justification screw ups is the powerful excitation of the vapour subsystem, explicitly if not irrelevant a few related segments like turbocharger or close coupled-catalyst are collided with resonation. Normal essential frustration modes are perplexing breaking and spillage. Those are connected with the plan and breaking point conditions if a proper surface tendency was executed regardless .Understanding the foundation goal of a failure is the most limit problematic part at the way toan answer.

3.1 Understanding Failures

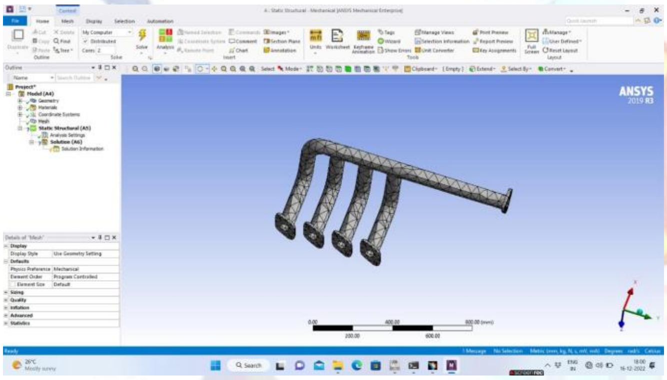
TMF Cracking A groundwork warm stacking of exhaust manifolds would thought process have the option to the material to outperform the yield strain in tremendous regions of the exhaust manifold. Cyclic temperature stacking reasons a couple regions to show adjoining cyclic plastic focusing of the material, which may besides perspective a split origin. Depending at the zone of the pointless stacked regions, particular arrangement boundaries ought to be considered for you to find a target arranged improvement technique. It winds up apparent that an all-around learning of the contraption direct is required, an incredible technique to translate results adequately. From an entertainment viewpoint the plans used for assessment need to take into account a nitty-gritty evaluation of individual boundaries. The planner needs to discover a compromise between disperse nature of model and breaking point conditions as opposed to unflinching quality. Specific organization limitations for each engine make singular complex answers. Thusly, influencing boundaries ought to be reflected for each plan before a system upgrade. Diversion is proper here a totally versatile instrument to assess the impact of every boundary. Depending at the grouping of boundaries, verifiable DOE methods may be used to capably instructional gathering the rule affecting boundaries.

Other than parting of exhaust manifold structures, the spillage bother may be each now and again additionally associated this mistake may be oftentimes chosen at the check seat with extending number of test cycles. At the point when spillage occurs, a midway pummeling of the gasket and the spine occurs, which may moreover achieve a subsequent complex split as a result of a changed weightskim inside the exhaust manifold.

3.2 High Cycle Fatigue

High cycle weakness (HCF) issues at the exhaust manifold are brought about by exceptional excitation. This sort of issue isn't by and large discovered occasionally, and is especially associated with threatening segment design. In a fundamental development, an Eigen repeat appraisal of the perplexing subsystem offers an basic idea; if the structure is peppy in the fundamental overpowering engine demands. Regardless, this offers simply a fundamental audit of the subsystem excitation and can be seen as a show for help assessments, in which an all-around exceptional examination veiling the get-together, temperature and dynamic stacking of the machine is directed to process the s upper fluous cycle shortcoming protecting edge.

4. RESULTS OF EXHAUST MANIFOLD



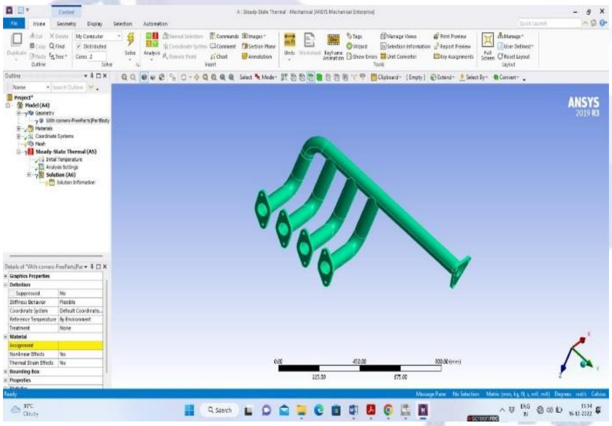


Fig:3 ALUMINIUM ALLOY

Fig:4 Meshed file

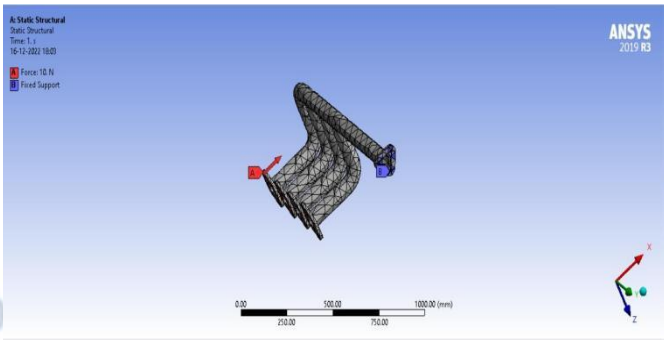


Fig:5 Boundary conditions of static structural

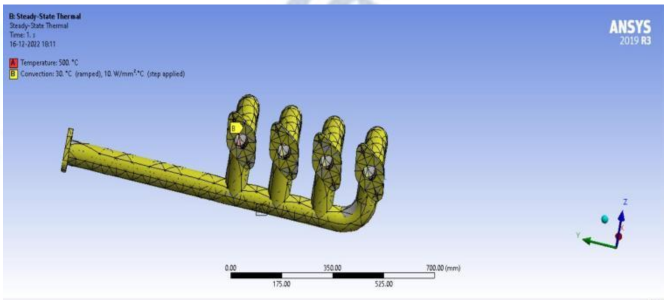
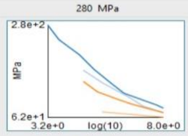


Fig:6 Boundary conditions of steady state thermal



Aluminum Alloy

General aluminum alloy. Fatigue properties come from MIL-HDBK-5H, page 3-277.

Density	2.77e-06 kg/mm³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	71000 MPa
Poisson's Ratio	0.33
Bulk Modulus	69608 MPa
Shear Modulus	26692 MPa
Isotropic Secant Coefficient of Thermal Expansion	2.3e-05 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	280 MPa
S-N Curve	
Tensile Ultimate Strength	310 MPa
Tensile Yield Strength	280 MPa

Fig:7 Imported file from Catia

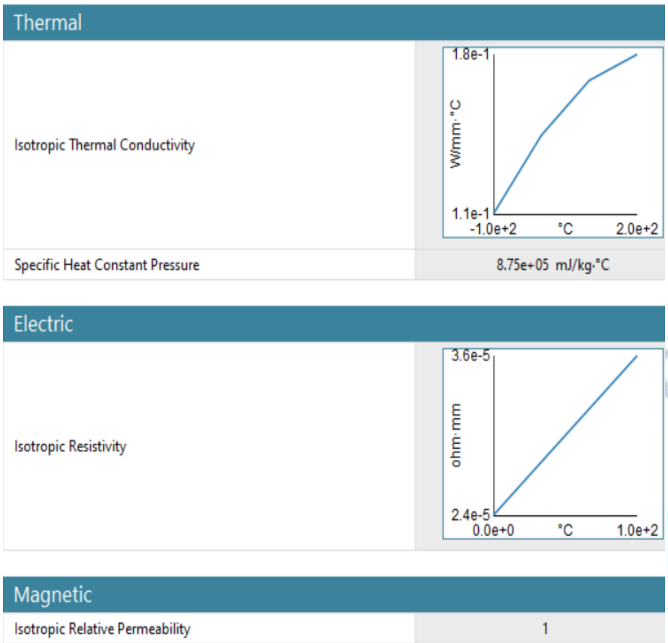


Fig:8 Material properties of aluminum alloy

Static Structural analysis of aluminium alloy

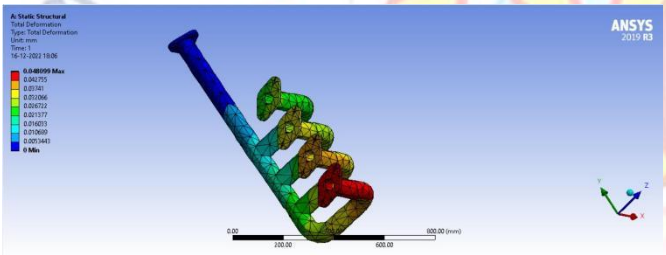


Fig:9 Total Deformation

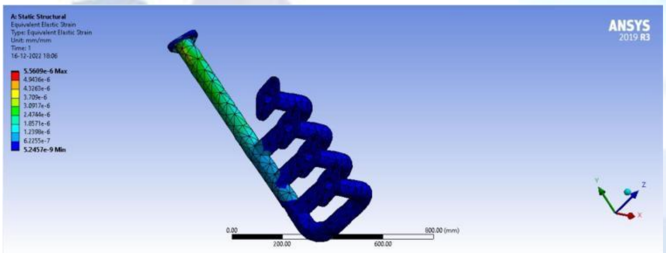


Fig:10 Equivalent elastic strain

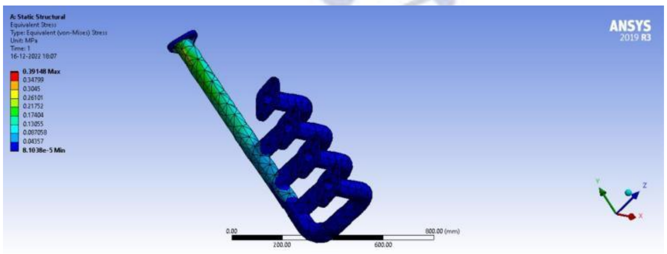


Fig:11 Equivalent stress

◉ Result Summary

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	0.	4.8099e-002	mm	1.
Equivalent Elastic Strain	5.2457e-009	5.5609e-006	mm/mm	1.
Equivalent Stress	8.1038e-005	0.39148	MPa	1.

Table:1 Results of aluminum alloy

4.1 Steady state thermal analysis of aluminium alloy

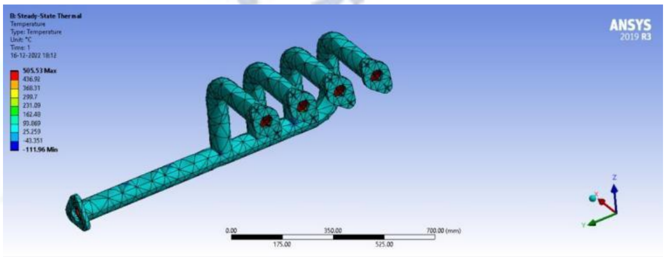


Fig:12 Temperature

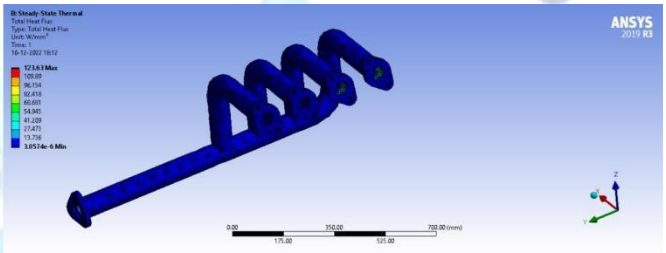


Fig:13 Total Heat flux

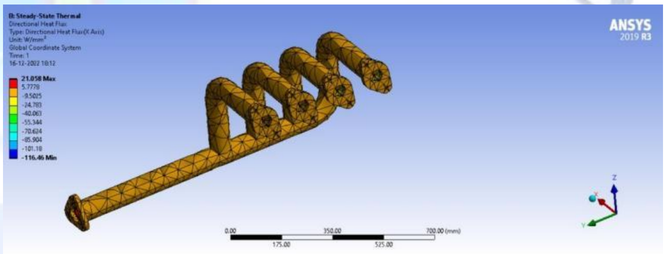


Fig:14 Directional Heat flux

◉ Result Summary

Results	Minimum	Maximum	Units	Time (s)
Temperature	-111.96	505.53	°C	1.
Total Heat Flux	3.0574e-006	123.63	W/mm²	1.
Directional Heat Flux	-116.46	21.058	W/mm²	1.

Table:2 Thermal results of aluminium alloy

4.2 MAGNESIUM ALLOY

Magnesium Alloy	
Density	1.8e-06 kg/mm³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	45000 MPa
Poisson's Ratio	0.35
Bulk Modulus	50000 MPa
Shear Modulus	16667 MPa
Isotropic Secant Coefficient of Thermal Expansion	2.6e-05 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	193 MPa
Tensile Ultimate Strength	255 MPa
Tensile Yield Strength	193 MPa
Thermal	
Isotropic Thermal Conductivity	0.156 W/mm·°C
Specific Heat Constant Pressure	1.024e+06 mJ/kg·°C
Electric	
Isotropic Resistivity	0.00077 ohm-mm

Table:3 Material Properties of magnesium alloy

4.3 Static structural of magnesium alloy

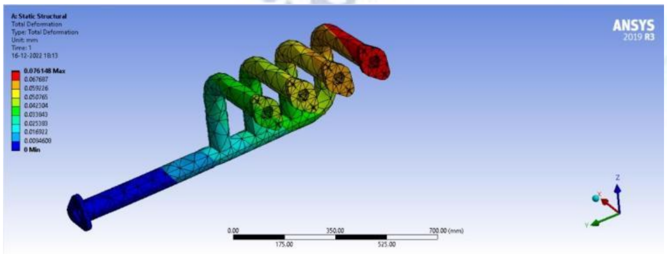


Fig:15 Total deformation

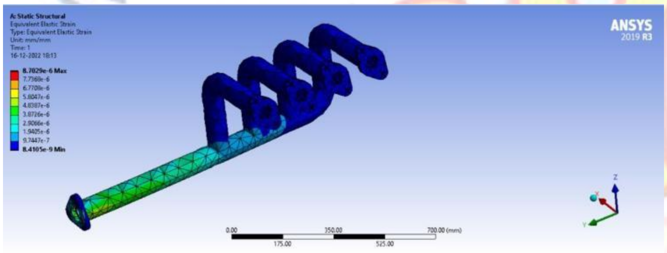


Fig:16 Equivalent elastic strain

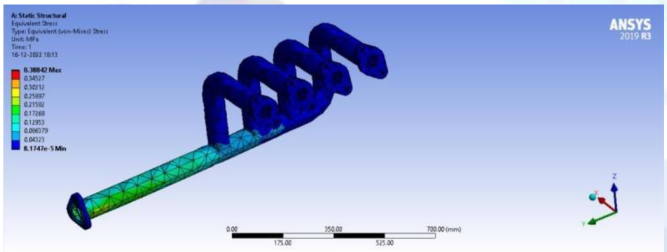


Fig:17 Equivalent stress

◉ Result Summary

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	0.	7.6148e-002	mm	1.
Equivalent Elastic Strain	8.4105e-009	8.7029e-006	mm/mm	1.
Equivalent Stress	8.1747e-005	0.38842	MPa	1.

Table:4 structural results of magnesium alloy

4.4 Thermal analysis off magnesium alloy

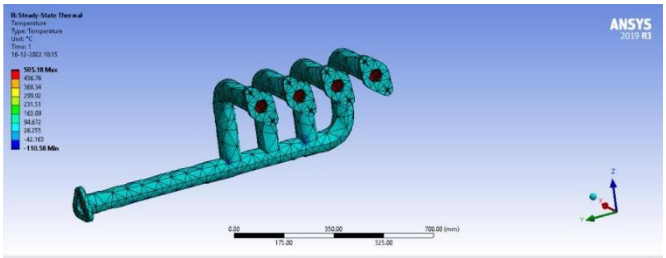


Fig:18 Temperature

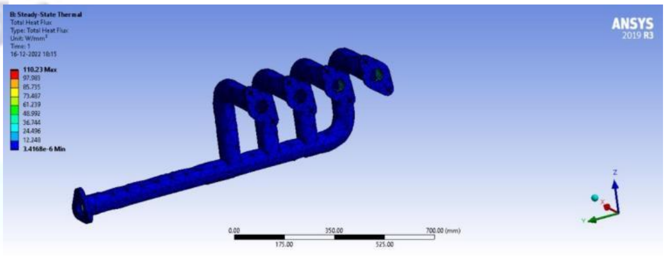


Fig:19 Total heat flux

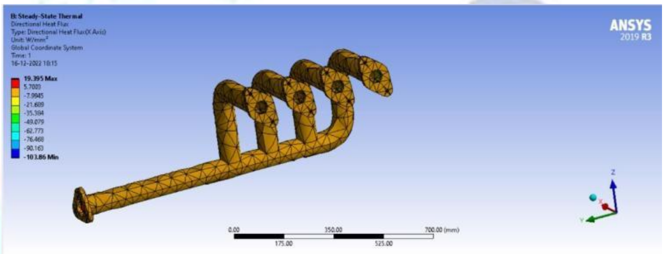


Fig:20 Directional heat flux

◉ Result Summary

Results	Minimum	Maximum	Units	Time (s)
Temperature	-110.58	505.18	°C	1.
Total Heat Flux	3.4168e-006	110.23	W/mm²	1.
Directional Heat Flux	-103.86	19.395	W/mm²	1.

Table:5 Thermal results of magnesium alloy

4.5 STAINLESS STEEL

Stainless Steel	
Density	7.75e-06 kg/mm³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	1.93e+05 MPa
Poisson's Ratio	0.31
Bulk Modulus	1.693e+05 MPa
Shear Modulus	73664 MPa
Isotropic Secant Coefficient of Thermal Expansion	1.7e-05 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	207 MPa
Tensile Ultimate Strength	586 MPa
Tensile Yield Strength	207 MPa
Thermal	
Isotropic Thermal Conductivity	0.0151 W/mm·°C
Specific Heat Constant Pressure	4.8e+05 mJ/kg·°C
Electric	
Isotropic Resistivity	0.00077 ohm-mm

Table:6 Material Properties of stainless steel

4.6 Structural analysis of Stainless Steel

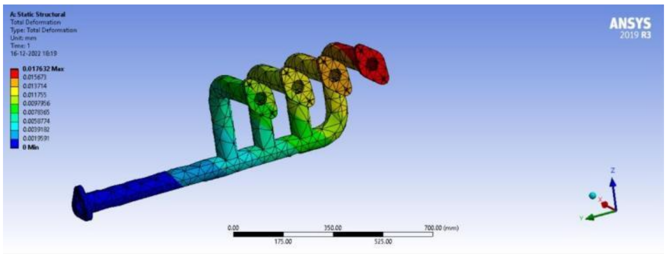


Fig:21 Total deformation

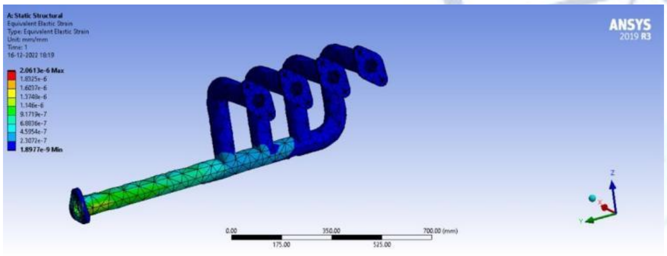


Fig:22 Equivalent elastic strain

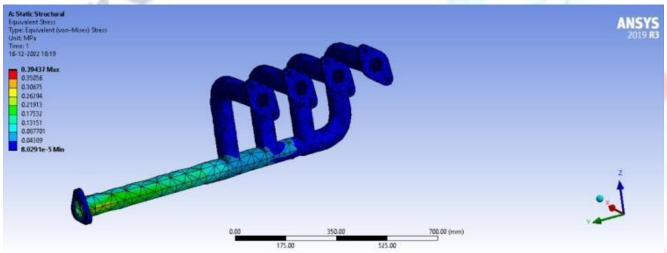


Fig.23 Equivalent stress

◉ Result Summary

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	0.	1.7632e-002	mm	1.
Equivalent Elastic Strain	1.8977e-009	2.0613e-006	mm/mm	1.
Equivalent Stress	8.0291e-005	0.39437	MPa	1.

Table:7 structural analysis of stainless steel

4.7 Thermal analysis of magnesium alloy

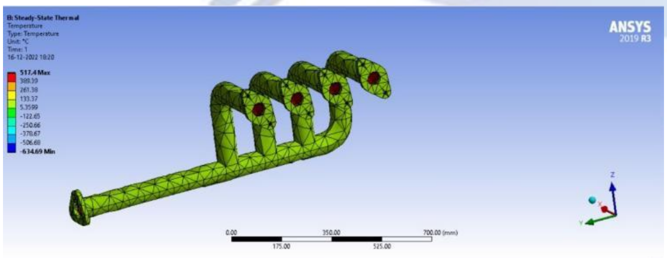


Fig:24 Temperature

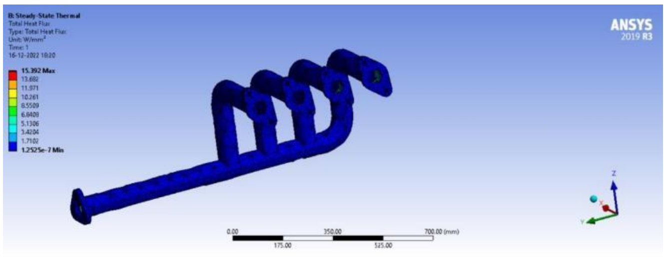


Fig:25 Total heat flux

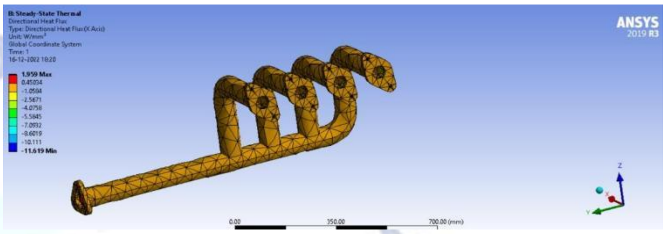


Fig:26 Directional heat flux

◉ Result Summary

Results	Minimum	Maximum	Units	Time (s)
Temperature	-634.69	517.4	°C	1.
Total Heat Flux	1.2525e-007	15.392	W/mm²	1.
Directional Heat Flux	-11.619	1.959	W/mm²	1.

Table:8 Thermal results of stainless steel

		uminiumalloy	**gnesiumalloy**	**Stainless steel**
eformation (mm)	**Minimum**	0	0	0
	Maximum	4.8099e-002	7.6148e-002	1.7632e-002
lent elastic strain	**Minimum**	5.2457e-009	8.4105e-009	1.8977e-009
	Maximum	5.5609e-006	8.7029e-006	2.0613e-006
alent stress (MPa)	**Minimum**	5.1038e-005	8.1747e-005	8.0291e-005
	Maximum	0.39148	0.38842	0.39437
Temperature (^oC)	**Minimum**	-111.96	-110.58	-634.69
	Maximum	505.53	505.18	517.4
tal heat flux (w/mm^2)	**Minimum**	3.0574e-006	34168e-006	1.2525e-007
	Maximum	123.63	110.23	15.392
Directional heat flux (w/mm^2)	**Minimum**	-116.46	-103.86	-11.619
	Maximum	21.058	19.395	1.959

Table:9 results of all materials

5. CONCLUSION

In this project we studied and learnt working of exhaust manifold and its types. Exhaust manifold modelled in CATIA V5 software by using different commands and tools. Model is converted into IGES (initial graphics exchange specification) file, and transferred to ANSYS 19 Workbench software for analysis.

Static and thermal analysis is performed on exhaust manifold to study its strength and heat characteristics such as force, loads and temperature. Force is 10 N and temperature is taken as 500^{o}C, and analysis is performed by three different materials such as stainless steel, Aluminium alloy and magnesium alloy.

Boundary conditions are applied on body. Self-load due to gravity is applied on model. Stress, stain, deformation, heat flux and mass of model on each material selection is noted and tabulated. According result table we can conclude that, Stainless steel is showing good thermal and good strength to weight ratio compare to Al and magnesium alloys and material as it showing less stress that is good strength and less weight. Hence we can conclude that stainless steel according good strength to weight ratio and economically better material than magnesium alloy.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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