DESIGN AND STATIC THERMAL ANALYSIS OF EXHAUST VALVE USING VARIOUS MATERIALS WITH FINITE ELEMENT METHOD

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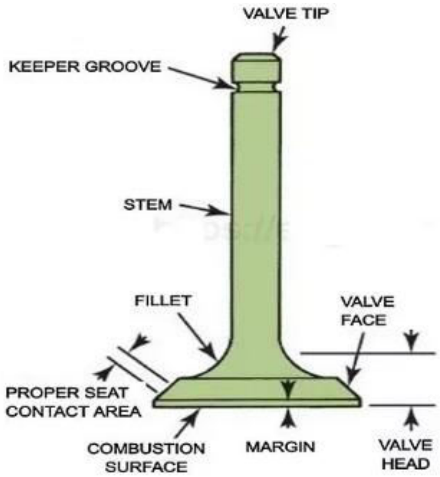
ABSTRACT

The exhaust valve is also an important part of the engine's emissions control system. The exhaust gases that pass through the exhaust valve are exposed to a catalyst, which helps to convert harmful pollutants into less harmful substances.Valves are essential components in engines for controlling the flow and exchange of gases. The intake valve allows fresh air and fuel to enter the combustion chamber, while the exhaust valve allows the exhaust gases to exit the chamber. Both valves are opened and closed by the valve train mechanism.running of an internal combustion engine is possible because of the exhaust valve. The exhaust valve is a critical component of an internal combustion engine that allows the passage of exhaust gases from the combustion chamber to the exhaust manifold. The exhaust valve is subjected to a number of stresses during operation, including:Axial stress due to the pressure of the exhaust gases, Cyclic stress due to the repeated opening and closing of the valve, Thermal stress due to the high temperature of the exhaust gases,Inertia force due to the mass of the valve and its components,This project aims to design and do the static and thermal analysis of the poppet valve used in CI engines. Modeling of the valve was done with the help of Catia V5 and static-thermal analysis was carried out in the ANSYS Workbench. Here we are using four materials i.e, Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, NIMONIC 105, AISI 4340, NIMONIC 80A. Finally suggesting the best material for poppet valve from these materials.

1.1.1INTRODUCTION TO I.C ENGINE INLET AND OUTLET VALVES:

Internal combustion (IC) engines are used in a wide variety of applications, from automobiles to construction machinery. They are a reliable and efficient source of power, and their applications are only growing. One of the most important components of an IC engine is the valve. Valves control the flow of air and fuel into and out of the engine, and they are subjected to high temperatures and stresses. Inlet valves allow air to flow into the combustion chamber, while exhaust valves remove the combusted gases.

The materials used for valves are carefully chosen to withstand the harsh conditions. Inlet valves are typically made of steel or aluminum, while exhaust valves are made of more heat-resistant materials such as nickel or cobalt alloys. The design of valves is also critical. The valve timing diagram determines when the valves open and close, and it is important to get this timing right to ensure efficient combustion.



Parts of exhaust valve

1.4 PROBLEM IDENTIFICATION:

The exhaust valve is a major component in an engine. It is responsible for controlling the flow of exhaust gases out of the engine. The exhaust valve is subjected to high temperatures and stresses, and the material used for the exhaust valve must be able to withstand these conditions.

Improper material selection for the exhaust valve can lead to premature failure. The exhaust valve may crack or break, which can cause serious problems for the engine.

LITERATURE REVIEW

[1] T.T.MON ET AL. (2021) carried out finite element analysis on thermal effect of the vehicle engine. In this work, the focus is given to the thermal and mechanical behavior of exhaust valves made of different materials. The analysis suggests the best material among them, which can be used for the construction of an exhaust valve.

[2] SAGAR.S. DESHPANDE ET AL. (2014) In order to improve the performance over time and fatigue life of a poppet engine valve, author utilized the Ansys programmed to study the effect of various materials and geometric parameters.

[3] S.K. RAJESH KANNA (2021) improved the valve output by coating alloy Al-Si on the engine valve's surface. Testing for alloy-covered valves, Al-Si has shown that mechanical characteristics have improved without affecting their performance.

[4] B SESHAGIRI RAO (2020) designed the exhaust valve for a four-wheel gasoline engine by theoretical calculations. The 2D drawings method is measured, and the 3D model and transient thermal analysis are performed on the exhaust valve when the valve is opened and closed. Analysis in ANSYS is performed.

[5] D.B. JANI (2022) introduced the system for thermal comportment study of the internal combustion engine exhaust valve. The research is to investigate the exhaust valve characteristics under thermal stress. The research findings are confirmed. The action of the exhaust valve under a given load and speed must be predicted accurately at the design level.

[6] LUCJANWITEK In recent years, several works have been done on the exhaust valve for various characteristics. The study "Failure and thermo-mechanical stress analysis of the diesel engine exhaust valve" This job involved performing a failure analysis on the diesel engine's exhaust valve. The non-linear finite element analysis was used to provide an explanation for the cause of premature valve damage. According to the results of the stress study done on the valve with the carbon deposit, there was significant bending stress in the valve stem.

[7] KUM-CHUL ET AL. In their article titled "A Study of Durability Analysis Methodology for Engine Valve Considering Head Thermal Deformation and Dynamic Behaviour," author addresses the problem of petrol engines' exhaust valve fracture. The stem region, where higher temperatures also occurred, was shown to have the highest levels of stress, according to the results. The stress at the valve head, which is comparable to the stress under the combustion pressure situation, is significantly lower than the stress on the valve neck, where the failure occurred.

[8] YUVRAJ K. LAVHALE and associates examined the general patterns of intake and exhaust valve failure. Numerous factors, such as fatigue, wear, thermal stress, and corrosion-erosion failure, which affect the mechanical properties of the valve material and its operation, might cause the exhaust valve to malfunction..

[10] B.E. GAJBHIYE ET AL. "Vibration Testing and Performance Analysis of IC Engine Exhaust Valve Using Finite Element Technique" Using FEA software, the author conducted a modal study of the valve. The valve's stem was discovered to be the area most severely impacted. The bottom side of the valve exhibits the distortion. High vibrations at resonance frequencies that are only a little bit higher than the exhaust valve's natural frequency could be the cause of damage to the exhaust valve.

[11] NARESH KR. RAGHUWANSHI ET AL. Research on the failure analysis of internal combustion engine valves was done by Overheating is the primary cause of valve failure, claim the authors. Decrease the strength of the material at high temperature, oxidation, and impact load.

[12] A.S.MORE ET AL. (2015) presented the analysis of valve mechanism and in that; they performed the kinematic and dynamic analysis of engine. They found that the valve mechanism is a complex system that is subjected to a variety of forces and moments. The kinematic and dynamic analysis of the valve mechanism can be used to improve the design and performance of the engine.

[13] PRADEEP KUMAR A.R.ET AL. (2016) performed heat transfer analysis in a low heat rejection diesel engine. They found that the heat transfer in the exhaust valve is a complex process that is influenced by a variety of factors, including the design of the valve, the material of the valve, and the operating conditions of the engine. The heat transfer analysis can be used to improve the design and performance of the exhaust valve.

[14] NARESH KR. RAGHUWANSHI ET AL. (2017) carried out failure analysis of internal combustion engine valves: A review. They reviewed the literature on the failure of internal combustion engine valves and found that the most common causes of failure are fatigue, wear, thermal loading, and corrosion-erosion. The failure analysis can be used to improve the design and manufacturing of exhaust valves to reduce their failure rate.

[15] A.S.MORE ET AL. (2015) presented the analysis of valve mechanism and in that, they performed the kinematic and dynamic analysis of engine. They found that the valve mechanism is a complex system that is subjected to a variety of forces and moments. The kinematic and dynamic analysis of the valve mechanism can be used to improve the design and performance of the engine.

PROJECT OVERVIEW

OVERVIEW OF PROJECT:

1. Be sufficiently stiff and strong mechanically.
2. Poppet valve is designed using CATIA software, and it is analysed using Ansys software.
3. Has the ability to effectively prevent heat before it reaches the Poppet surface.
4. Corrosion resistance at high temperatures.
5. Finally, it was determined that these materials would make good poppet valve material. Super Alloy 21-4N, AISI 4340, NIMONIC 80A, and NIMONIC 105 are examples of alloys.

SPECIFICATION OF THE PROBLEM:

The exhaust valve is a critical component of an engine. It is a moving component that is subjected to high temperatures and stresses. The valve head is a small disc, which is a functional requirement of the exhaust valve. However, the sudden change in cross-section at the junction of the valve stem and valve head can lead to stress concentration. This can cause the valve to fail prematurely. The stress concentration can be reduced by selecting a suitable material for the valve. The material should have high strength and stiffness to withstand the high stresses. It should also have good thermal conductivity to dissipate heat away from the valve.

The problem statement is to design an exhaust valve with modeling and structural-thermal analysis. The goal is to select a suitable material for the valve based on static and thermal values. The material that minimizes stress should be recommended as the best alternative material.

SPECIFICATION OF THE EXISTINGVALVE:

4-STROKE CI ENGINE-

a) Bore x Stroke (D X L) = 120 x 125 (mm),

b) Valve seat angle, □ □ 450,

c) Gas Velocity, vg= 2100m/min

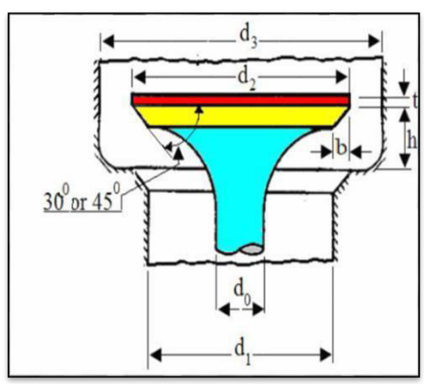
d) Length of stem = 10.5 cm,

e) Engine speed, Ns = 1150 rpm,

f) Max. Gas Pressure, Pmax= 6.0 N/mm2

g)Mean Piston Speed, N = 275 m/min,

h) Exhaust valve Temperature, T=7500C



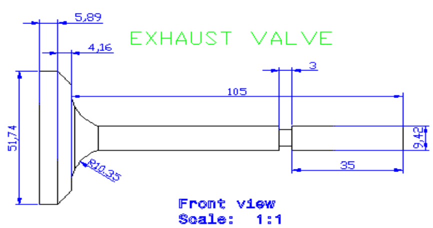
Geometry Of Exhaust Valve

DIMENSIONS OF EXHAUST VALVE:

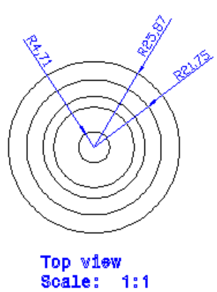
Sr. no	Design Parameter	Symbol	Dimension
1.	Port Diameter	d1	43.42
2.	Valve lift	h	15.35
3.	The thickness of valve disc	t	5.89
4.	Valve head Diameter	d2	51.74
5.	Width of seating	b	4.16
6.	Diameter of the valve stem	do	9.42

Table 2.Calculated dimensions of the exhaust valve

VALVE DRAWING WITH DESIGN DIMENSIONS:



Valve drawing with measurements



Top view of the poppet valve

3.8 MATERIALS PROPERTIES:

MATERIAL PROPERTIES	Density g/cm^3	Possion's Ratio (μ)	Young's modulus (Mpa)	Tensile strength (Mpa)	Thermal conductivity w/m°c	Specific heat J/kg °K
Ti-4.5Al-3V-2Fe2Mo	4540	0.32	110000	1023	17	518
Super Alloy21-4N	7720	0.31	215000	882.6	14.5	555
Nimonic 105	8195	0.31	222000	999.7	11.25	419
AISI 4340	7850	0.28	200000	745	44.5	460
Nimonic 80A.	8190	0.30	210000	1250	12.3	448

Table 4: Material Properties

INTRODUCTION TO CATIA

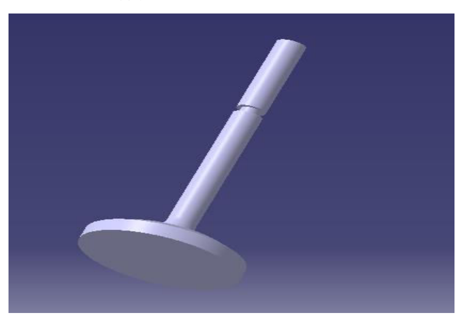
CATIA V5 is a high-end CAD/CAM/CAE software package that is used by thousands of users worldwide. It is a completely re-engineered, next-generation family of software solutions for Product Lifecycle Management (PLM).

CATIA V5 has a state-of-the-art user interface that makes it easy to use. It also offers innovative technologies for maximum productivity and creativity, from the inception concept to the final product.

CATIA V5 provides three basic platforms: P1, P2, and P3. P1 is for small and medium-sized companies that are looking to grow. P2 is for advanced design engineering companies that require product, process, and resource modeling. P3 is for high-end design applications, such as the automotive and aerospace industries.

EXHAUST VALVE DESIGN PROCEDURE IN CATIA:

Create the sectional view of the exhaust valve in Sketcher Workbench by selecting the line and rectangular corner options, and then go to Part Design Workbench and select the shaft option as indicated in the diagram below.

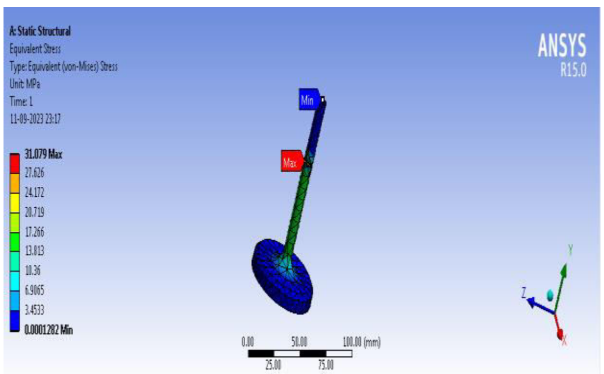


Exhaust valve in part design workbench

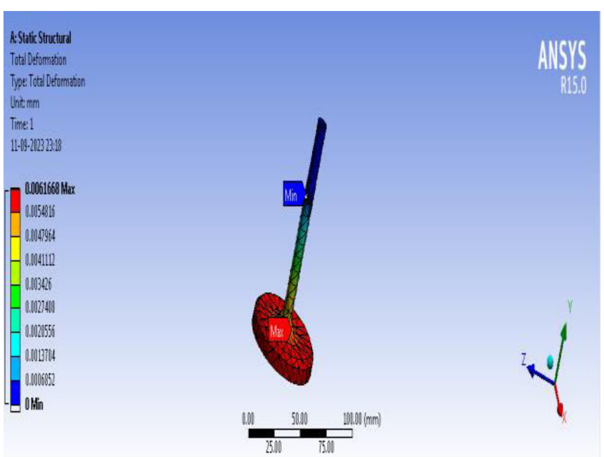
RESULTS AND DISCUSSIONS

The constructed exhaust valve in CATIA is analyzed using ANSYS V15.0 and the results are depicted below. Combustion of gases in the combustion chamber exerts pressure on the head of the exhaust valve. Consider the materials are Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, Nimonic 105, AISI 4340, Nimonic 80A. Fixed support has been given at the surface of the exhaust valve top part. Because the exhaust valve will move from up and down here consider the force is 1034.8N as shown below figure.

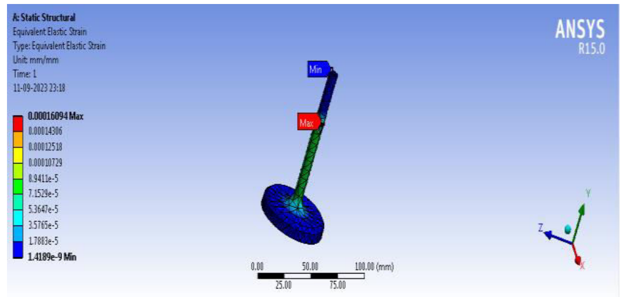
Ti-4.5Al-3V-2Fe2Mo Material:



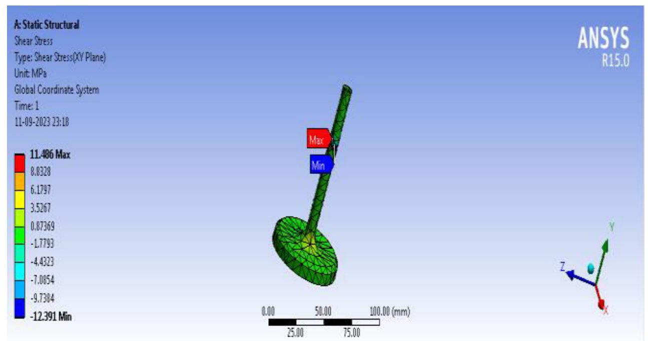
Von-misses stress of Ti-4.5Al-3V-2Fe2Mo Material



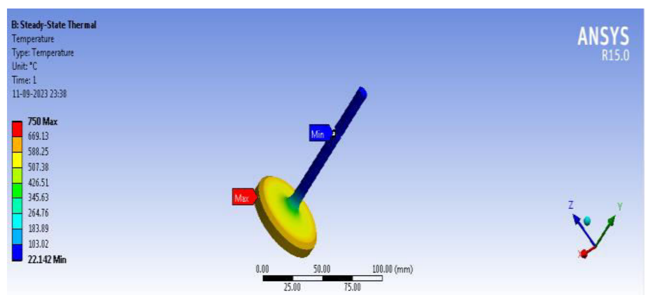
Total deformation of Ti-4.5Al-3V-2Fe2Mo Material



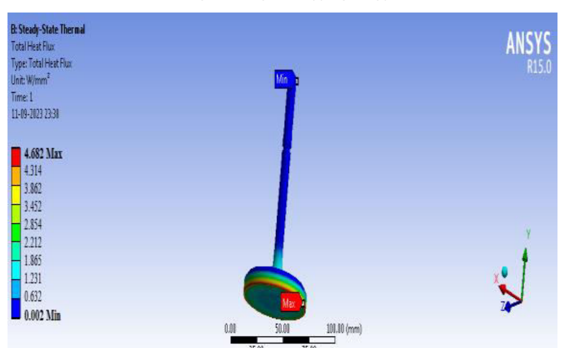
Strain of Ti-4.5Al-3V-2Fe2Mo Material



Shear stress of Ti-4.5Al-3V-2Fe2Mo Material



Temperature distribution of Ti-4.5Al-3V-2Fe2Mo Material



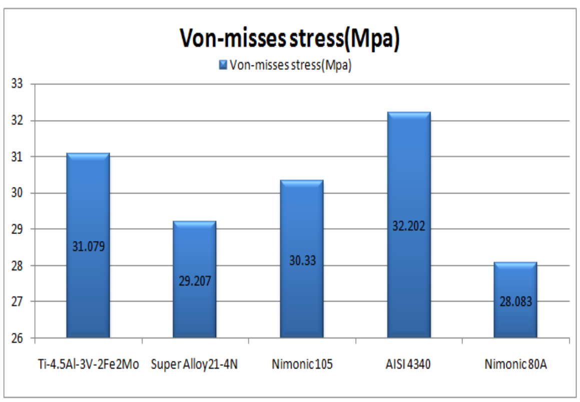
Total heatTi-4.5Al-3V-2Fe2Mo Material

GRAPHS:

The static structural analysis of Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, Nimonic 105, AISI 4340, Nimonic 80A are done and results are obtained for Equivalent Von-Misses stress, shear stress, total deformation, Temperature distribution, Total heat flux, These results are plotted graphically and a comparison is made between these results.

Von-misses stress graph:

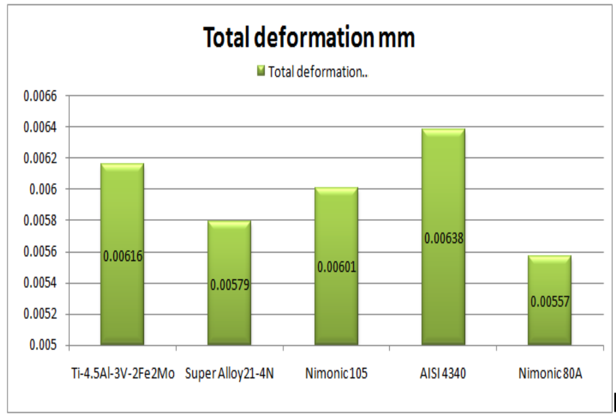
we can observe that in the case of equivalent von-misses stress, Exhaust valve various materials made of Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, Nimonic 105, AISI 4340, Nimonic 80A after analysis we found to have the least stress of 28.083Mpa and Ti-4.5Al-3V-2Fe2Mo 31.079 super alloy 21-4N 29.207 in comparison with remaining materials. The highest Von-misses stress of AISI 4340 is 32.202 Mpa observed as shown below the graph.



Von-misses stress graph

Total deformation graph:

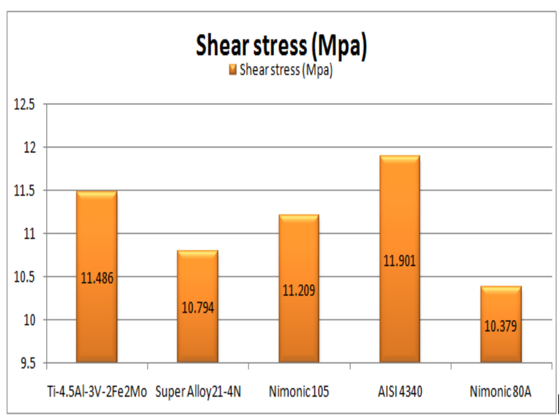
we can observe that in the case of Total deformation, the Exhaust valve various materials made of Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, Nimonic 105, AISI 4340, Nimonic 80A after analysis we found to have least Total deformation Nimonic 80 A 0.0057mm super alloy 21-4N 0.00579mm comparison with remaining materials. The highest Total deformation Ti-4.5Al-3V-2Fe2Mo is 0.00638mm observed as shown below the graph.



Total deformation graph

Shear stress graph:

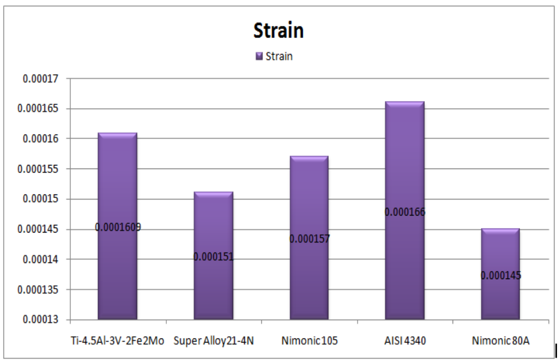
we can observe that in the case of equivalent Shear stress, Exhaust valve various materials made of Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, Nimonic 105, AISI 4340, Nimonic 80A after analysis we found to have least Shear stress of Nimonic 80A 10.379Mpa and super alloy 10.794Mpa in comparison with remaining materials. The highest Shear stress of AISI 4340 is 11.901 Mpa observed as shown below the graph.



Shear stress graph

Strain graph:

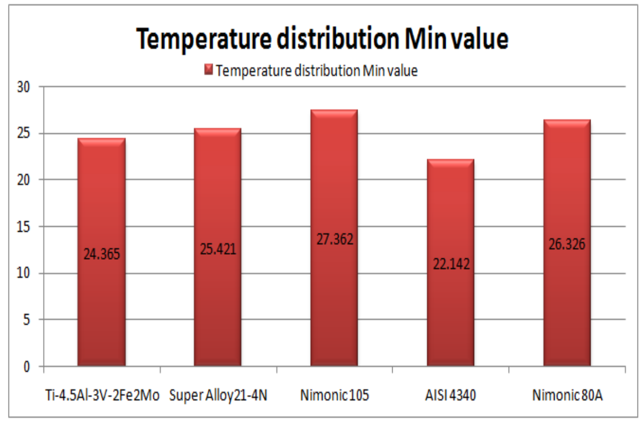
we can observe that in the case of Strain, the Exhaust valve various materials made of Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, Nimonic 105, AISI 4340, Nimonic 80A after analysis we found to have least strain Nimonic 80A 0.000145 and Super Alloy 21-4N 0.000151 in comparison with remaining materials. The highest strain AISI 4340 0.000166 observed as shown below the graph.



Strain graph

Temperature distribution Minimum:

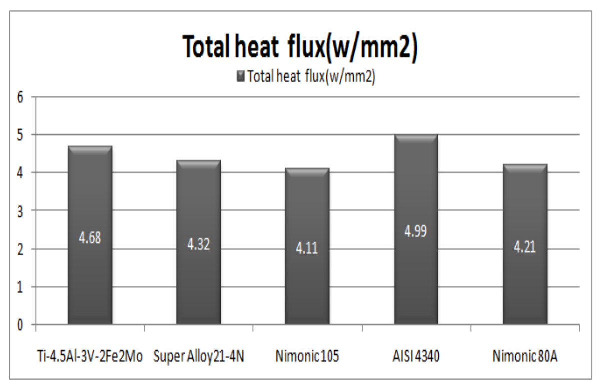
We can observe that in the case of Temperature distribution Exhaust valve various materials made of Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, Nimonic 105, AISI 4340, Nimonic 80A after analysis we found to have least value of Temperature distribution is AISI 4340 Ti-4.5Al-3V-2Fe2Mo 24.365, Super alloy 21-4N 25.421 Highest Temperature distribution is Nimonic 105 observed as shown below the graph.



Temperature distribution Min value graph

Total heat flux:

we can observe that in the case of Total heat flux w/mm^2, Exhaust valve various materials made of Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, Nimonic 105, AISI 4340, Nimonic 80A after analysis we found to have least Total heat flux w/mm^2 of Nimonic 105 4.11w/mm^2, Nimonic 80A 4.21 w/mm^2, Super Alloy 21-4N 4.32 W/mm^2, Highest Total heat flux AISI 4340 4.99 w/mm^2 observed as shown below the graph.



Total heat flux graph

CONCLUSION :

The exhaust gases that pass through the exhaust valve are exposed to a catalyst, which helps to convert harmful pollutants into less harmful substances.Valves are essential components in engines for controlling the flow and exchange of gases. The intake valve allows fresh air and fuel to enter the combustion chamber, while the exhaust valve allows the exhaust gases to exit the chamber.

In this project, the 3D model of the Exhaust poppet valve was designed by using CATIA software. The model is static and thermal analysis meshed by using ANSYS software. The static and thermal analysis was successfully done and carried out to determine the Von misses stress, deformation, Shear stress, and Temperature distribution and total heat flux on the Exhaust valve using various materials Ti-4.5Al-3V-2Fe2Mo, Super Alloy21-4N, NIMONIC 105, AISI 4340, NIMONIC 80A. Finally concluded the Ti-4.5Al-3V-2Fe2Mo, and Nimonic 80 A,Nimonic 105 is the suitable materials because of less Von misses stress, deformation, Shear stress, and better heat transfer of total heat flux compared to the remaining materials. so it is suitable for manufacturing the exhaust valve.

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