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Optimal selection of valve material for C I engines using ANSYS

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Exhaust valve of an Internal Combustion engine is one of the most critical parts. It is the source of most problems like pre-ignition, run-on etc. Design of valves depends on many parameters, like fluid dynamics of exhaust gas, fatigue strength of valve material, oxidization characteristics of valve material and exhaust gas, behavior of material at high temperature, the configuration of the cylinder head, the coolant flow, the shape of the exhaust port. The most significant factor underlining the performance of a valve is its operating temperature. The importance of temperature can best be appreciated by its affect on the physical properties of the valve material. Most automotive exhaust valves operate in the temperature range of from 650^{o} C to 875^{o} C. It is therefore proper care has to be given in selecting the material for the valve operating at high temperatures. This project deals with the stress induced in a valve due to high thermal gradient and high pressure inside the combustion chamber. To analyze the valve ANSYS has been used as the tool. A thermal and structural analysis is performed on the valve. In the first stage of analysis the temperature distribution across the valve is determined. In the second stage this temperature distribution is transferred on to another element and pressure load was applied on the valve to determine the displacement distribution in the valve. The above said process will be repeated for the different valve materials and finally the best material will be suggested for the valve based on its strength and thermal properties capability.

I. INTRODUCTION

The heads of the valves are subjected to the high temperature of the burning gases, and it is essential that they should not warp under the influence of the heat, and That their seats should not scale or corrode, as in either case they would become leaky. Occasionally small particles of scale will get onto must be of sufficient hardness at the high temperature at which they operate so they will not pit under this condition. Lubrication of the valve stems is hard to effect, and the stems must not wear too rapidly in their guides, even though poorly lubricated or not lubricated at all. That portion of the stem immediately below the head is subject also to the heat of the burning gases which, when the exhaust opens rush by it at a velocity of up to 91.4m/s; and to the corrosive action of unconsumed, hot oxygen and intermediate products of combustion.

Trouble of a rather serious nature is sometimes caused by valves breaking a short distance below the head, at the point where their working temperature is the maximum.

This is probably due to corrosion fatigue; in other words, it results from repetitive applications of mechanical stress combined with corrosive action by the exhaust gases or certain constituents thereof. Air-hardening properties of the valve steel sometimes have been blamed for such breakages, but these latter occur also with valves made of a steel having no such properties.

High resistance to corrosion fatigue is therefore desirable in valve steels. Finally, the tip of the stem receives a quick succession of blows from the tappet as the clearance is being taken up, and it must be sufficiently hard to withstand these blows without undue wear. Hardening of the tips is sometimes affected by the so-called cyaniding process (dipping in a bath of molten potassium ferro-cyanide).

II. VALVE OPERATING TEMPERATURES

Tests have shown that under continued full-load conditions, exhaust valves may reach a temperature of 800°C-a cherry red. Valves of large diameter run hotter than smaller ones, and the valve temperature increases with engine speed. An increase in the compression ratio, as a rule, lowers the valve temperature, but if the compression is carried too high and detonation sets in, the effect is reversed. It is usually assumed that exhaust valve temperatures are highest with retarded ignition and weak mixtures, probably because the exhaust pipe is hottest under these conditions, but a large number of tests carried out on a particular engine showed that the reverse holds true, the exhaust-valve temperature being lower with a weak mixture and retarded ignition. The explanation is that the temperature of the valve depends not only on that of the exhaust gases, but also on the temperature of combustion, which latter is lowered by weakening the mixture and retarding the spark.

It was found that the exhaust valve ran cooler when a long valve guide was used; that is, when the valve guide was carried closer to the valve head. The guide then has the effect of protecting the valve stem from the hot gases passing through the valve immediately after opening. One objection to such a long valve guide is that it is difficult to lubricate, and as a result wear on both the valve stem and guide is rapid. The experiment was therefore tired of enlarging the bore of the guide 0.4mm.by counter boring from the valve-head end as far as the wall of the valve pocket, and this was found to result in decreasing the valve temperature (27° at 1500 rpm and 72° at 4500 rpm). An increase in the valve-stem diameter from 8.7mm to 10mm. lowered the temperature of the valve about 40°throughout the speed range. If an exhaust valve becomes leaky, as, for instance, through "dishing" of its head by reason of loss of strength at high temperature, through improper adjustment, or through excessive warping, the head will be destroyed very quickly, as the burning gases will then blow by it.

A. EXHAUST VALVES

Exhaust valves operate under relatively more severe conditions on account of higher temperatures involved. An exhaust valve is subjected to:

1. Longitudinal cyclic stresses due to the return spring load and the inertia response of the valve assembly.
2. Thermal stresses in the circumferential and longitudinal directions due to the large temperature gradient from the centre of the head to its periphery and from the crown to the stem. A typical variation of temperature in an exhaust valve is given in Fig.
3. Creep conditions due to operation at very high temperatures, particularly in case of valve head.
4. Corrosion conditions.

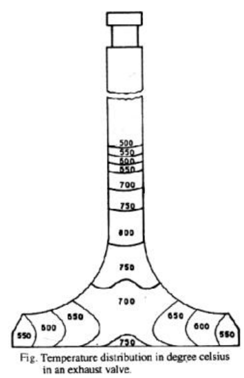

Fig 1 .Temperature Distribution Exhaust Valve

B. EXHAUST VALVE MATERIAL REQIREMENTS

On account of operating conditions described above the material for exhaust valve should have the following requirements

1. High strength and hardness to resist tensile loads and stem wear.
2. High hot strength and hardness to combat head cupping and wear of seats.
3. High fatigue and creep resistance.

4. Adequate corrosion resistance.
5. Least coefficient of thermal expansion to avoid excessive thermal stresses in the head.
6. High thermal conductivity for better heat dissipation.

III.ANSYS ANALYSIS

By using ansys software we can analyse the exhaust valve for various materials such as 21-4A, Nimonic 80A, Nimonic 105for structural and thermal analysis. From this analysis we can find out the best material for exhaust valve. Static analysis is used to determine the displacements stresses, stains and forces in structures or components due to loads that do not induce significant inertia and damping effects. Steady loading in response conditions are assumed. The kinds of loading that can be applied in a static analysis include externally applied forces and pressures, steady state inertial forces such as gravity or rotational velocity imposed (non-zero) displacements, temperatures (for thermal strain). A static analysis can be either linear or non linear. In our present work we consider linear static analysis.

The procedure for static analysis consists of these main steps

- Building the model
- Obtaining the solution
- Reviewing the results.

A.THERMAL ANALYSIS

- A thermal analysis calculates the temperature distribution and related thermal quantities in brake disk. Typical thermal quantities are:
- 1. The temperature distribution
- 2. The amount of heat lost or gained
- 3. Thermal fluxes

Types of thermal analysis:

- 1. A steady state thermal analysis determines the temperature distribution and other thermal quantities under steady state loading conditions. A steady state loading condition is a situation where heat storage effects varying over a period of time can be ignored.
- 2. A transient thermal analysis determines the temperature distribution and other thermal quantities under conditions that varying over a period of time.

B.STRUCTURAL ANALYSIS

- Structural analysis is the most common application of the finite element analysis. The term structural implies civil engineering structure such as bridge and building, but also naval, aeronautical and mechanical structure such as ship hulls, aircraft bodies and machine housing as well as mechanical components such as piston, machine parts and tools. A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects such as those caused by time varying loads. A static analysis can, however include steady inertia loads (such as gravity and rotational velocity), and time varying loads that can be approximated as static equivalent loads (such as static equivalent wind and seismic loads).

IV.MODELING AND ANALYSIS

It is not mandatory to exactly model the exhaust valve, in which there are still researches are going on to find out thermo elastic behavior of exhaust valve during its operations. There is always a need of some assumptions to model any complex geometry. These assumptions are made, keeping in mind the difficulties involved in the theoretical calculation and the importance of the parameters that are taken and those which are ignored. In modeling we always ignore the things that are of less importance and have little impact on the analysis. The assumptions are always made depending upon the details and accuracy required in modeling.

The assumptions which are made while modeling the process are given below:-

1. The valve material is considered as homogeneous and isotropic.
2. The domain is considered as axis-symmetric.
3. Inertia and body force effects are negligible during the analysis.
4. The analysis is based on pure thermal loading and structural and thus only stress level due to the above said is done. The analysis does not determine the life of the exhaust valve.
5. The exhaust valve model used is of solid type.
6. The thermal conductivity of the material used for the analysis is uniform throughout.
7. The specific heat of the material used is constant throughout and does not change with temperature.
8. Under normal operation, when the valve is properly seating at the cam ramp, stresses arising from seating are quite moderate. They can become very high when the valve train is improperly engineered so that the valve bounce occurs, or when the engine is over speeded or the valve lash is improperly set. In this analysis the stresses due to valve seating has been not taken into account assuming a normal operation.
9. The distortion stresses in a valve arise due to misalignment of valve with the seat. The valve head must deflect to accommodate to the seat, and this causes bending stresses in the stem. Under most conditions, gas pressures and spring loads will be sufficient to bring the valve head into conformity with a mildly distorted seat.
10. The engine considered for the analysis is a medium range engine (500 kW). It is assumed that it is water cooled.
11. The heat generated inside the chamber is taken away by water chamber around cylinder liner and in the cylinder head.
12. The temperature of water in the chamber is maintained at 50^{o} C. Heat from valve is lost through this water only.
13. The valve keeps popping up and down. The analysis has been done for a stationary valve assuming that the fatigue life of the valve is very high and the stress arising due to that has been neglected.

V. DEFINITION OF PROBLEM DOMAIN

The sources of stress in an exhaust valve are as follow-

1) Thermal stresses

i. Temperature gradient

2) Mechanical stresses

i. Stress arising from seating

ii. Distortion stress

Gas pressure and mechanical load

A medium range engine with rating 500 kW produces around 60-80 bar of pressure and the temperature inside combustion chamber varies from 800 - 1200^{o}. The combustion process for spark ignition and compression ignition are different. Even the condition inside the chamber is different for SI and CI engines. The condition here taken is for CI engines. But the same analysis can be done for SI engines by varying the boundary conditions.

The heat generated inside the chamber is so high that it becomes very important to remove it continuously. The heat transfer from an engine takes place in following ways -

1. water cooled - medium and large engines are usually water cooled the range of such engines varies from 100 hp - 8000 hp.
2. sodium cooled - this takes place in very large engines.
3. air cooled - Most of the small engines and some medium engines are air cooled.

The above mentioned stresses induced in the exhaust valve results in valve failure during repeated gas pressure loading and thermal loading. This could be overcome by changing the valve materials as stresses induced are influenced by the material of the exhaust valve.

A. DIMENSIONS OF EXHAUST VALVE

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The dimensions of exhaust valve used for transient thermal and static structural analysis are shown in Fig.

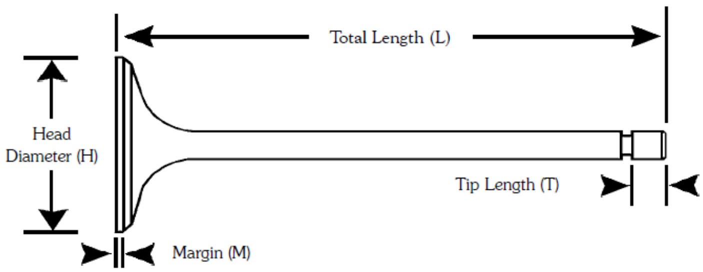

Fig 2. Dimensions of Exhaust Valve

B. CREATING A FINITE ELEMENT MODEL AND MESH

AXISYMMETRY MODEL:

1. From the blue print, the dimensions of the exhaust valve are taken and modeled in the Ansys.
2. Axisymmetric Model - As the geometry of the Valve is symmetry about its axis, its enough to model only half of the exhaust valve.
3. The drawn axisymmetric model of the exhaust valve can be converted into 3D Model at any time in the Ansys software with the help of the EXPANSION commands available in it.

. 4. Treating the exhaust valve model as axisymmetric, would drastically reduce the

Computational time and cost which is one of the major roles of the design engineer while attempting any analysis problem in the Ansys software.

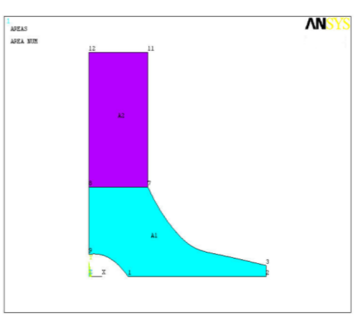

Fig 3. Axisymmetric model of Exhaust Valve

B.MODEL WITH MESH

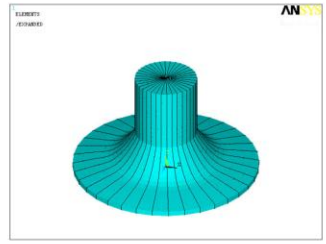

Fig 4. 3 Dimensional model of Exhaust Valve with mesh

C. ELEMENT GEOMETRY

The element type PLANE 35 2D 6 Node Triangular solid is taken for the transient analysis of the disc brake rotor. The disc brake rotor is assumed to be axisymmetric problem in 2D as the geometry of the rotor is symmetric about its axis. To reduce the computational costs of the analysis, the problem is treated as 2D axisymmetric. for the analyze of any 2D axisymmetric thermal problem, PLANE 35 2D 6 Node Triangular is considered to be the right choice as each of it nodes degree of freedom represent temperature. As the temperature distribution is our concern in the thermal transient analysis, this element type fulfills it. Node in the mid side of this element represents that the field variable temperature variation is parabolic along the element edge this in turn gives very accurate solution.

PLANE35 - 2-D 6-Node Triangular Thermal Solid

A. PLANE35 Element Description

PLANE35 is a 6-node triangular element compatible with the 8-node PLANE77 element. The triangular shape makes it well suited to model irregular meshes (such as produced

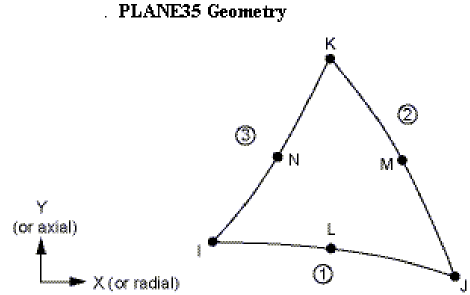

Fig 5. Plane 35 geometry

from various CAD/CAM systems). The element has one degree of freedom, temperature, at each node. The 6-node thermal element is applicable to a 2-D, steady-state or transient thermal analysis. If the model containing this element is also to be analyzed structurally, the element should be replaced by an equivalent structural element (such as PLANE2). The element may be used as a plane element or as an axisymmetric ring element.

D. MATERIAL PROPERTIES

Table 2. Materials Properties of valves

Properties	**21-4N**	**Nimonic 80A**	**Nimonic 105**
Modulus of elasticity	2E5 N/mm^2	2.2 E5 N/mm^2	2.2 E5 N/mm^2
Thermal expansion	18.8 E-6 / K	14.5 E-6 / K	12.2 E-6 / K
Thermal conductivity	14.5 W/m K	13 W/m K	10 W/m K

E. BOUNDARY CONDITIONS

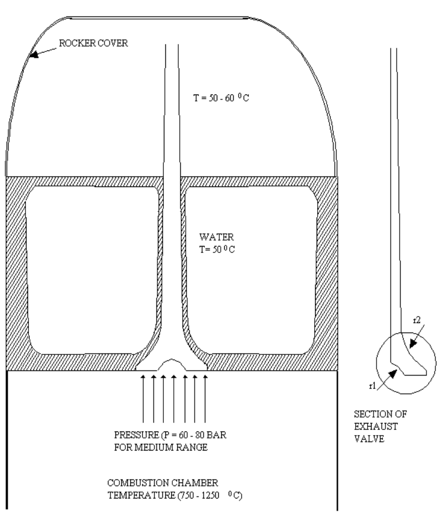

Fig 5. Boundary Conditions

For Thermal analysis the temperature on the surface was considered to be 50^o C. In practice this temperature is substantially high because this surface comes in contact with the exhaust gas. For structural analysis the pressure inside the combustion chamber was taken to be 60 bar. The constrains on the valve was applied from the top since essential and non-essential boundary conditions can't be applied at the same boundary.

VI.RESULTS AND DISCUSSION

Thermal and structural analysis of the exhaust valve for different materials such as 21-4N, Nimonic 80A and Nimonic 105 are carried out using Ansys software. The properties of different exhaust valve materials such as thermal conductivity, thermal expansion, density, specific heat, young's modulus are given as input for the steady state thermal analysis. The boundary conditions at the outer and the inner surfaces are given as input which has been considered for the specified operating conditions is given as the thermal load in to the FEA model. The results for the three different exhaust valve materials are given below. As the analysis carried out was steady state thermal and structural the results for all the materials are

A.21-4N:

THERMAL ANALYSIS

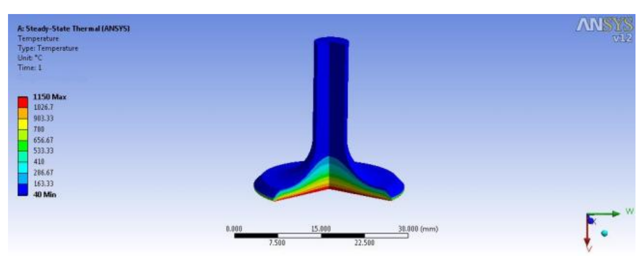

Fig 6. Temperature distribution of 21-4N

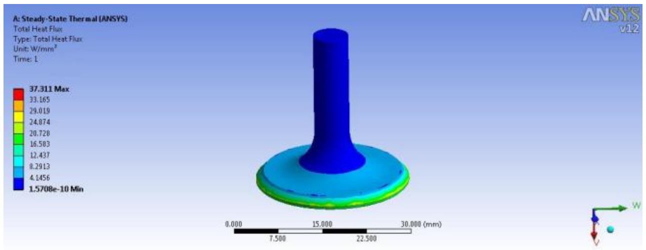

Fig 7. Heat flux distribution of 21-4N

STATIC STRUCTURAL ANALYSIS

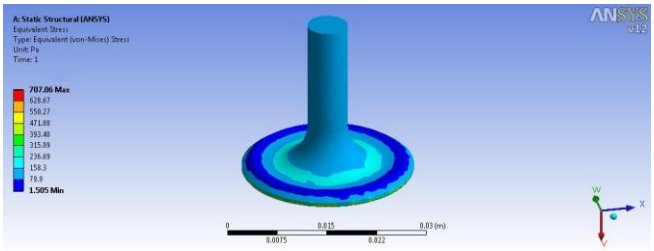

Fig 8. Equivalent stress of 21-4N

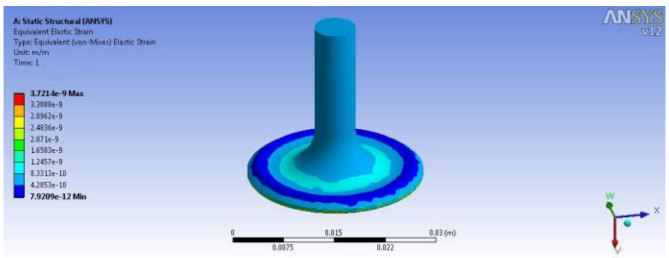

Fig 9. Equivalent strain of 21-4N

B. NIMONIC 80A

THERMAL ANALYSIS

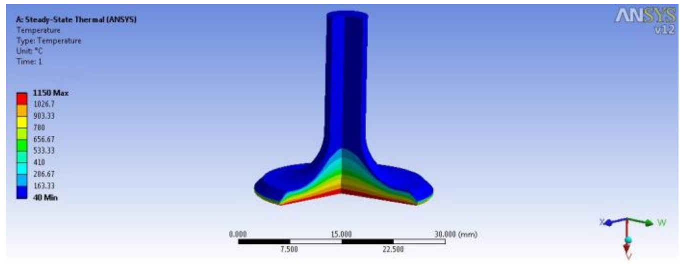

Fig 10. Temperature distribution of Nimonic 80A

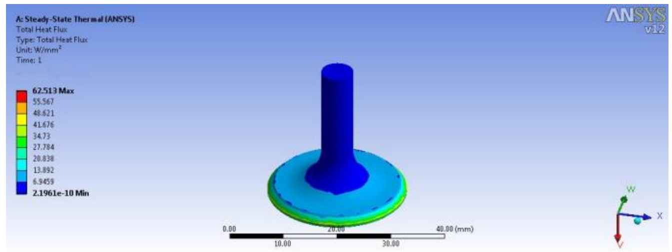

Fig 11. Heat flux distribution of Nimonic 80A

STATIC STRUCTURAL ANALYSIS

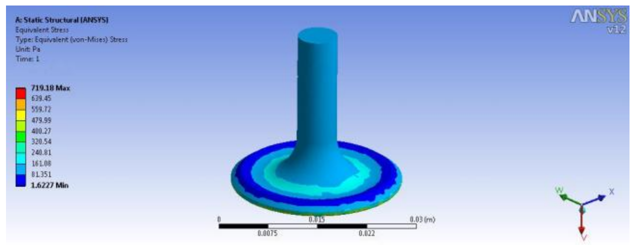

Fig 12. Equivalent stress of Nimonic 80A

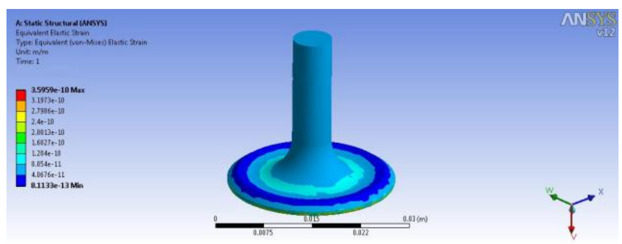

Fig 13. Equivalent strain of Nimonic 80A

C. NIMONIC 105

THERMAL ANALYSIS

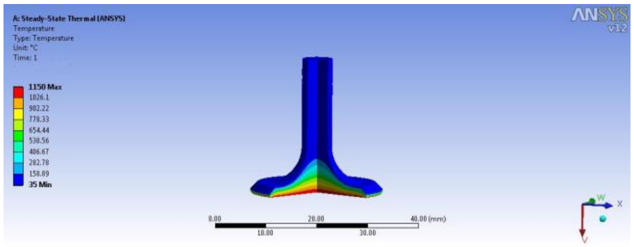

Fig 14. Temperature distribution of Nimonic 105

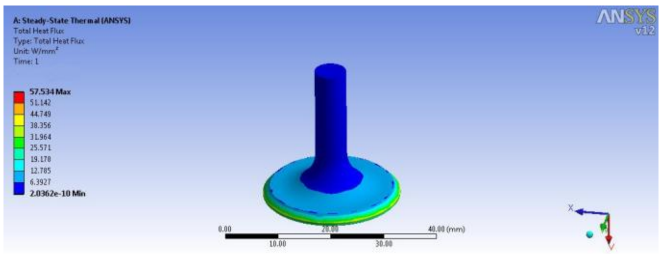

Fig 15. Heat flux distribution of Nimonic 105

STATIC STRUCTURAL ANALYSIS

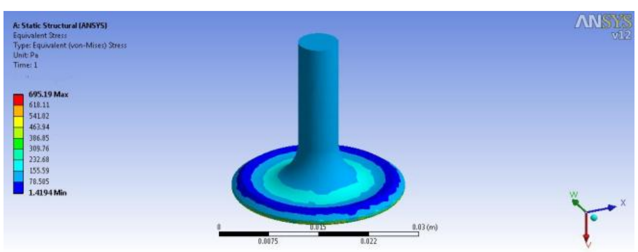

Fig 16. Equivalent stress of Nimonic 105

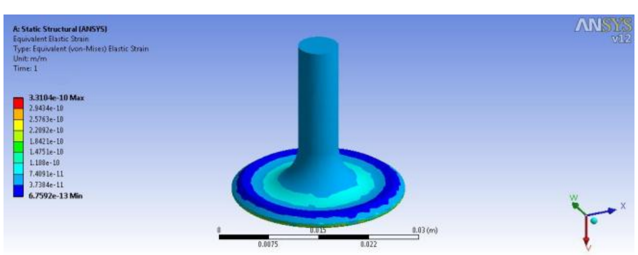

Fig 17. Equivalent strain of Nimonic 105

D. EQUIVALENT STRAIN VS MATERIAL TYPE

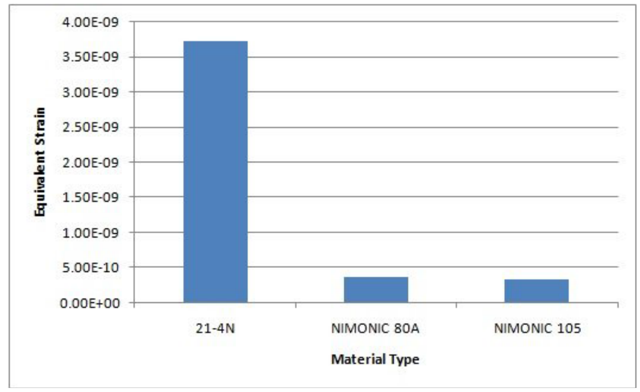

Fig 18. Equivalent strain vs Material type

F. EQUIVALENT STATIC STRESS VS MATERIAL TYPE

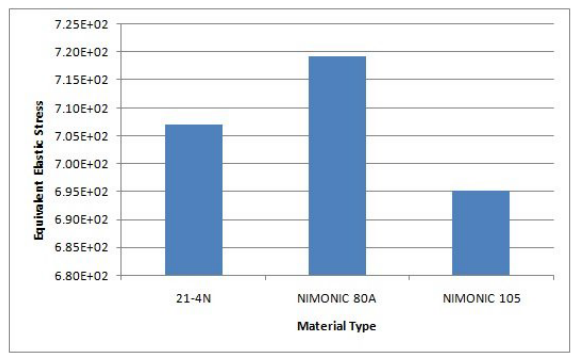

Fig 19. Equivalent static stress vs Material type

G. TOTAL HEAT FLUX VS MATERIAL TYPE

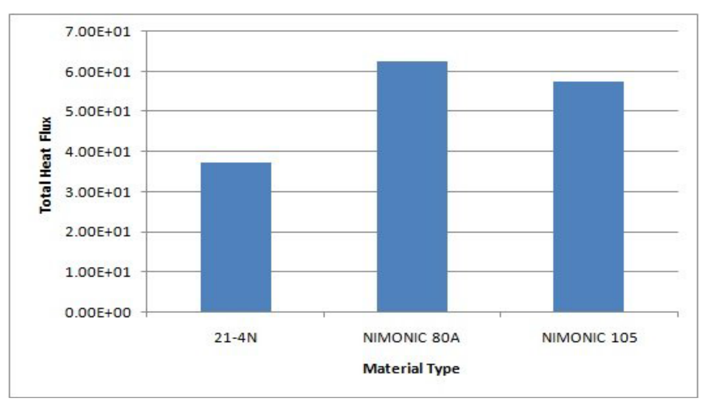

Fig 20. Heat flux vs Material type

VII.CONCLUSION

Static structural analysis of the exhaust valve for different materials such as 21 4N, Nimonic 80Aand Nimonic105A is carried out. The properties of different exhaust valve materials such as thermal expansion, young's modulus are given as input for the structural analysis. The outer surface is constrained which has been given as the mechanical load in to the FEA model. The results for the three different valve materials are given above. It has been concluded from the results that among the three materials chosen for the structural analysis, the Nimonic105A are best as far as stiffness are concerned compared to the other two material as the maximum displacement in the Nimonic105A is greater than the other two material which is evident in the figure above.

A detailed study about engine valve and its failure has been done, the steady state thermal analysis and structural analysis of the exhaust valve for the different materials such as 21 4N,Nimonic 80A and Nimonic105A have been analysed using ANSYS software.

From the above graph plotted between equivalent strain and material type Nimonic 105 has the lower equivalent strain value when compared to Nimonic 80A and 21-4N. Thus Nimonic 105 is preferable material as per equivalent strain analysis concerned

From the above graph plotted between equivalent elastic stress and material type Nimonic 105 has the lower equivalent elastic stress value when compared to Nimonic 80A and 21-4N. Thus Nimonic 105 is preferable material as per equivalent stress analysis concerned.

From the above graph plotted between total heat flux and material type Nimonic 80A and Nimonic 105 has the greater heat flux distribution when compared to 21-4N. Thus Nimonic80A and Nimonic 105 is preferable material as per equivalent stress analysis concerned .From the structural and thermal analysis results for all the three valve materials have been analyzed , its been concluded that the displacement values for the Nimonic105A is very less than the values of other material steel for the same thermal load and Structural loads. It's evident from the analysis, the best material for the valve is Nimonic105A as far as thermal and structural behavior is concerned.

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