Thermo Mechanical Analysis of Engine Valve

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Abstract: ***Exhaust valve of an Internal Combustion engine is one of the most crucial parts. It is the main cause of most problems like pre-ignition, burned valves etc. Design of the valve depends on many parameters likebehavior of material at high temperature, fluid dynamics of exhaust gas, oxidization characteristics of valve material and exhaust gas, fatigue strength of valve material, configuration of the cylinder head, coolant flow and the shape of the exhaust port. The most important factor affecting the performance of a valve is its operating temperature. 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 is used as the tool. Thermal and structural analyses are 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 will be applied to the valve to determine the displacement distribution in the valve. The above said process is repeated for the different valve materials and finally the best material is suggested for the valve based on its strength and thermal properties.***

Keywords: exhaust valve, analysis, temperature, stress, alloy, nimonic

1. Introduction

The valves used in internal combustion engines are of the three types; 1.Poppet or mushroom valve; 2.Rotary valve; 3.Sleeve valve. Out of these three valves, poppet valve is very frequently used. It consists of head, face and stem. The head and face of the valve are separated by a small margin to avoid sharp edge and also to provide provision for the regrinding of the face. The face angle varies from 30° to 45°generally. The lower part of the stem is provided with a groove in which spring retainer lock is installed.

The poppet valve derives its name from its popping movement up and down. This is also known as mushroom valve because of its shape which is similar to a mushroom. It consists of a head and a stem. It possesses certain advantages over the other valve types because of which it is extensively used in the automotive engines. The advantages are;

1. Simplicity of construction
2. Self-centering.
3. Free to rotate about the stem to the new position.
4. Maintenance of sealing efficiency is relatively easier.

Generally inlet valves are larger than the exhaust valves, because velocity of incoming charge is less than the velocity of exhaust gases which leave under pressure. Further, because of pressure, the density of exhaust gases is also comparatively high. Moreover, smaller exhaust valve is also preferred because of the shorter path of heat flow in this case and consequent reduced thermal loading.

In order to study the thermo elastic behavior of the valve, the literature related to the thermo elastic analysis of engine components has been studied. Since in the past, most of the studies of automobile components were carried out for thermo elastic analysis by considering it as a case of two dimensional. The following section details the literature available and relevant to the proposed study of thermo elastic analysis of a solid exhaust valve, as a case of three dimensional. For instance, Pradeep Kumar A.R.et al.[1] performed heat transfer analysis in a low heat rejection diesel engine. Naresh Kr. Raghuwanshi et al. [2] carried out failure analysis of internal combustion enginevalves: A review. M. H. Shojaefard et al. [3] carried out analysis heat flow between seat and valve of ICE. Nurten Vardar et al. [4] performed an investigation of exhaust valve failure in heavy – duty diesel engine. Singaiah Gali et al. [5] performed diesel engine exhaust valve design, analysis and manufacturing processes.T.T.Mon et al. [6] carried out finite element analysis on thermal effect of the vehicle engine. In this work, 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 construction of exhaust valve.

2. Material Selection

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.

2.1 Suggested materials

Nimonic 80A
Nimonic 80A alloy is a nickel-chromium alloy that is strengthened by the additions of titanium and aluminium. It

has high tensile and creep-rupture properties at temperatures up to 815°C.

Table 1: Chemical composition of Nimonic 80A

Element	*Percentage*
Chromium, Cr	18-21%
Iron, Fe	3%
Titanium, Ti	1.8-2.7%
Aluminium, Al	1-1.8%
Silicon, Si	1%
Manganese, Mn	1%
Copper, Cu	0.2%
Cobalt, Co	0.2%
Carbon, C	0.1%
Phosphorus, P	0.045%
Boron, B	0.008%
Nickel, Ni	Balance

Nimonic 105
Nimonic alloy 105 is a wrought nickel-cobalt-chromium base alloy strengthened by additions of molybdenum, aluminium and titanium. It has been developed for service up to 950°C, and combines the high strength of the age-hardening nickel-base alloys with good creep resistance.

Table 2: Chemical composition of Nimonic 105

Element	*Percentage*
Nickel, Ni	51%
Cobalt, Co	18-22%
Chromium, Cr	14-15.7%
Molybdenum, Mo	4.50-5.50%
Aluminium, Al	4.50-4.90%
Iron, Fe	1%
Manganese, Mn	1%
Silicon, Si	1%
Titanium, Ti	0.90-1.50%
Copper, Cu	0.20%
Zirconium, Zr	0.15%
Carbon, C	0.12%
Sulphur, S	0.010%
Boron, B	0.0030-0.010%

3. Modeling and Analysis

3.1 Design and Modelling

The assumptions made in modelling 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. This analysis does not calculate 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 seated at the ramp of the cam, stresses generated from seating are moderate. They can be 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 not properly set. In this analysis the stresses arising 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 and seat. The valve head should deflect to accommodate to the seat, and this will cause bending stresses in the stem. Under all conditions,spring loads and gas pressures 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 the valve is lost through this water only.

The valve keeps popping up and down. The analysis is 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.

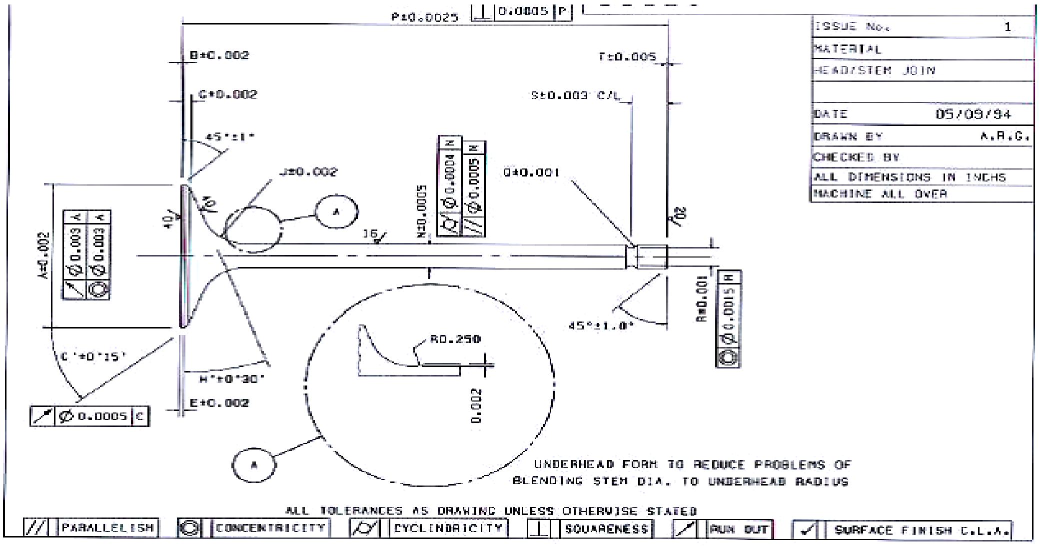

Figure 1: Detail drawing

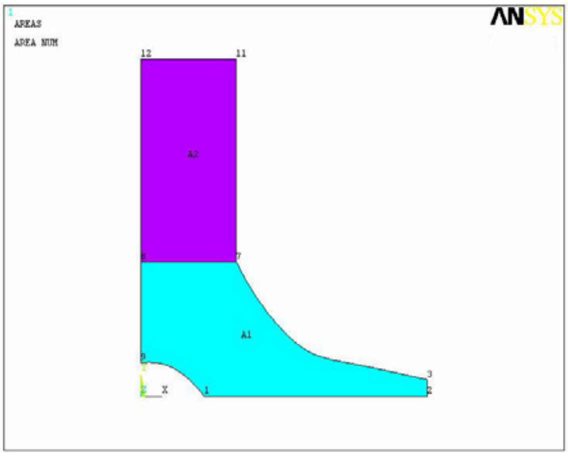

Figure 2: Axisymmetric model of exhaust valve

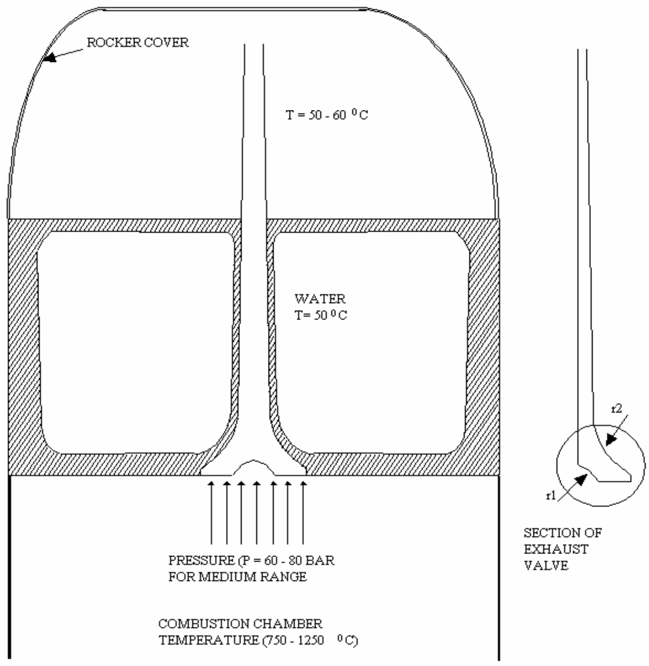

Figure 3: Boundary conditions

3.2 Material properties & Boundary conditions

Table 3: Material Properties

Properties	*Nimonic 80A*	*Nimonic 105*
Modulus of elasticity	$2.2x10^5$ /mm^2	$2.2x10^5$ N/mm^2
Coefficient of thermal expansion	$14.5x10^{-6}$/K	$12.2x10^{-6}$/K
Thermal conductivity	13 W/mK	10 W/mK

4. Results

4.1 Thermal analysis

Thermal analysis of the exhaust valve for different materials such as Nimonic 80A and Nimonic 105 are carried out. The results of the two different exhaust valve materials are given below. As the analysis carried out was steady state thermal, the results for all the materials are almost same.

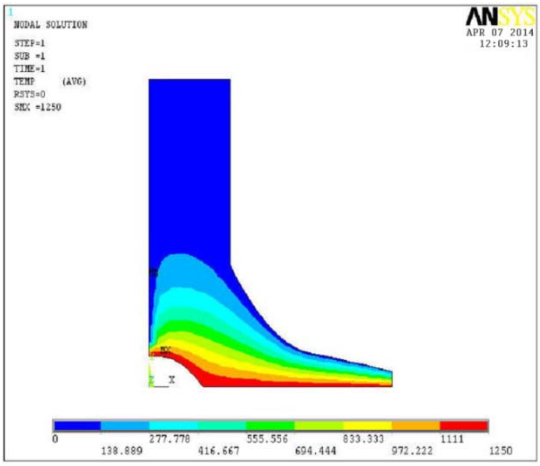

Figure 4: Thermal analysis result of Nimonic 80A

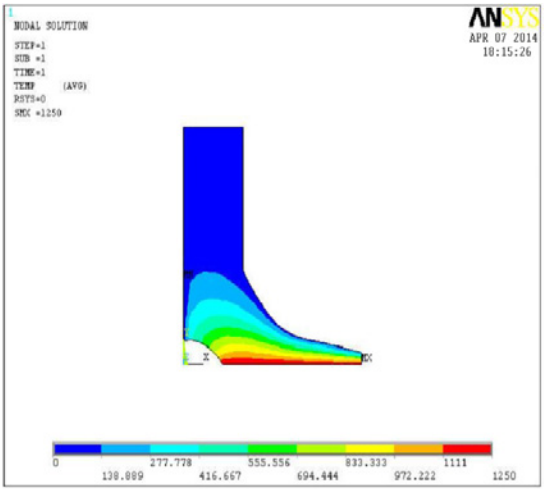

Figure 5: Thermal analysis result of Nimonic 105

4.2 Structural Analysis

Static structural analysis of the exhaust valve for different materials such as 21-4N, Nimonic 80A and Nimonic105A is carried out. The properties of different exhaust valve materials such as thermal expansion, young's modulus are given as input to the structural analysis.

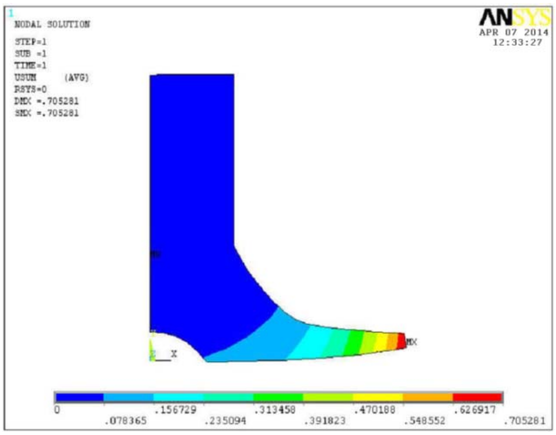

Figure 6: Nodal displacement for Nimonic 80A

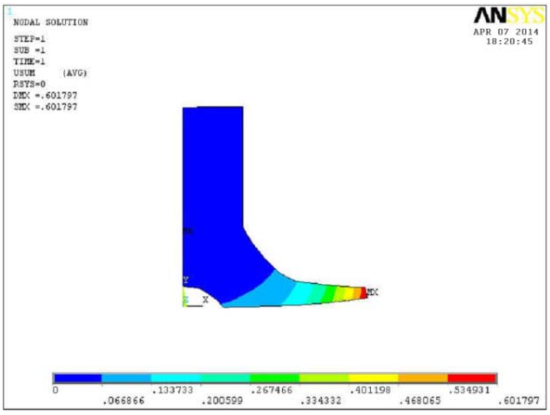

Figure 7: Nodal displacement for Nimonic 105

Table 4: Results comparison

Material	*Displacement at node 2 & 3*
Nimonic 80A	0.705281
Nimonic 105	0.601797

5. Conclusions

In this project thermal and structural analysis for two materials produces excellent result by treating the problem as coupled field analysis. From the analysis results for both valve materials, it has been concluded that the displacement value for Nimonic105A is very less than the values of other material for the same thermal and structural loads. It's evident from the analysis that, the best material for the valve is Nimonic105A as far as thermal and structural behavior is concerned.

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