ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Experimental optimization on durability of exhaust valves in CI engines

Dr.P.Senthilkumar, R.Pradeep, E.R. Sivakumar
Department of Automobile Engineering, Madras Institute of Technology, Chrompet, Chennai 600044, India
***Corresponding author: E-Mail: yourmailstopradeep@yahoo.co.uk**

ABSTRACT

The intention of this work is to design and develop exhaust valve for diesel engines, possessing improved durability characteristics that reduces failure on application. While stating about exhaust valve failures, in any internal combustion engine the exhaust valve is considered one of the major critical parts. Eventually it is the root cause for most problems like pre-ignition, run-out, etc. Design of valves are determined by various parameters, like fatigue strength of valve material, oxidation behaviour of valve material, exhaust gas behaviour of valve material at high temperatures, configuration of cylinder head, coolant flow, shape of exhaust valve, fluid dynamics of exhaust gas and some more.

KEY WORDS: Valves, materials, engines.

1. INTRODUCTION: The most important factor underlining the performance an engine valve is it's in appropriate operating temperature. The role of temperature can be seen by its effect on physical properties of the valve. Most automotive exhaust valves are operating at 600°C to 1200°C temperature range. It can be seen that considerably different valve performances can result from same valve material under diverse temperature conditions. Objective of this work is to overcome the failure in the existing exhaust valves to increase the durability. The approach is done by measuring stress, temperature distribution in the valve at high temperature and pressure ranges. This manipulation will influence software examination of various coatings on valves.

Hence the property of material varies with respect to pressure and temperature, Finite Element Analysis is used to determine the near values of thermal and mechanical stress levels. While after analysing with various coatings, the better results are supposed to be taken forward towards real-time application of coating, and physical identification of the preferred coating will be found after installing the coated valves to run in an engine for particular hours of operation and the wear rate is to be determined by Scanning Electron Microscope (SEM) / X-Ray Diffraction (XRD) analysis.

2. FAILED VALVES

Failed Valve 1: It is known that a valve stem is always experiencing less stress than the valve head portion; the stress levels would be around $18x10^3$KPa over the 2.5 centimeter small face area. However, the stem is also affected by the seating load, which is generally less than $13x10^3$KPa. The above valves were in good condition, with minute wear and corrosion. But, the stem was bowed approximately 25°as shown in figure.1

Figure.1. Failed Valve 1

This kind of failure is not of regular or series nature, but may probably be caused by clash with the cylinder. A few engines enclose tight tolerances where the valves actually extend as much as necessary to enter the combustion chamber so they ram with the piston.

Failed Valve 2: Valve heads are subjected to drastic loads weighing around 1.5 tonnes. Also they are subjected to extreme thermal stresses, with temperature range of up to 1200°C across a 2.5centimetre diameter face. And thus a smallest alter in seating may possibly cause failure.

This valve seemed to be older and well used, even though there was only very little development of corrosion on the valve. The mere damage was the absence of small flake in lip of the valve head. This damage was hard to decide, and guessing it would most likely caused by some fatigue.

Figure.2. Failed Valve 2

Failed Valve 3: This valve had various points of breakup. The three key points of damage were rough projections of a valve face cut out from the stem area, an upward bent lip pressed towards the stem and in the end the absence of stem itself. Also there were several cuts within the sides of the valve, which would be some hard collapse and not a cause of failure.

The stem, cut out off the face also had sharp angles. And thus the point of damage obviously shows that the failure was not of slow progress, but perhaps a sudden and violent collision. Eventually, the stem looked almost like a twisted staircase with large fractured planes, pointing radially from the centre.

Figure.3. Failed Valve 3

Failed Valve 4: Valve 4 visibly looked that it is failed barely due to corrosion. To prove it, some of the deposits were placed on a thin paper and was held over a magnet.

If deposits are magnetic, the cause of corrosion would be since of combustion process (deposits from several iron based alloy and austenitic steel will be magnetic). And of course the deposits were magnetic, so it’s sure that the corrosion was caused by combustion.

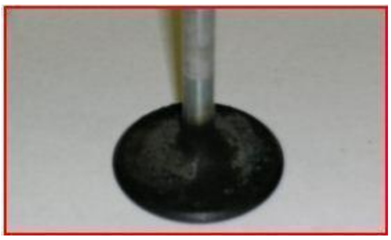

Figure.4. Failed Valve 4

Simulation of failure: The failure juncture of exhaust valves were studied and applied in simulation with the thermal load to the valve dynamic stress. As a result, the heat transfer percentages of each area are shown in above. The heat generated by exhaust gas is the main source to the valve’s thermal loading, 60% of the heat generated is absorbed at flame contact side i.e. the underneath of valve resulting in thermal shocks ending in failure.

Also the 20% of heat is absorbed at the upper surface of the valve and 16% is at the valve neck region. Because of this in-desirable heat release at the face of valve, the temperature level on the seat contact (A) is inferior to the valve seat but still they face the exhaust gas directly. It can be seen in the above figure that, the maximum temperature is at the valve neck where the failure is occurred. The results of exhaust valve temperature analysis were applied to thermal load of stress analysis.

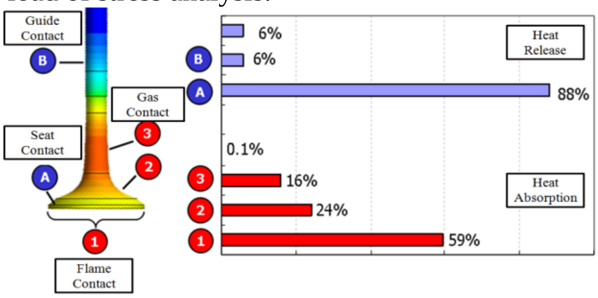

Figure.5. Simulation of failure

3. SIMULATION RESULTS

Table.1. Input values of valve material for simulation

Material	Steel
Young’s modulus	2e+011Nm^2
Poisons ratio	0.266
Density	7860kgm^3
Coefficient of thermal expansion	1.17e-005 kdeg
Yield strength	2.5e+008Nm^2

A meshed exhaust valve model: A well-known method before working on any kind of analysis is meshing. Meshing (creation of grid-points called nodes) is the most important element in any of the computer simulations, since it can show drastic alterations in results with perfection. The mesh results are calculated by computing the tool, which does it with relevant governing equations numerically at each node of the mesh.

In all this simulation process, an OCTREE tetrahedron mesh was applied with; Mesh size: 8mm and Absolute sag: 1.138mm.

Combustion pressure of 140 bar with temperature of 800°C was considered for all the simulation analysis to check the temperature /stress distribution.

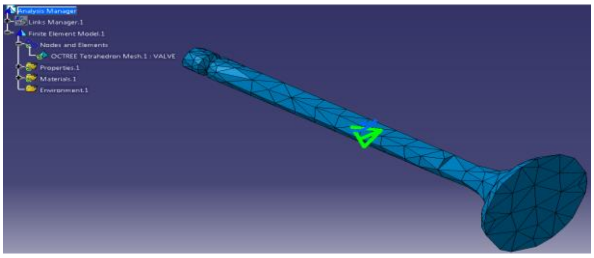

Figure.6. An OCTREE tetrahedron meshed valve for simulation

Thermal analysis - coated with Stellite (Cobalt-Chromium alloy): While observing the thermal ability of the coating, it was not bad until it reached the set value, when the temperature was increased; it was found that this Stellite coat loses its ability to adhere with the valve material, resulting in failure of coating due to unbearable thermal stress.

But it was quite good to see the deformation value of 0.00072079mm that was really better than general composition sequences.

It may be due to the physical properties of stellite (non-magnetic and non-corrosive) itself, and little deformations were noted only at contact areas i.e., in valve seat, guide groove, that’s because of lesser cross-section at the groove area that has been provided to seat the valve lift.

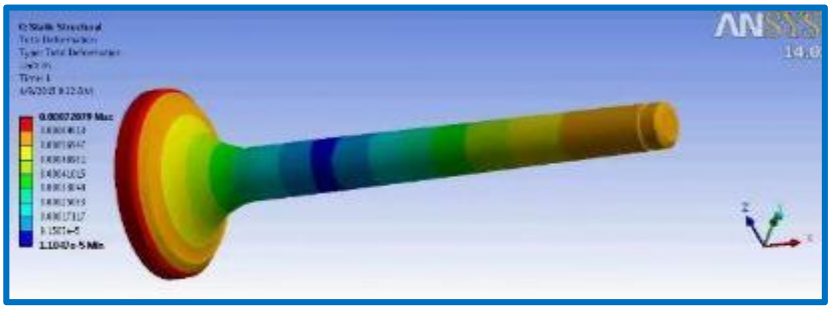

Figure.7. Simulation result of valve coated with stellite (cobalt-chromium alloy)

Thermal analysis - coated with Nimonic (Nickel-Cr. alloy): While it was the result of Nimonic coating, it seemed to be just opposite to behaviour of stellite in case of thermal ability (upto 1090°C).

Nimonic was well enough to compensate thermal stress and sudden temperature raise, but deformed bit more than others.

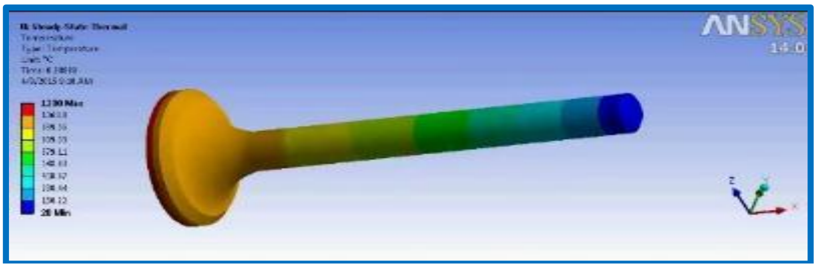

Figure.8. Simulation result of valve coated with Nimonic (nickel-chromium alloy)

Thermal analysis - coated with DLC (Amorphous carbon): Since it was difficult to apply DLC’s properties in ANSYS, it was done with ABAQUS CAE for fine results of simulation.

When looking at thermal mapping, it was clear that this coating was able to withstand higher temperatures with good thermal energy distribution even at high temperature range.

After looking the results of DLC’s thermal distribution, having better values than other types, it was another added feature of having a very low deformation than another’s that were overviewed.

It had a merely less value below $6.2115e^{-05}$ mm even at peak mode of 140 bar, only few areas are dragging the deformation as seen in the figure.

These values show that DLC can be less resistant to wear, and possibly protect the valve mechanically.

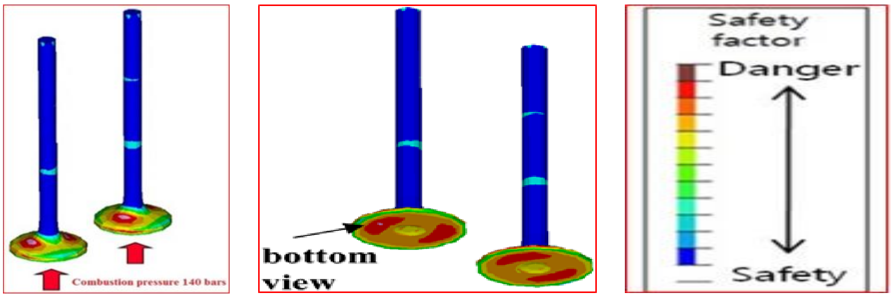

Figure.9. Simulation result of valve coated with DLC

4. CONCLUSION

From the CAE analysis results, it was noticed that ultimately rather using a steel valve it is better to use a coated valve to increase durability; whereas cost is a factor to be noticed.

And the final complication will majorly be depending on the operating modes and engine characteristics.

Finally after replicating different combinations of coatings that was analyzed, it was better to stay with a DLC coating which is superior to others since it showed better performances in durability of the valve and a good resistance to wear that which is very important in case of a diesel engine.

So as the next step, the diamond like carbon (DLC) type of coating is coated on a basic valve and then the real-time durability (by making the coated valve to participate in engine operation for few hours) of the (by measuring wear characteristics using SEM) valve will be determined for external publication.

REFERENCES

Abaqus CAE, User's Manual, Dassault Systemes Simulia Corp., Providence, RI, USA, 2013.

Deborah D.L. Chung, Applied Materials Sciencce: Applications of Engineering Materials in Structural, Electronics, Thermal, and Other Industries, CRC Press, Washington D.C., 2009.

Klaus Mollenhauer, Helmut Tschoeke, Handbook of Diesel Engines, Springer Heidelberg, London, New York, 2012.

Naresh Kr. Raghuwanshi, Ajay Pandey, Mandloi R.K, Failure Analysis of Internal Combustion Engine Valves: A Review, International Journal of Innovative Research in Science, Engineering and Technology, 1 (2), 2012.

NPCS Board of Consultants and Engineers, Surface Coating: Technology Handbook, Asia Pacific Business Press Inc., Delhi, 2007.

Nurten Vardar, Ahmet Ekerim, Investigation of Exhaust Valve Failure in Heavy – duty Diesel Engine, Gazi University Journal of Science, 23 (4), 2010, 493-499.

Pang M.L, Smith S.P, and Buuck B, Stress Analysis of an Automotive Engine Valve by FEM, SAE, 2006.

Roth G, Fatigue Analysis Methodology for Predicting Engine Valve Life, SAE, 01, 2003, 0726.

Sato K, Saka T, Ohno T, Kageyama K, Sato K, Noda T, and Okabe M, Development of Low-Nikel Super alloys for Exhaust Valves, SAE, 1998, 980703.

Stan Grainger, Jane Blunt, Engineering Coatings: Design and Applications, Woodhead Publishing Ltd in association with The Welding Institute, Cambridge, England, 2nd Edition, 2010.

Umino S, Hamada A, Kenmoku T, and Nishizawa Y, New Fe-base Exhaust Valve Material for Higher Heat Resistance, SAE, 1998, 980704.

Von Wielligh A.J, Burger N.D.L, and Wilcocks T.L, Diesel engine failures due to combustion disturbances, caused by fuel with insufficient lubricity, Industrial Lubrication and Tribology, 55, 2003, 65–75.

Voorwald H.J.C, Coisse R.C, and Cioffi M.O.H, Fatigue strength of X45CrSi93 stainless steel applied as CI engine valves, Procedia Engineering, 10, 2011, 1256-1261.

Yu Z.W, and Xu X.L, Failure analysis and metallurgical investigation of diesel engine exhaust valves, Engineering Failure Analysis, 13, 2006, 673-682.