PERFORMANCE EVALUATION OF COMPOSITE (TICN) COATED ENGINE VALVE USING FINITE ELEMENT ANALYSIS

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Abstract

Engine valves are critical component in controlling intake and exhaust gases. The exhaust valve is subjected to both thermal and mechanical loading during closing and opening of the valve. To withstand the valve at high temperature conditions under fatigue, the valve material must possess high temperature properties like high hardness, high hot hardness, high thermal conductivity and high strength etc. The performance of valve can be improved using hard coatings on the valve. The coated valves have less wear due to fatigue, and high corrosion and thermal resistance. In this paper the performance of composite coated and uncoated valves (poppet valve) of two wheeler engine is simulated under both thermal and structural loading conditions using finite element analysis. The simulation results indicate coated valves have less thermal loading and structural failure than uncoated valve. The simulation results of both coated and uncoated valves is presented and analyzed in this paper.

1. INTRODUCTION

In Internal Combustion (IC) engine the engine valve regulates the flow of gases/air by opening and closing during engine operation. The opening and closing of the valves is controlled by cam shaft. There are several types of valves like poppet, rotary, disc and a sleeve are used and the most common valve is the poppet valve. The schematic diagram of poppet valve is shown in Fig.1. The valves are subjected to mechanical loading during closing and opening, and thermal loading during combustion and exhaust process. In four stroke engine, the inlet valve subjected to mechanical loading during suction stroke, during combustion both inlet and exhaust valve faces subjected to thermal loading, during exhaust stoke the exhaust valve subjected to thermal loading due to the passage of burnt gases and mechanical loading due to closing and opening of the valve. In each cycle of the engine the valves are subjected to mechanical loading for opening and closing, and subjected to thermal loading due to combustion and flow of flue gases

The valve seat is subjected to the most severe conditions, one side of which being exposed to the extremely high temperatures of combustion. In the case of the exhaust valve, the stem side face of the valve is subjected to the flow of hot combustion gases. The valves also subjected to repeated impact loading upon closure of the valve under the influence of the valve train. To withstand the valve at these conditions, the valve material must possess high temperature properties like high hardness, high hot hardness, high thermal conductivity, and high fatigue strength etc. Many materials are used in valve manufacturing to improve the valve durability and engine performance for example martensitic steels are used in inlet valves, austenitic alloys and nickel based alloys for the exhaust valves to increase the life of the valve. In Internal Combustion, the valve failures occurs due to valve wear, metallurgical defects, corrosion, and variation in the metallurgical properties

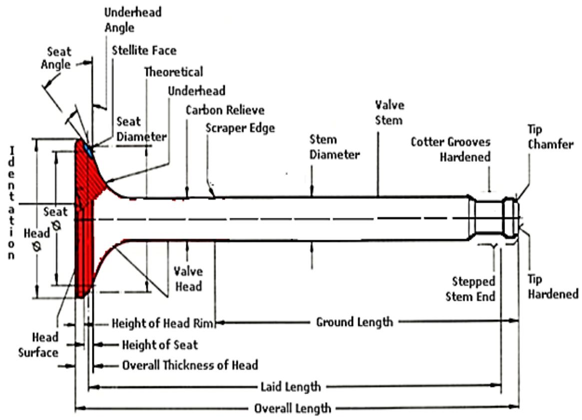


Fig. 1 Elements of engine valve

during combustion. Valve breakage is also one type of valve failure that takes place to either intake or exhausts valves due to cyclic or fatigue loads. The rapid opening and closing of the valves against the cylinder heads lead to rapid wear, and the valve is continuously subjected to wear and it affects the engine performance. The valves attain high temperature during combustion and exhaust which causes the variation in the metallurgical composition and properties; this finally leads to valve failure [1, 2, 3].

Coatings play an important role to improve the surface properties of any engineering component. Thermal Barrier Coating (TBC) have major influences on the performance of various component of IC engine under both thermal and mechanical loading in terms improving the efficiency of the engine. In case of valves in IC engine the valves give high resistance to thermal loading and favours for corrosion resistance, and improves the wear resistance. Coatings improve the wear resistance by reducing friction, adhesion, diffusion, and oxidation in addition to relieving thermal and mechanical stresses induced upon the substrate. Ekrem Buyukkaya (2008) indicated that the maximum surface temperature is observed that functionally graded NiCrAl and $MgZrO_3$ coated AlSi alloy and steel pistons than uncoated pistons. ImdatTaymaz (2007) observed that under the same operating conditions, CaZrO3 and MgZrO3 onto the base of the NiCrAl plasma coated ceramic diesel engine giving better performance in terms of reduction in fuel consumption and heat losses to engine cooling system and an improving effective efficiency when compared to uncoated diesel engine.

In recent years, the finite element method (FEM) has particularly become the main tool for simulating the performance of many IC engine components under both mechanical and thermal loading. Finite element models are widely used for calculating the stress, strain, strain-rate and temperature distributions [3]. The FEM analysis helps to investigate the influence of coatings on the heat transfer and friction, and resulting temperature distribution. In the present work the influence of coating system on temperature generated in engine valve is studied using 3D finite element simulation. The 3D model of the valve is generated and analysis is carried out in the commercial software ANSYS. In this work the simulation is carried out for both uncoated and composite (TiCN) coated valves

2. FINITE ELEMENT MODELLING OF ENGINE VALVE

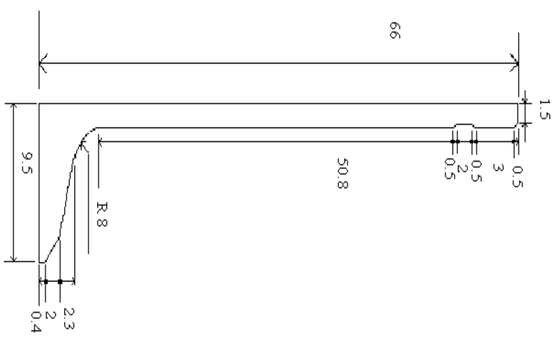
In this work the finite element model is developed for both coated and uncoated engine valves. The valve is a deformable body with rigid-plastic material data, which depends on strain, strain rate and temperature. The simulation of valve opening and closing under thermal loading is done for coated and uncoated valves under same cutting conditions to study the temperature distribution and stresses generated. The exhaust valve made up of special steel grade SUH11 material used in four stroke two wheeler engine is selected for the present study. The metallurgical properties of SUH11 material are given in Table.1. The properties of composite (TiCN)is given in Table. 2. The dimensional specifications of the valve is shown in Fig.2. Three dimensional (3D) analysis offers a more realistic modeling of the process used for a wider range of components in IC engines. Fig.3 shows an illustration of the model of the valve. The heat is generated due to combustion and flow of exhaust gases. Thermal boundary conditions are defined to model heat gain from the combustion due to convection. In this work numerical analysis is carried out in both uncoated and TiCN coated valve. The coating thickness of the valve is assumed as 150µm. For analysis 8 node solid 70 is selected for meshing. The finite element mesh of the valve model using ANSYS is shown Fig 4. The thermal boundary conditions and the mechanical loading on the valve are defined on the valve is given in Fig.5. In simulation, first thermal analysis is carryout to find the temperature distribution on the valve surface due to flow of hot combusted gases. For thermal analysis the boundary conditions are applied based on the temperature of flue gases.

TABLE.1. PROPERTIES OF ENGINE VALVE MATERIAL

Type of Material	Modulus of elasticity (E)	Poisson's ratio (μ)	Density (ρ)	Thermal conductivity (K)	Specific heat (C)
SUH11	600 GPa	0.3	9010 kg/m^3	30 W/m-K	520 J/kg-K

TABLE. 2 PROPERTIES OF COMPOSITE (TiCN) MATERIAL

Coating Type	Modulus of elasticity (E)	Poisson's ratio (μ)	Density (ρ)	Thermal conductivity (K)	Specific heat (C)
TiCN	317 GPa (or) 3.17e11	0.22	3260 kg/m3	20.06 W/m-K	1002.78 J/kg-K



All dimensions are in mm

Fig.2 Specifications of the valve

The temperature distribution at different places of the valve based on the thermal analysis is calculated and as shown in Fig.5. The thermal result containing valve temperature distribution is then taken to perform structural analysis to test mechanical failure of the valve. The mechanical loads on the valve are applied based on the cam load acting on the valve tip, gas pressure on the valve head surface, spring force acting at the keeper groove. Under these conditions structural analysis is done on the valve.

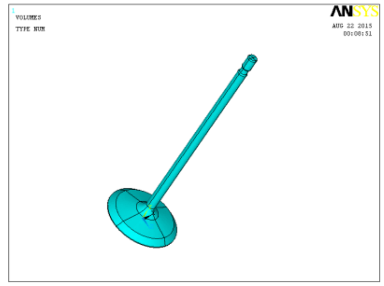


Fig. 3.3D Element Model of Engine Valve

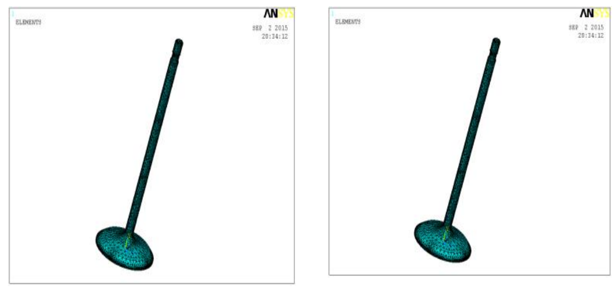


Fig 4.1 (a) Uncoated valve mesh Fig 4.1 (b) Coated valve mesh

Fig. 4. Finite element model of engine valve

<u>Loads acting when the valve is Open</u>

1. Spring force acting in upward direction at the keeper grooveF_{spring}=650 N.
2. Cam load acting at the valve tip in downward directionF_{cam}=2000 N.
3. Exhaust gas pressure acting on the face of the valve head and also along the valve surfaceP_{gas}= 25 bar.
4. Thermal load is transferred from the exhaust gas along the surface of the exhaust valve.

<u>Loads acting when the valve is closed</u>

1. Spring force acting in upward direction at the keeper groove Fspring=650 N.
2. Combustion gas pressure acting on the face of the valve headPgas= 80 bar.
3. Thermal load is transferred from the exhaust gas to the face of valve head.

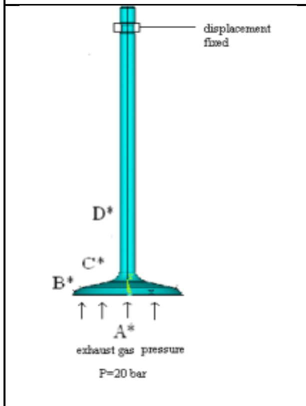
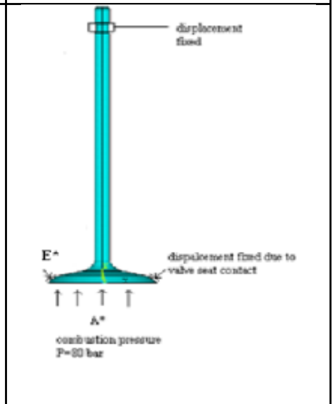
Valve in open condition	Valve closed condition
	
A=750^{O}C B= 600^{O} C C= 500^{O} C D = 500^{O}C	

Fig. 5. Thermal and mechanical Boundary conditions

3. RESULTS AND DISCUSSION

Finite element simulation of valve is carried out for two different cases. In each case all the boundary conditions are same except the type of the valve is used. Uncoated and TiCN coated valves are used for the simulation. The coated and uncoated valves are simulated during opening for one cycle of operation. The simulated results for both uncoated and coated valves are shown in Fig.6 and Fig.7 respectively. When the valve is open it is subjected to thermal and mechanical loading. Due to thermal loading the valve temperature raises due to passage of flue gases on the valve surface.In the thermal analysis the temperature distribution is found. The temperature distribution of uncoated and coated valves under thermal loading are shown in Fig.6 (a) and Fig.7 (a). The maximum temperature is observed in coated valve, this is due to the refractoriness of the coated material. Due to refractoriness of the coating more heat is stored on the surface of the coating. Whereas uncoated valve he heat distributed to valve body. The boundary conditions for mechanical loading as shown in Fig.5 are applied on the valve. Fig.6 (b) and Fig. 7(b) shows the variation in Von misses stress induced in the valve. For uncoated valve has more stresses induced than coated valve, this indicates that the coated valve has more durability and the coating material is more effective. Similarly Fig.6 (c) and Fig. 7(c) shows variation in strain for uncoated and coated valves. It is observed that the coated valve has less strain than uncoated valve.

The temperature distribution in uncoated and coated valves in both open and closed conditions for the given boundary conditions is shown in figures 6 (a) and (b). The results showed the maximum temperature is observed for coated valves than uncoated SUH11 valve for same boundary conditions. The heat loss with uncoated valve is more compared with coated valves. The surface temperature of coating material is high due to its high refractive and low thermal conductive properties. The maximum temperature and minimum temperatures of valve in open condition are 674.274 K and 653.11 K. The maximum temperature and minimum temperatures of valve in closed condition are 518.365 K and 494.008 K. The temperature distribution from thermal analysis for the TiCN coated valve in closed and open condition is shown in the fig 7 (a) and fig 7 (b).

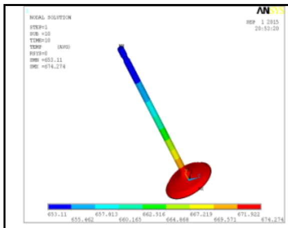
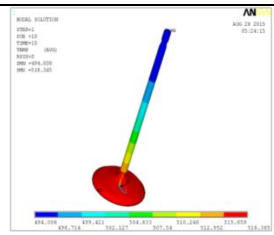
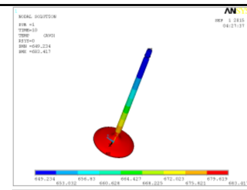
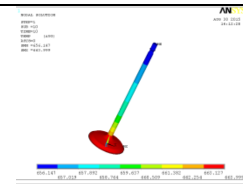
			

Fig: 6 (a)Temperature distribution of Uncoated Valve In Open Condition	Fig 6 (b) Temperature distribution of Uncoated Valve In Closed Condition	Fig:7 (a)Temperature distribution TiCN coated Valve In Open Condition	Fig 7 (b) Temperature distribution Of TiCN coated Valve In closed Condition

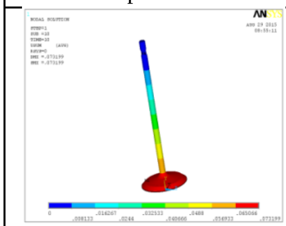
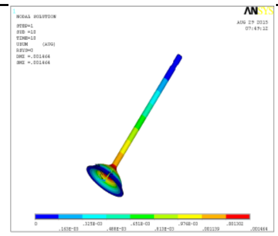
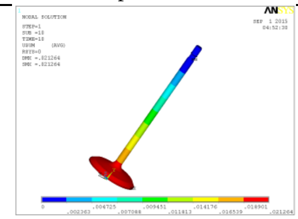
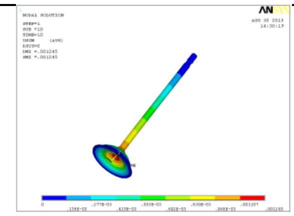

			

Fig:6 (c) Displacement of uncoated valve in open condition	Fig:6 (d) Displacement of uncoated valve in closed condition	Fig: 7 (c) Displacement ofTiCN coated Valve In Open Condition	Fig: 7 (d)Displacement of TiCN coated Valve In closed Condition

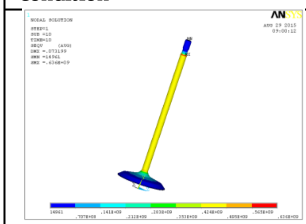
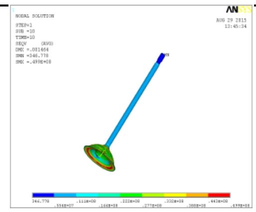
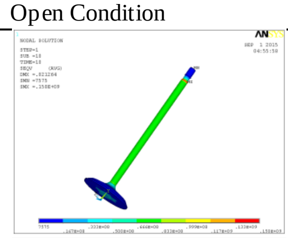
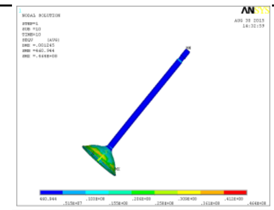

			

Fig:6 (e) Von misses Stress Distribution In Open Condition For Uncoated Valve	Fig:6 (f) Von misses Stress Distribution In Closed Condition For Uncoated Valve	Fig: 7 (e)Von misses Stress Distribution ofTiCN coated Valve In Open Condition	Fig: 7 (f)Vonmisses Stress Distribution of TiCN coated in closed condition

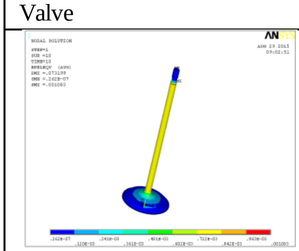
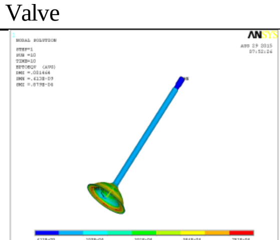
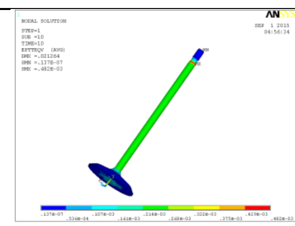
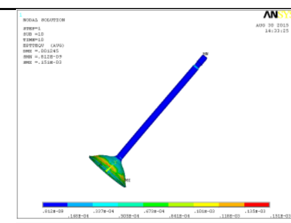

			

Fig:6 (g)Von misses Strain In Open Condition For Uncoated Valve	Fig:6 (h)Von misses Strain Distribution In Closed Condition For Uncoated Valve	Fig: 7 (g)Von misses Strain In TiCN coated Valve In Open Condition	Fig: 7 (h)Vonmisses Strain Distribution for TiCN Uncoated Valve In Closed Condition
Fig. 6. Finite element analysis of uncoated valves		Fig. 7. Finite element analysis of coated TiCN valves	

These results are then taken as input into structural analysis to get the mechanical failure of the valve. The mechanical loading conditions during valve opening and closing are fitted. The structural analysis results for coated valves are shown in the figures above. The maximum and minimum displacement values of valve in open condition are 0.021264mm and 0.002363mm. The maximum temperature and minimum displacement values of valve in closed condition are 0.001245mm and 0.138e-3mm. The maximum and minimum stress values of valve in open condition are 0.150e9 and 0.167e8. The maximum and minimum stress values of valve in closed condition are 0.464e8 and 0.515e7. The maximum and minimum strain values of valve in open condition are 0.482e-3 and 0.137e-7. The maximum and minimum strain values of valve in closed condition are 0.151e-3 and 0.168e-4. The simulation assumes a steady state condition of valve. From the result, when the valve is compared with and without coating, the thermal loading on base valve material for coated valves is less than that of uncoated valve. The stress and strain induced for coated valve is reduced and results in more life.

Exhaust valve		Uncoated valve	TiCN coated valve
	Valve condition	Max. and min. values	Maximum and min. values
Temperature distribution	Open	674.27	683.417
		653.11	649.234
	closed	518.365	663.999
		494.008	656.147
displacement	open	0.0731	0.021264
		0.008133	0.002363
	closed	0.0014	0.001245
		0.163e-3	0.138e-3
stress	open	0.636e9	0.150e9
		0.707e8	0.167e8
	closed	0.499e8	0.464e8
		0.554e7	0.515e7
strain	open	0.001083	0.482e-3
		0.120e-3	0.536e-4
	closed	0.879e-4	0.151e-3
		0.977e-5	0.168e-4

4. CONCLUSIONS

The coating plays a vital role in protecting the valve from thermal and mechanical failure. In the present work the performance of uncoated valve with composite TiCN coated valve is compared using finite element analysis. The simulation results it was observed that the coated valve has better performance in terms of high temperature on valve material due to refractoriness of coating resulting less heat transfer into the valve material, less stress and strain, and less displacement. The same method can be useful to simulate various type of coating material sand can be optimized using finite element analysis.

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