Simulation of composite Titanium Nitrite (TiN) coated Internal Combustion engine exhaust valve using ANSYS

R Sundara Rao, K Hemachandra Reddy, Ch R Vikram Kumar

Abstract: In Internal Combustion Engine, valves play a crucial role in the circulation of intake and exhaust gases. Although inlet valve is exposed to higher temperatures during combustion, its failure rate is less when compared with exhaust valve. This is because the inlet valve is cooled by fresh charge admitting into the cylinder. But exhaust valve is heated up by the enormous heat carrying flue gases. Hence it is more prone to failure and has become the focus of study. The exhaust valve undergoes mechanical and thermal loads when gases are circulated from the cylinder. The valve is exposed to these extreme high temperatures subjected to fatigue loads which cause failure of valve. The valves should possess good material properties at high temperatures i.e., higher hardness, hot hardness, higher thermal conductivities and high strength properties. It has been observed that the exhaust valve performance can be appreciably enhanced by using thin film Titanium coatings like Titanium Nitride (TiN), Titanium Carbide (TiC), Titanium Nitride (TiCN) based Titanium coatings. The Titanium based thin film coatings have high corrosion resistance, less wear rates due to cyclic loads, and higher thermal resistance. In the present work, the valve coated with TiN and uncoated IC engine exhaust valves, here poppet valve of four stroke two wheeler engine valve is chosen and simulated under both high temperature loads and mechanical loads using finite element analysis(FEA). The simulated results obtained are then compared for both coated TiN and uncoated valve. It indicates that the Titanium Nitrate (TiN) coated valve has low thermal resistance and less thermal and mechanical failure than uncoated valve. FEA simulated results of TiN coating on the valve and uncoated exhaust valves are analyzed and presented in the research article.

Keywords: Poppet Valve, Titanium based Coatings, TiN, TiC, TiCN, Finite element Analysis (FEA)

I. INTRODUCTION

In Internal Combustion (IC) engine operates by the opening and closing of engine valves which are responsible for the circulation of gases into the cylinder. Cam shaft actuates the inlet and exhaust valves according to valve timing hence making it opens and close appropriately. The valve actuation decides the efficiency of the engine. Hence valves are the crucial elements of the engine cycle operation. There are wide varieties of valves available such as disc, popet, and a sleeve are used, out of which poppet valve is commonly used. The poppet valve is pictographically represented with all the parts in Fig.1. The inlet and exhaust valves are operated under four strokes of the engine i.e., suction, compression, expansion and exhaust processes. During these strokes the valves are cyclic loaded when the valves opens and closes. Simultaneously, they are also subjected to high temperature loads in expansion and exhaust processes. Consider a four stroke two wheeler engine its intake valve is structurally loaded when the engine sucks fresh charge into it, during suction. But, during the combustion (expansion) process both intake and exhaust valve faces undergoes high temperature loads. Finally, when the exhaust process starts hot flue gases passes over the exhaust valve, then exhaust valve is subjected to higher temperature of hot flue gases. Hence exhaust valve fails often when compared with intake valve. The exhaust valve is subjected to high temperature flue gases is under thermal loading also subjected to mechanical loads when the valve opens and closes during engine cycle operation. When the engine is operating in every cycle, the valves are subjected to mechanical loading as it opens and closes, and the valves are also exposed to high temperature loads during combustion process and also during exhaust strokes as the hot fumes flows along the valve length. [7]

The valve seat undergoes extreme thermal, mechanical loading conditions, of which one side is exposed to the extremely higher orders of temperature of combustion. On the other hand, the hot flue gases, the byproducts of combustion process heats up one side of the valve stem. The valves are often subjected to cyclic fatigue cam and spring loads as it closes. In order to tolerate these extreme loads during opening and closing, the valve material should have higher thermal properties like higher values of hardness, refractoriness and higher values of thermal conductivities, and high impact strength. Different materials are used in valve production to improve the durability of the valve and to enhance engine efficiency. Widely manufacturers prefer martensitic steels for producing intake valves, whereas austenitic steel alloys and nickel metal alloys are also in use for the manufacture of exhaust poppet valves to uplift the valve life [7].

In IC engine, the reasons of failure of the valve are due to the wear of valve, material defects, corrosion, and variation in the material properties at high temperatures. Out of all, Valve breakage is the most common type of valve failure that occurs during intake or exhausts processes. Valve failure is also due to repeated mechanical loads. The rapid

Revised Manuscript Received on August 19, 2019.

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impact forces during when valve opens and closes also causes valve failure. This rapid fatigue loads results in valve failure hence affecting the engine performance. The valve also acquires high temperatures during combustion and exhaust strokes resulting in the change of metallurgical composition and properties; this finally leads to valve failure [1, 2, 3].

Coatings eventually enhance the surface properties of the engine valves. Thin film temperature resistant Coatings has greater impact on the functioning of several IC engine components, which works under high temperatures and cyclic mechanical loads. These coatings help in improving engine efficiency. This type of coated valve withstands higher temperatures and mechanical loads also improve corrosion resistance, and reduce wear rates. Thermal Barrier thin film coatings improves the wear resistance by reducing friction, adhesive, diffusive, and oxidative properties. It also relieves temperature and mechanical induces stresses generated on the substrate. Ekrem Buyukkaya (2008) found that the surface temperatures for functionally graded NiCrAl and MgZrO3 coated AlSi alloy are higher than uncoated steel pistons. Imdat Taymaz (2007) investigated and concluded that under the similar environment, CaZrO3 and MgZrO3 onto the base of the NiCrAl plasma ceramic coatings on diesel engine make the engine to perform better in terms of less fuel consumption and lesser amount of heat lost to engine cooling system and thereby showing an improvement in the efficiency of the engine when compared with uncoated diesel engine [5]. K C Charan and Ch R Vikram kumar (2015) simulated TiCN coated valve and SUH11 uncoated valve using ANSYS and observed that the performance of Coated TiCN valve was better in terms of less stresses and strains. Hence an attempt is made in the work using TiN coating and the result is compared with uncoated SUH11 valve material [7].

II. MODELLING OF IC ENGINE EXHAUST VALVE IN ANSYS

In the modern world, the Finite element Analysis (FEA) has eventually become essential for evaluating the performance of almost all the design modifications of IC engine components under both thermal and mechanical loads. Finite element (FE) models are prominently used for predicting the induced stresses, strains, strain-rates and temperature distribution profiles [3].

The FE analysis helps to determine the influence of thin film coatings on the performance of valve. It also helps in finding out heat transfer phenomenon and friction, and resulting temperature distribution of the valve. In the present work the influence of thermal barrier Composite coatings on temperature generation in engine valve is studied using three dimensional FE Analysis. The valve is modeled within the commercially available software ANSYS itself. In the work the simulation is done for both valve without coating and TiN coated valves.

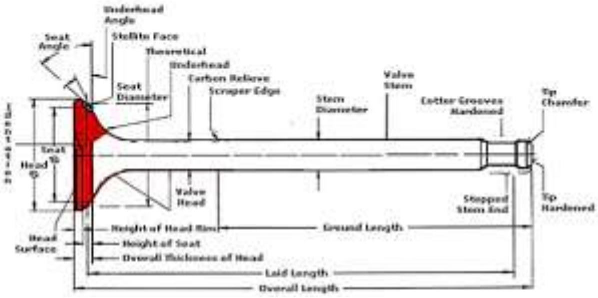

Fig. 1 Internal Combustion Engine Exhaust Valve

In the present work, the FE models are generated for uncoated Valve and TiN coated IC engine valves. The valve body considered being deformable with rigid-plastic material properties, and these properties are dependent on strain, strain rate and temperature. The FE simulation is carried out when the valve closes and opens for both uncoated and coated valves under similar operating conditions. Hence the temperature distribution and stresses induced are obtained. The exhaust valve of four stroke two wheeler automobile engine which is generally made of SUH11 material, a special grade of steel is chosen for the simulation. The properties of SUH11 valve base material are listed in Table.1. The properties of composite (TiN) material are listed in Table. 2. The dimensions of the valve to be modeled are displayed in Figure2.

Three dimensional (3D) FE Analysis of valve takes the advantage of more realistic simulation of the process which can be further implemented for a wider range of components in IC engines. The valve model in 3D is generated in ANSYS. The valve is subjected to high pressures and temperatures during combustion and high temperatures and mechanical loads during exhaust processes. Temperature boundary values are inputted to obtain temperature profile generated due to the heating up of valve which is in turn due to the convective heat transfer of flue gases. In this current work, FE based numerical simulation is done for both uncoated and TiN coated exhaust valves. The thin film thermal barrier coating thickness on the valve is considered as 150µm (allowable). In the analysis ‘8 noded solid 70 element’ is chosen during meshing. The FE meshed model of the valve in ANSYS is shown Fig 4. The mesh here is automatic fine mesh is chosen. The temperature boundary conditions and the mechanical loading conditions are defined on the valve shown in the Figure.5.

In the simulation process, initially thermal analysis is done to find the temperature profile along the valve surface due to the passage of high temperature gases generated during power stroke. For obtaining temperature profile, the boundary conditions are applied depends on the temperature of exhaust gases.

Retrieval Number: B11150882S819/2019©BEIESP
DOI:10.35940/ijrte.B1115.0882S819

Published By:
Blue Eyes Intelligence Engineering
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TABLE-I: 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-II: Properties Of Composite (TiN) Material

Coating Type	Modulus of elasticity (E)	Poisson's ratio (μ)	Density (ρ)	Thermal conductivity (K)	Specific heat (C)
TIN	260 GPa	0.25	5430 kg/m3	8.36 W/m-K	670.8J/kg-K

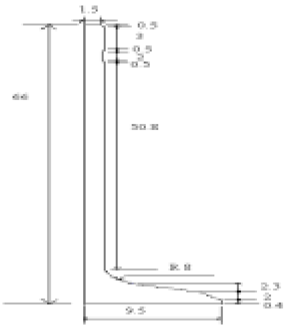

Fig.2 2D-Valve Sketch for modeling (Dimensions in mm)

The temperature profile along the length of the valve is acquired from FE thermal simulation which is shown in Figure.5. The thermal output FE elements are then switched to structural analysis module of APDL-ANSYS in order to predict valve failure due to cyclic fatigue loads. The structural loads acting on the valve are then defined on the thermal output valve. The major loads acting on the valve are cam load due to valve train, combustion gas pressures during exhaust and power strokes and there is a spring force at the groove. At this specified loading environment, APDL FE Analysis (Structural) is carried out.

Fig. 3.Exhaust Valve modeling in ANSYS

Fig 4.1 (a) Uncoated valve

Fig 4.1 (b) TiN Coated valve

Fig. 4. Meshed FE models

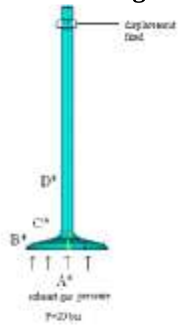

Fig 5.1 Valve opening

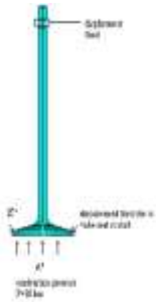

Fig 5.2 valve closing

A=750^{O}C B= 600^{O} C C= 500^{O} C D = 500^{O}C

Fig. 5. Engine Exhaust valve loading conditions

Boundary Conditions for the valve when it is opened:

1. At the keeper groove, the spring force is acting in upward direction F_s = 650 N.
2. At the valve tip Cam load acts in the downward direction F_c=2000 N.
3. On the Valve head face gas pressure acts and passes over the valve surface which is around 25 bar, P_g= 25.
4. The flow of high temperature exhaust gases along the length of the valve raises its base temperature.

Boundary Conditions for the valve when it is closed:

1. At the keeper groove, the spring force is acting in upward direction F_s = 650 N.
2. The Cam load is absent when the valve is closed, F_c= 0 N.
3. The pressure of the gas impacts the valve face during power stroke, Pgas= 80 bar.
4. High temperature of burnt gases inside the cylinder is transferred to the valve face.

III. RESULTS AND DISCUSSION

The FE Analysis of the valve is done by using APDL-ANSYS for TiN coated and uncoated valves. In each of these cases, boundary conditions are similar i.e., mechanical and thermal loads acting on the valve are identical. The FEA simulation is carried out for both TiN coated valve and uncoated valve. This analysis is done when the valve opens and closes for one engine cycle operation. This simulation results for the valve without coating and the valve with TiN coating can be viewed in figures 6 and 7. As the valve opens it experiences high temperature of flue gases and structural loads. When the hot flue gases flows over the surface of the valve, its temperature raises. The simulation is carried out in two stages. Initially in stage1, FE analysis is done to find the temperature profile along the length of the valve. It is then followed by structural analysis in stage2 which aims in finding out failure of valve due to mechanical loads. The temperature profile obtained due to the flow of very hot flue gasses for uncoated and TiN coated valves can be seen in Fig6 (a), 6(b) and Fig.7 (a), 7(b). The higher values of temperature is seen in valve with TiN coating, this because of the refractory property of TiN. As of the coating heat is not transferred into the valve material and is retained at the surface of the coating. But when valve is not coated a huge amount of heat is transferred into valve body resulting in valve failure. The mechanical loads acting on the valve body can be seen in Fig.5. The displacement profile for uncoated and TiN coated valves can be seen in Fig6 (c), 6(d) and Fig. 7(c), 7(d) respectively, indicating that the TiN coated valve is displaced less when compared with uncoated valve. The Von Misses Stresses induced in the uncoated and coated valves are obtained under the specified mechanical boundary conditions. The stress distribution profile for the uncoated and the TiN coated valves can be seen in Fig6 (e), 6(f) and Fig7(e),7(f) respectively. The TiN coated valve has lesser amounts of induced stress when compared with uncoated valve, indicating that the coated valve is more durabile and the TiN coating makes the valve more efficient. The strain distribution profile for the uncoated and TiN coated valve are shoun in the Fig.6 (g), 6(h) and Fig. 7(g), 7(h) respectively. These figures indicate that the uncoated valve has more strain when compared with TiN coated valve.

The temperature ranges of the uncoated valve as it opens vary between 674.274 K and 653.11 K. The temperature ranges of the uncoated valve when it closes for one engine cycle operation vary between 518.365 K and 494.008 K.

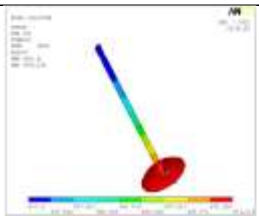

Fig: 6 (a) Temperature profile of opened uncoated valve

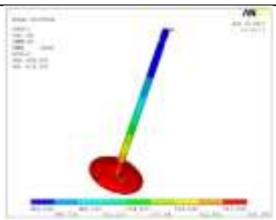

Fig:6 (b) Temperature profile of closed uncoated valve

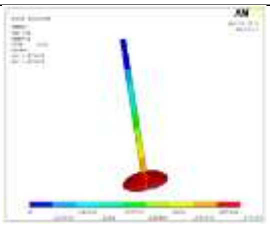

Fig:6 (c) Displacement profile of uncoated valve when it is opened

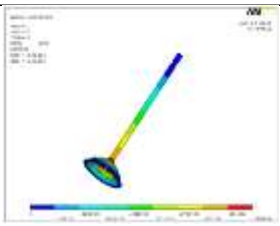

Fig:6 (d) Displacement profile of uncoated valve when it is closed

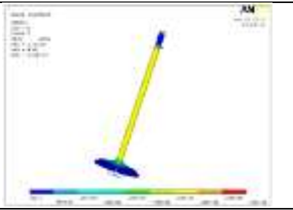

Fig:6 (e) Stress induced for uncoated valve when it is opened

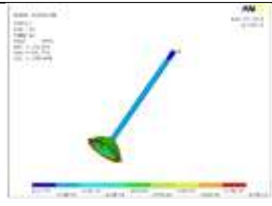

Fig:6 (f) Stress induced for uncoated valve when it is closed

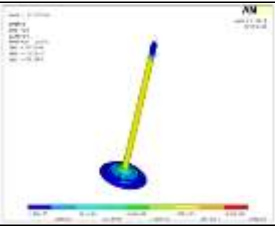

Fig: 6 (g) Strain distribution profile for opened uncoated valve

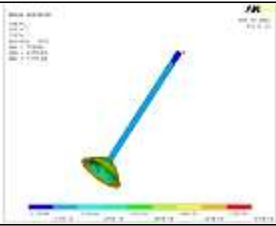

Fig: 6 (h) Strain distribution profile for closed uncoated valve

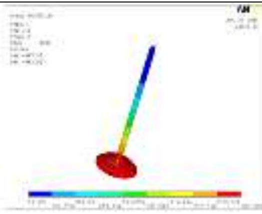

Fig:7 (a)Temperature profile when TiN is coated on valve and it is in open Condition

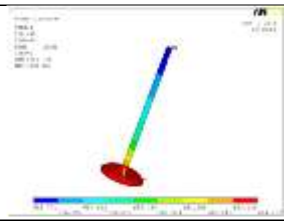

Fig 7 (b) Temperature profile when TiN is coated on valve and it is in closed Condition

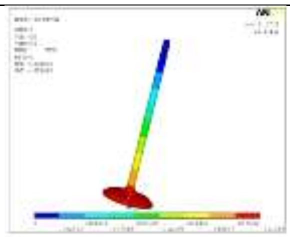

Fig: 7 (c) Displacement profile for opened TiN coated valve

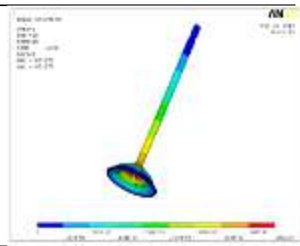

Fig: 7 (d) Displacement profile for closed TiN coated valve

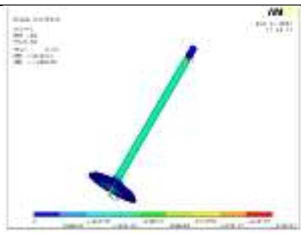

Fig: 7 (e)   Stress distribution profile for opened TiN coated Valve

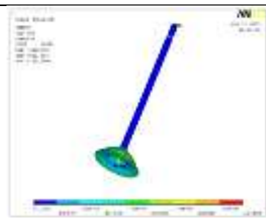

Fig: 7 (f) Stress distribution profile for closed TiN coated Valve

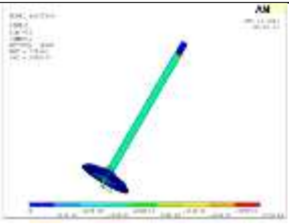

Fig: 7 (g) Strain distribution profile for opened TiN coated Valve

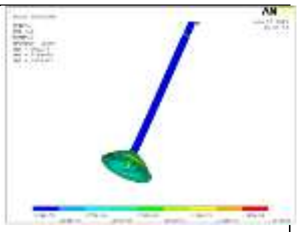

Fig: 7 (h) Strain distribution profile for closed TiN coated Valve

The temperature profile obtained due to the heating up by flue gases during exhaust process for the TiN coating on valve when the valve opens and closes are shown in the figures 7 (a) and fig 7 (b).

These results are then inputted for evaluation of structural analysis to test valve failure under mechanical loads. During Structural Analysis all the mechanical boundary conditions are specified when the valve is opening and closing and the simulation results are obtained for TiN coated and uncoated valves. These results presented in the above figures. The ranges of the displacement values of valve when it is opening are 0.021648mm and 0.002405mm. The ranges of displacement values, when the valve is closing are 0.001273mm and 0.141e-3mm. The induced stress values when the valve is opening vary in-between 0.141e9 and 0.156e8. The induced stress values, when the valve is closing vary in-between 0.422e8 and 0.469e7. The strain rate values when the valve is opening fluctuate between 0.548e-3 and 0.608e-4. The strain values when the valve is closing fluctuate between 0.167e-3 and 0.186e-4.

The FEA simulation here considers that analysis is done for a steady state condition of exhaust valve. From the result obtained, a comparision is made between TiN coated valve and the uncoated valve. The results tell us that, the temperature load on the valve when coated with TiN is less than that of valve without coating. The induced stresses and strains for the TiN coated valve are less indicating that the life time for the coated valve is more. It also indicates that the TiN coated valve is less susceptible to failure.

Exhaust valve		Uncoated valve	TiN coated valve
	Valve condition	Maximum and min. values	Maximum and min. values
Temperature Profile	Open	674.27	683.927
		653.11	647.97
	closed	518.365	579.554
		494.008	552.716
Displacement	open	0.0731	0.021648
		0.008133	0.002405
	closed	0.0014	0.001293
		0.163e-3	0.141e-3
Vonmisses Stress	open	0.636e9	0.141e9
		0.707e8	0.156e8
	closed	0.499e8	0.422e8
		0.554e7	0.469e7
Strain	open	0.001083	0.548e-3
		0.120e-3	0.608e-4
	closed	0.879e-4	0.167e-3
		0.977e-5	0.186e-4

IV. CONCLUSION AND FUTURE SCOPE

The permissible levels of thin film coating on the valve surface played a crucial role in safeguarding the valve which often fails due to high temperature and mechanical loads. The obtained FEA results in the research article indicate that uncoated valve has less life cycle time when compared with composite TiN coated valve. From the results obtained, it is clearly understood that the coatings on the valve makes it to perform better in terms of high temperature tolerance, high refractoriness, less heat absorption. It is also observed that the coated valve has lower values of induced stresses, strains and displacements. The similar methodology could be used for the analysis of various types of coating materials and can be optimized.

REFERENCES

1. Pang. L., Smith, S.P., Herman, R and Buuck, B (2006) Stress Analysis of an Automotive Engine Valve by Finite Element Methods,2006-01-0017.
2. Gregory, Eaton Corporation (2003) Roth Simulation of an Engine Valve Stress/Strain Response during a Closing Event, 2003-01-0727.
3. Yeongching Lin, Prashant Ramachandra and YoshikazuTanaka (2004) Valve Train Dynamic Analysis and Validation, 2004-01-1457.
4. EkremBuyukkaya, (2008) Thermal analysis of functionally graded coating AlSi alloy and steel pistons Surface & Coatings Technology 202, 3856–3865.
5. ImdatTaymaz (2007), The effect of thermal barrier coatings on diesel engine performance, Surface & Coatings Technology, 20, 5249–5252.
6. Douglas M. Baker and Dennis N. Assanis (1994)A methodology for coupled thermodynamic and heat transfer analysis of a diesel engine, Appl. Math. Modeling, 1994, Vol. 18, 590-601.
7. K C Charan and Ch R Vikram kumar (2015) Performance Evaluation of Composite TiCN Coated Valve Using Ansys, South Asian Journal of Engineering and Technology (SAJET) Vol2 No.1 - ISSN: 2454-9614 .
8. The automotive application of discontinuously reinforced TiB-Ti composites JOM May 2004, Volume 56, Issue 5, pp 33–36.
9. Titanium in Engine Valve Systems by J. E. Allison, A. M. Sherman,M. R. Bapna JOM, March1987, Volume 39, Issue 3, pp 15–18.
10. C.N. Cochran and R.H.G. McClurle, "Automotive Materials Decision: Energy, Economy and Other Issues," SAE paper 820149 (Warrendale, PA: Society of Automotive Engineers, 1982).
11. W.S. Giles, "Fundamentals of Valve Design and Material Selection," SAE Paper 660471, (Warrendale, PA:Society of Automotive Engineers, 1966).
12. R.P. Worthen and D.G. Rauen, "Measurement of Valve Temperatures and Strain in a Firing Engine," SAE Paper 860356, (Warrendale, PA: Society of AutomotiveEngineers, 1986).

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