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Performance evaluation using FEA on Al-Si coated engine valve

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A B S T R A C T

The efficiency and performance of a four stroke engine mainly depend upon the valve opening and closing. In IC engines, the effect of the heat transfer results in reduced coefficient of friction and in turn increase in wear rate. Thus the deviation/delay occurs in valve opening and closing and leads to reduction in engine performance. In this research, valve performance has been improved by coating Al-Si alloy on the surface of mating zone of engine valve. Al-Si alloy coated valve had tested and the comparative results proved that the mechanical characteristics increased without affecting the functionality. The Al-Si coating was done on the engine valve by physical vapor deposition method in a controlled environment. As the analysis results are satisfactory, the same coating can be extended to other parts of the engines to improve the overall effectiveness of the engine.

Introduction

In four stroke IC engines, to open and close the inlet and exhaust port, inlet valve and the outlet valves are used. The major functions of these valves are to seal the combustion chamber and to control the charging and discharging process. The major parts of the engine valves are the stem and seat. Valve stem is controlled by the cam shafts for producing up and down movements and subjected to high mechanical stresses (Sagar *et al.*, 2001). The valve seat over the stem is used to lock the combustion chamber and subjected to high thermal stress. Also it is exposed to corrosive environments. Inlet and outlet valves reach temperatures of 300 ºC to 550ºC and 600 ºC to 750 ºC respectively. In general, engine valves are made of cast iron and Titanium alloys such as valve Ti6246, Ti1100, Ti6Al3Sn4Zr, etc (Arabi Jeshvaghani *et al.*, 2011). Because titanium alloys are low density (40 % lighter than steel) and corrosive resistance, but not having satisfactory tribological properties. To overcome these properties, higher tribological property material needs to be coated over the valves (Heydarzadeh Sohi, 2001).

In recent days, Aluminum metal matrix composites are finding increased applications in all the areas such as automotive, aircraft, aerospace, mechanical industries, etc due to its characteristics like lesser weight, resistance to corrosion, etc. In this research, Al-Si composite have been used to improve properties of the engine valves. Engine valves are fabricated through casting and powder metallurgy processes and in which the Al-Si coating will be done using vapor deposition method. In order to identify the optimal proposition of the Al-Si before fabrication and testing, the engine valve has been designed in the CAD and analyzed using Ansys software. The finite element analysis of the Al-Si composite engine valve was carried out for identifying the temperature distribution, deformation, mechanical properties, principal stress and principal strain over the entire surface. The result showed that the stresses are well below the allowable values and the mechanical characteristics are better than the cast iron valve without coating.

Literature survey

Tribological behavior and the deposit formation on the engines and the valves are affected due to higher surface temperature. So numerous engine studies are also focused on the effects of heat transfer and distribution over the engine and valves (Alkidas and Myers, 1982; Enomoto and Furuhama, 1984; Hayes *et al.*, 1993; Tillock and Martin, 1997), also the development of heat transfer correlations (Woschni, 1967; Annand, 1963; Hohenberg, 1979) and relationship between deposition and heat transfer (Overbye *et al.*, 1961). Due to digital revolution, researchers are using various computational and analytical models for analyzing the heat transfer effects (Noori and Rashidi, 2007) by simulating the real time environment in the high end computers. So in this research, finite element analysis has been used to analyze the coating characteristics. The most common coatings currently used in high temperature engine applications are stabilized zirconias due to their very low thermal conductivity and higher coefficient of thermal expansion which is higher than majority of the ceramic materials (Assanis and Mathur, 1993; Furuhama and Enomoto, 1987). Various researchers used different thickness of coating varied from 0.1mm to 4.5mm (Tolokan *et al.*, 1984). Also it is proved that the thicker coatings theoretically providing greater resistance to heat flux (Soltani *et al.*, 2005). The nano-structured ceramic and metal-based TBCs (Shin *et al.*, 2007) with CTEs more comparable to typical metallic substrates have been studied, with some promising results.

Methodology

The alloy of aluminum and silicon proved to have better hardness, crushing strength, higher wear resistance, etc (Buytoz, 2006). So in this research, Al-Si composites have been used by varying the percentage of silicon from 0 to 75 %. In the standard engine valve, coating of 0.2 mm will be done using vapor deposition method over the entire surface. The ratio of Al-Si composition in the alloy has been optimally identified by conducting various simulations on the computer using Ansys software. In this research, finite element technique is used identify the mechanical properties and characteristics of the Al-Si composites. The output obtained will be investigated to identify the best optimal coating for four stroke IC engine valves to improve its life and wear resistance. The finite element analysis of engine valve was done along with its valve guide to correlate the relation between the valve and valve guide. For analysis, geometric modeling of the valve had done using solidworks software as a single part. Then the model had converted to a neutral format and then imported to the Ansys software for analysis. As the valve is a symmetrical object, axis symmetry analysis had been carried out to reduce the computational time (Terrence and Robert, 1998). Major boundary conditions considered for the analysis are the temperature, pressure and degrees of freedom. The ranges of the boundary condition parameters are as follows,

(i) Temperature boundary conditions:

Temperature at cylinder end : 750 °C & 600 ºC for outlet and inlet valves respectively.
Temperature at outer end : 450 °C & 300 ºC for outlet and inlet valves respectively.

(ii) Pressure boundary conditions:

Pressure on cylinder head : 90 MPa
Pressure on engine valve guide: 10 MPa

(iii) Displacement boundary conditions:

Rotational degrees of freedom: 0

$$dx = dy = 0; dz = 1$$

The analysis had carried out after meshed with eight nodded triangular solid element. The valve stem also analyzed for hallow and solid nature. The meshed image of the hallow valve stem is shown in the figure 1.

The output obtained from the von-missies stress plot are the temperature, stress and strain distribution over the entire surface of the engine valve along with the deformations. Similarly by increasing the weight percentage of silicon i.e. by varying the material properties such as elastic modulus, Poisson ratio, thermal conductivity, coefficient of thermal expansion, etc. analysis were conducted. At present, the engine valve guides are made of iron-based materials, so that material also analyzed for comparative study. The material properties considered for the finite element analysis are given in the table 1.

Table.1 Properties of different material used for the finite element analysis

Material	**Al + Si (10 %)**	**Al + Si (15 %)**	**Al + Si (20 %)**	**Al + Si (25 %)**	**Al + Si (30 %)**
Density Kg/m3	2744	2766	2788	2811.5	2835
Elastic Modulus Gpa	77.4	82	86	89	92
Poisson ratio (µ)	0.33	0.325	0.32	0.315	0.31
Thermal conductivity W /mK	173	170	168	166	164

Table.2 Comparison of the properties of cast iron and Al-Si engine valves

Valve Material	**Al + Si (10 %)**	**Al + Si (15 %)**	**Al + Si (20 %)**	**Al + Si (25 %)**	**Al + Si (30 %)**	**Cast iron**
Rockwell Hardness (HRC)	46.25	49.18	51.52	52.14	53.56	35
Radial crushing load (KN)	19	20	23	28	32	17
Wear rate mm3/ minute	0.2497	0.1421	0.0876	0.1362	0.1218	0.1945

Figure.1 Ansys meshed image of engine valve stem

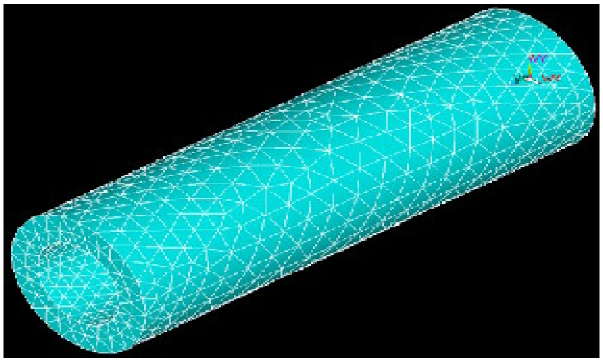


Figure.2 HRC comparison

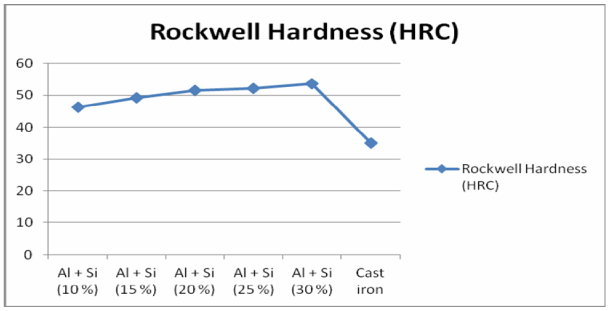


Figure.3 Wear rate comparison

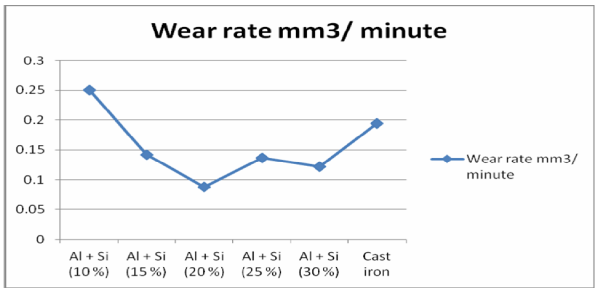
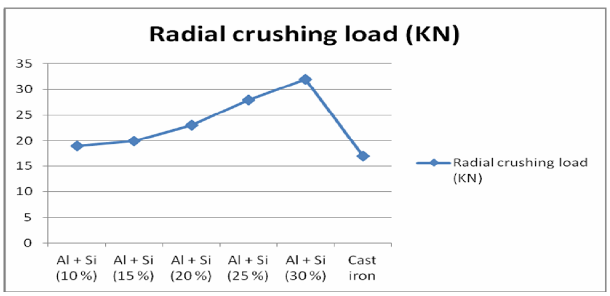


Figure.4 Crushing load comparison



From the obtained result for the various combination of the alloy by varying the silicon percentage, it is found that the silicon percentage variation between 10% and 30% producing promising results compared to the other percentage of silicon in the alloy. The output obtained from the analysis of the engine valve is given in the table 2.

From the graph provided in figure 2, it is proved that the HRC of the alloy is higher compared to the commonly used cast iron without coating. Form the figure 3, it is proved that the wear rate for the alloys of aluminum with 20 % of silicon having higher wear resistance compared to all other combination of materials. From the figure 4, it is proved that the alloys of Aluminum with 30 % of silicon having higher crushing strength compared to the other combination of materials. Thus the coating proved to be the better in most of the mechanical properties.

The maximum deformation due to stress on the valve under various load conditions has been identified as 0.00238 mm for the 14 mm valve. The obtained value is very small and the gap between the valve and the engine is 0.05 mm, so the deformation will not seal the gap and there by the frictional effect due the sealing the gap and the wear rate reduces.

Form the detailed analysis, it has found that the temperature distribution over the entire surface varies from 620 °C to 460 °C, which is in the acceptable range i.e. lies between 750°C to 300°C. In this temperature ranges, the thermal expansion of the valves is also found to be negligible.

Conclusion

The obtained result proved that the deformation due to loading and deformation due to thermal expansion of the valves will not seal the gap between the valve and the engine block. So the wear on the valve stem will be reduced. Due to higher wear resistance properties, the wear of engine valve during the cold start is also proved to be reduced. The maximum and minimum principal stress acting on the engine values are found to be within the allowable limits of the alloy and thus the valve life increased. The alloy coated engine valves also have higher Rockwell hardness, radial crushing strength and wear resistance than the cast iron engine valve guide. Thus it is proved that the Al-Si composites coating over the engine valve have the enough potential as an optimal better material for the engine valve and engine guides.

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