Optimization of Thermal Barrier Coating Material for Diesel Engine Cylinder Liner

[1]K.Thiruselvam,[2]B.Balamugundan,[3]S.Senthil,[4]R.Saravanan
[1]Research scholar, AnnaUniversity, Chennai.
[2]Research scholar,Sathiyabama Deemed University, Chennai.
[3,4]Assistant professor, Department of Mechanical Engineering, Panimalar Engineering College,Chennai.

***Abstract* - The present study focuses on improving the thermal efficiency of CI engine by decreasing the heat transfer in combustion chamber. In this paper, analyze the different ceramic powder coating materials on the Nickel chromium cast iron alloy cylinder liner by conducting various tests in order to finalize the best ceramic coating on the cylinder liner.**

Four different coating materials combination have been chosen for the analyses which are Yttrium Stabilized Zirconia (YSZ), Aluminum oxide (Al_2O_3), Aluminum Oxide and Yttrium Stabilized Zirconia (Al_2O_3 +YSZ), Aluminum Oxide and Titanium Oxide (Al_2O_3+TiO_2). The optimum level of thickness 100 microns has been chosen for the observing the results.

The mechanical strength test of wear test, adhesive test, SEM and EDX test, in additionally flow analyze test of CFD have been conducted. From the results, it's showed that combination of Aluminum Oxide and Titanium Oxide (Al_2O_3+TiO_2) had better ceramic coating than other materials.

Key words: Thermal barrier coating (TBC), Low Heat Rejection (LHR),Ceramic materials, Diesel Engine.

I. INTRODUCTION

Design of diesel engines with low heat rejection has major focus on recent research work.T.Hejwowski [1] et.al., concluded that 0.5mm lower thickness of thermal barrier coating on piston crown has reduce the fuel consumption around 20% and increased power about 8%. Winkler et.al.[2-3] reported that Diesel engine are in reducing automotive emissions and improving combustion efficiency by the use of ceramic coatings. Buyukkaya et al.[4] achieved that the reducing 8% specific fuel consumption by the combined effect of the thermal barrier coating (TBC) and injection timing. Cerit M.,[5] experimentally proved optimum thermal barrier coating is less than 1mm otherwise the shear stress causes to increase lateral cracks and reaches its maximum level at the inner edge of the coated region.

Materials physical parameter of melting point,thermal conductivity,thermal shock resistance,corrosion and coefficient of thermal expansion are the major focus on selection of thermal barrier coating [6,7]. V.Gnanamoorthi [8],the test results shows that thermal barrier coateddiesel engine achieved low BSFC and an high brake thermal efficiency (BTE) of about 6% but considerable4.32% high$NO_x$and reduced CO and HC emission. With this aim, coating combustion chamber components with low thermal conductivity materials becomes a more important subject at these days. Hence, in this research work four different materials are tested for selection of suitable ceramic coating in the diesel engine cylinder liner.

2. METHOD OF COATING:

MATERIAL	Nickel chromium grey cast iron
BORE DEPTH	280mm
BORE DIAMETER	127mm
THICKNESS	6mm
CASTING	Centrifugal casting
APPLICATION	Ashok Leyland 680 engine

TABLE 1: Cylinder liner material specification

Table 1 shows base cylinder liner material specifications. Figure1 shows a schematic of the plasma spray gun and table 2 shows process parameter for plasma spraying.

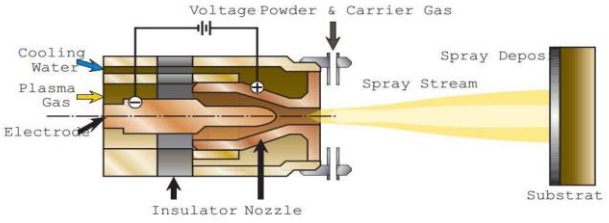


FIGURE 1: Schematic diagram of Plasma spray gun

The cylinder liner base metal has cut in to number of pieces for conducting wear test, adhesive test and SEM test. The test pieces are coated by different materials of yittria stabilized zirconia,alumina ,combination of YSZ and alumina, YSZ and titanium oxide by using plasma spray coating method. All the metal pieces are coated uniformly about 100 microns thickness.

Sl.No.	Parameters	Value
1	Spray gun	3 MB
2	Nozzle	GH
3	Current (A)	490
4	Voltage (V)	60-70
5	Powder feed (g/min)	40-50
6	Spray distance	76.2-127±10%min
7	Particle velocity (m/s)	Upto 450
8	Arc temperature (^{0}c)	16,000
9	Particle size (µm)	14.5-45
10	Inert gas flow	
	a) Argon (l/min)	100-200± 5%
	b) Hydrogen (l/min)	100 ± 5%

TABLE 2: Process parameter for plasma spraying

3.RESULTS AND DISCUSSION

1.1. SEM/EDX:

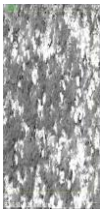
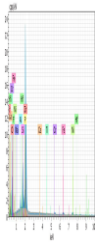
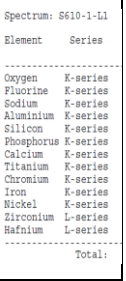
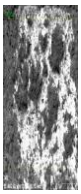
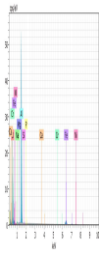
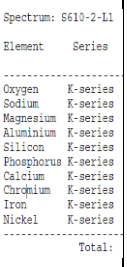
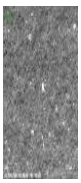
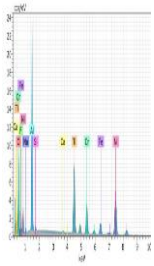
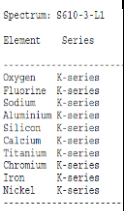
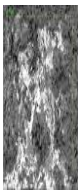
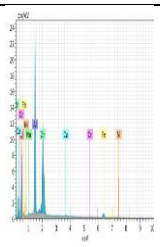
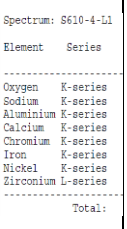
Sl. no	Coating materials	SEM Image	EDX Graph	Materials composition
1.	YSZ			
2.	AL_2O_3			
3.	Al_2O_3+TiO_2			
4.	Al_2O_3+YS			

TABLE 3:SEM and EDX results of testing materials image and compositions.

Table 3 shows SEM and EDX results of the different testing materials.The SEM results are in the form of black and white images clearly indicate the ductile and brittle fracture mode of the materials. The image of Al_2O_3 + TiO_2 shows that full black and small white voids so that it has more ductile fracture mode material where as other materials has more brittle fracture mode materials since they all have more white voids images.

The EDX graph indicates materials composition of testing materials. The Yttria Stabilized Zirconia contains 55% of Zr and 26% of O_2, Aluminium Oxide contains 50% of Al and 40% of O_2,Aluminium Oxide and Titanium Oxide contains 21% of Al, 21% of Ni,26% of O_2,14% of Ti,Aluminum Oxide and Yttria Stabilized Zirconia contains 32% of Zr,38% of O_2 and 24% of Al.

3.2 Adhesive Test (Peel Off Test):

Figure 2:Sample After Sticking Paper Tapes

Sl.no	Coating materials	Initial Weight in gram	Final Weight in gram	Weight loss in gram
1.	YSZ	42.334	42.312	0.220
2.	Al_2O_3	51.427	51.415	0.012
3.	Al_2O_3+TiO_2	49.328	49.317	0.011
4.	Al_2O_3+YSZ	51.840	51.830	0.010

TABLE 4:Peel off test result

Figure 2 shows the four sample materials after sticking paper tape for testing. Table 4 shows adhesive strength of testing materials. The adhesive nature of coating materials with substrate has calculated by using the peel adhesion test, the above table shows that the amount of material removed from all the compositions is almost equal except Yttria Stabilized Zirconia (YSZ).

3.3 WEAR TEST:

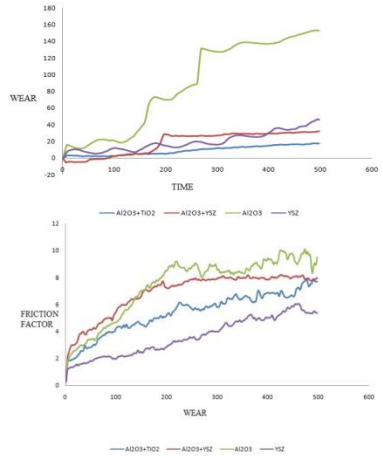


Figure 3:Wear and Time FIGURE 4:Friction factor and Wear

The wear test is conducted by using pin-on-disc equipment. Wear rate and friction factor has calculated for various materials. The figure 3 shows that the variation of wear rate and figure 4 shows the friction factor for different materials. The combination of alumina and titanium oxide (Al_2O_3+TiO_2) has low wear rate and moderate friction factor compared with other coating materials.

3.4 Thermal Analysis Using Cfd

2.4.1. Workpiece Al_2o_3 :

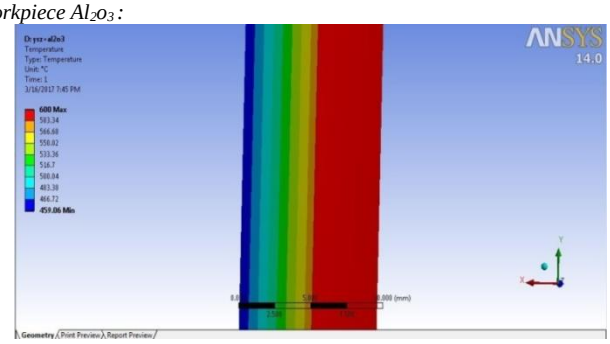


Figure 5:CFD OF AL_2O_3

Figure 5 shows that CFD analysis of Al_2O_3. The maximum temperature was assumed to be 600^0C and ambient temperature was considered to be 450^0C. The temperature maintained within the chamber is 459^0C.

2.4.2.*Workpiece of Ysz:*

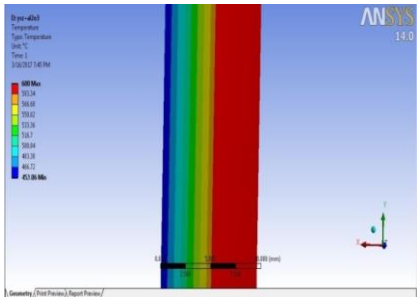


Figure 6: CFD OF YSZ

The figure6 shows the temperature contours showing the Temperature difference across the thicknessof the TBC, bond coat and substrate.The maximum temperature was assumed to be 600^{0}C and ambient temperature was considered to be 450^{0}C. So from the results the temperature retained in the chamber is 453^{0}C.

2.4.3. WORKPIECE Al_2O_3 +TiO_2:

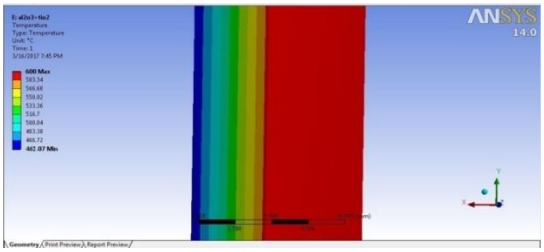


Figure 7:CFD of Al_2O_3 +TiO_2

The figure7 shows the temperature contours showing the Temperature difference across the thicknessof the TBC, bond coat and substrate.The maximum temperature was assumed to be 600^{0}C and ambient temperature was considered to be 450^{0}C. The temperature retained by this material is 462^{0}C.

2.4.4. WORKPIECE Al_2O_3 + YSZ :

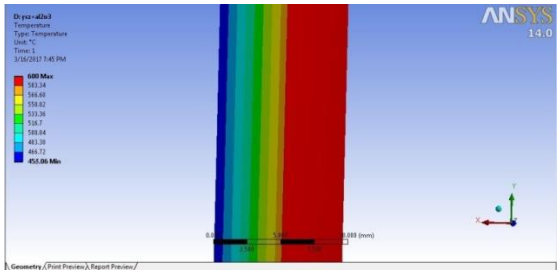


Figure 8:CFD of Al_2O_3 + YSZ

The figure 8 shows the temperature contours showing the Temperature difference across the thicknessof the TBC, bond coat and substrate.The maximum temperature was assumed to be 600^{0}C and ambient temperature was considered to be 450^{0}C. This material retained the temperature is 455^{0}C.

CONCLUSION

The current work focuses on improving the thermal efficiency of the diesel by decreasing the heat transfer. By taking particular emphasis of the test methods of wear test, adhesive bond strength, EDX and thermal flow analysis are made to find out the best ceramic powder blend. From the wear and adhesive bond strength tests, Al_2O_3+TiO_2 and Al_2O_3+YSZ were best blend characteristics materials. The elemental analysis or chemical characterization of the sample is taken by the EDX test. The thermal heat flow analysis in the combustion chamber is considered by CFD. The main perspective is to retrain heat in the chamber and by taking that into account, Al_2O_3+TiO_2 and Al_2O_3+YSZ were best thermal barrier coating material for diesel engine cylinder liner.

REFERENCES

[1]. T.Hejwowski, A.Weronski., “The effect of thermal barrier coatings on diesel engine performance”, Vacuum surface engineering, surface instrumentation & vacuum technology,vacuum 65(2002) 427-432.
[2]. Winter M.F.,Parker D.W and Bonar J.A.,1992, “Thermal barrer coatings for diesel engines: ten years of experience”,SAEInternational,paper no.922438.
[3]. Winkler M.F,and Parker D.W.,1993, “The role of diesel ceramic coatings in reducing automotive emissions and improving combustion efficiency”, SAE International,paper No.930158.
[4]. Buyukkaya E.,Engin T. and Cerit M.,2006, “Effects of thermal barrier coating on gas emissions and performance of a LHR engine with different injection timings and valve adjustments”, Energy Conversion and Management,47,1298-1310.
[5]. Cerit M.,2011, “Thermo mechanical analysis of a partially ceramic coated piston used in an SI engine”, Surface and Coatings Technology,205,3499-3505.
[6]. X.Q.Cao, R.Vasen and D.Stoever,Ceramic materials for thermal barrier coatings,Journal of the European Cermaic Society 24(2004) 1-10.
[7]. V.Sankar, Thermal barrier coatings material selection,method of preparation and applications-review,vol.3,no.2,ISSN 2278-0149,April 2014.
[8]. V.Gnanamoorthi and G.Devaradjane, “The effect of thermal barrier coating material in CI engine using higher fraction ethanol diesel belend”. Journal of Chemical and Pharmaceutical Research,2015, 7(2):416-422
[9]. K.Thiruselvam, “Thermal barrier coatings in internal combustion engine”. National Conference on Recent Trends and Developments in Sustainable Green Technologies, www.jchps.comISSN: 0974-2115
[10]. Chan S., H. and Khor K., A. “The effect of thermal barrier coated piston crown on engine characteristics”, Journal of Materials Engineering and Performance, 9(1), 103-109, (2000).
[11]. Taymaz I., Çakır K., Mimaroğlu A., “Experimental study of effective efficiency in a ceramic coated diesel engine”, Surface and Coatings Technology,1182-1185, (2005).
[12]. Chan S., H. “Performance and emissions characteristics of a partially insulated gasoline engine”, International Journal of ThermalSciences, 40, 255-251, (2001).
[13]. B.B. Goash., T.K.Banerjee., “Experimental investigations on some performance parameters of a diesel engine using ceramic coatings on the top of the piston”. SAE paper No. 970207.
[14]. Palaniswamy E, ManoharanN."ceramic coated combustion chamber for improving ic engine performance" International Journal on Design and Manufacturing Technologies, Vol.2, No.1, July 2008