JJMIE

Volume 5, Number 5, Oct. 2011
ISSN 1995-6665
Pages 403 - 406

Jordan Journal of Mechanical and Industrial Engineering

The Effect of Thermal Barrier Coatings on Diesel Engine Performance of PZT Loaded Cyanate Modified Epoxy Coated Combustion Chamber

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Abstract

The performance of internal combustion engines should be improved depending on some technological requirements and rapid increase in the fuel expenses. On the other hand, the improvements in engine materials are forced by using alternative fuels and environmental requirements. Therefore, the performances of engine materials become increasingly important. The purpose of PZT loaded cyanate modified epoxy system (60EPCY 20PI) is to focus on developing binder systems with low thermal conductivity and improve the coating durability under high load condition. The coating material is made up of 20% Lead Zirconate Titanate (PZT) in 60% Cyanate modified Epoxy system. The triazine ring of cyanate ester offers better thermal resistance characteristics to the epoxy system. Experimental investigation is carried out under different load condition on a single cylinder diesel engine with PZT loaded cyanate modified epoxy resin system of 0.5 mm thickness to the piston, cylinder head with valves and cylinder liner. The result showed 15.89 %of reduced specific fuel consumption. Emissions of unburnt hydrocarbon, carbon monoxide are reduced whereas NOx is increased.

Keywords: 60EPCY 20PI; triazine ring; Diesel engine; Emissions; Thermal Resistance

1. Introduction

Diesel engine has become the most fuel efficient power plant sustainable for mobile application. It has assumed a leading role in both transport and agricultural sector because of its outstanding fuel economy and its lower running cost. Even in diesel engine the coolant and exhaust gases carry substantial amount of fuel energy away from the combustion chamber [1]By using PZT loaded cyanate modified epoxy system (60EPCY 20PI) coated combustion chamber there is reduction in heat transfer to the coolant and an improvement in power output along with an increase in exhaust energy.

The transfer of heat is conducted through the combustion chamber elements, like valves, piston surfaces and liners. Ceramic of this element by a composite with low thermal conductivity keeps the heat in the chamber and hence increases the temperature [2]. The requirement for more efficient engines in the future will also require even higher operating temperatures. Ceramic with their high temperature resistance, may offer an excellent coating surface to reduce the amount of degradation and to extend the life. Composite coating absorbs thermal shocks and protects the substrate.

The primary purposes of high temperature structural coatings are to enable high temperature components to operate at even high temperature, to improve component durability of engines [3]. 60EPCY 20PI are characterized by excellent mechanical and low thermal conductivity properties, high chemical and corrosion resistance, low shrinkage on curing and the ability to be processed under a variety of conditions.

In this paper main emphasis is placed on investigating the effect of 60EPCY 20PI coated combustion chamber on the engine fuel consumption and thermal efficiency. Emission measurement of unburned hydrocarbon, carbon monoxide and NOx were also conducted.

Figure 1 shows the 60EPCY 20PI coated piston, cylinder head with valves and liner.

Figure 1: Photographic view of 60EPCY 20PI coated piston, cylinder head with valves and liner.

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2. 60EPCY 20PI Material

Epoxy resin LY556 (diglycidyl ether of bis phenol A), curing agent HT972 (DDM - diamino diphenyl methane), Arocy b10 (bis phenol dicyanate), E-glass fibre and lead zirconate titanate (PZT).

The composites are fabricated from E-glass fiber and commercial epoxy resin/cyanate modified epoxy resin. The glass fiber with an aerial density of 200 g/m2 was used as the reinforcement for composite laminate. The liquid epoxy was taken in a beaker, which was heated to 90^{o}C to lower the resin viscosity and desired amount of cyanate was added into resin. The Cyanate loading is 60% and 20% PZT loading by weight of epoxy resin. The mixture was degassed in a vacuum oven followed by addition of DDM (curing agent) in 27% by weight of epoxy and stirred for 3 minutes at 90^{o}C. It is coated on the combustion chamber which has high temperature phases like tetragonal and cubic structures.

The mechanical properties are investigated by using universal Testing Machine (Model H50K-S, Hounsfield Test Equipment Ltd, UK).The cross head speed was 1mm / min The span length of the specimen was 150mm .Tensile modulus studies were evaluated as per ASTM D 3039.The flexural strength and flexural modulus of the composites were studied as per ASTM – D790. The crosshead speed was 1.0 mm / min. The double cantilever beam (DCB) test samples for GIC fracture toughness measurements were prepared according to the ASTM D 5528 (dimension 125 x 25 x 3mm) with a preinitiated crack of 50mm. Aluminium hinges were attached to the surfaces of the specimens to facilitate crack propagation. Measurements of load and crack displacement were taken at the initial crack propagation, at 1mm intervals for first 5mm, then at 5 mm interval up to a total crack length of 45 mm and at 1mm intervals for the last 5 mm giving a total of 19 readings. Three methods of data reduction were applied, using software programs, the data quoted being those obtained by compliance method at peak load. The displacement of crack was observed using a camera and the test was carried out in universal testing machine .Table 1 shows the mechanical properties of 60EPCY 20PI.

Table 1: Mechanical Properties of 60EPCY 20PI.

Properties	**60EPCY 20PI**
Tensile Stength (MPa)	355
Tensile Modulus (GPa)	7.98
Flexural Strength (MPa)	465
Flexural Modulus (GPa)	9.5
Fracture Toughness (kJ/m^{2}s)	0.9
Damping Factor	0.10029
Stiffness (N/mm)	62.97

3. Test Engine

Tests were carried out on a Kirloskar, single cylinder, water cooled, direct injection, four stroke stationary diesel engine. Once the steady state condition was reached after loading then the readings such as time taken for 10cc fuel consumption, exhaust gas temperature, HC, CO and NOx were taken. The air flow rate was measured by a U tube manometer. The pollutant emissions such as unburnt hydrocarbon, carbon monoxide, carbon dioxide, oxides of nitrogen and oxygen concentrations were measured by AVL 444 exhaust gas analyzer. The analyzer consists of an electrochemical sensor, which converts the concentration of different species in the exhaust gas into corresponding electrical signals. The exhaust gas temperature was measured by using a k- type thermocouple.

The following Figure shows a photographic view of the Experimental set up.

Figure 2: Photographic view of Experimental set-up.

The Technical specifications of the engine used in the experiments are illustrated in table 2.

Table 2: Technical specification of the engine used in the experiments.

Engine Type	Kirloskar, Vertical, Four stroke diesel engine
Bore Diameter	80mm
Stroke Length	110mm
Brake Power	3.68kW
Compression Ratio	16:01
Speed	1500rpm
Injection Type	Direct Injection
Cooling	Water
Fuel Injection	23^{o} bTDC
No.of.Cylinder	1
Injection Pressure	210 bar

4. Results and Discussion

The performance and Emission characteristics of 60EPCY 20PI material coated combustion chamber diesel engine was investigated and compared with standard engine. 60EPCY 20PI material acts as a thermal barrier coating which can improve BSFC and increase thermal efficiency. UBHC and carbon monoxide emission are reduced compared to standard engine. The results obtained from the experiments conducted on the engine are presented in Figure3 to Figure 8.

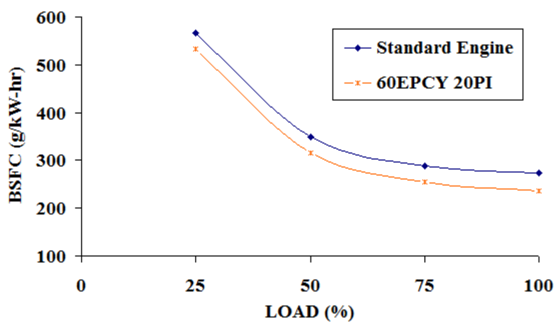

Figure 3: Comparison of Brake Specific Fuel Consumption for different loads.

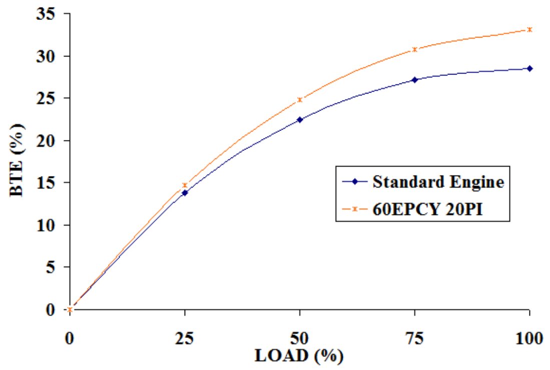

Figure 4: Comparison of Brake Thermal Efficiency for different loads.

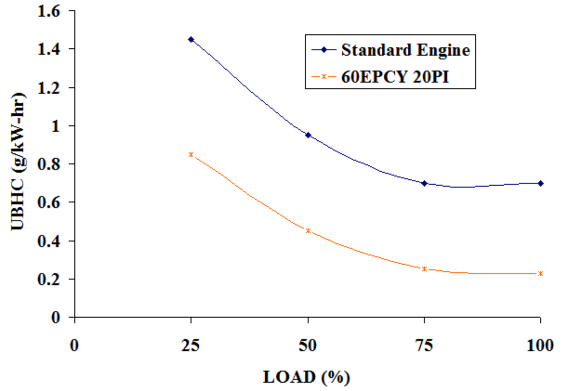

Figure 5: Comparison of Hydrocarbon emission for different loads.

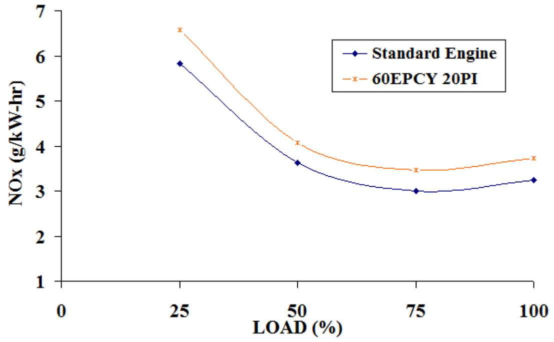

Figure 6: Comparison of Oxides of Nitrogen emission for different loads.

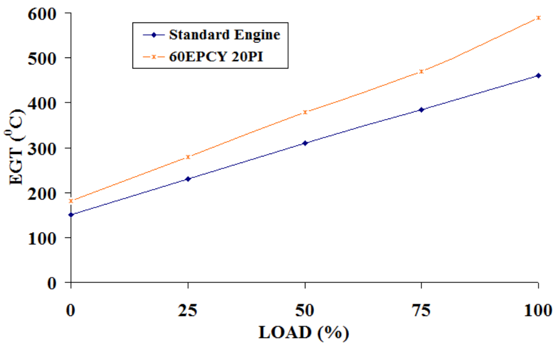

Figure 7: Comparison of Exhaust Gas Temperature for different loads.

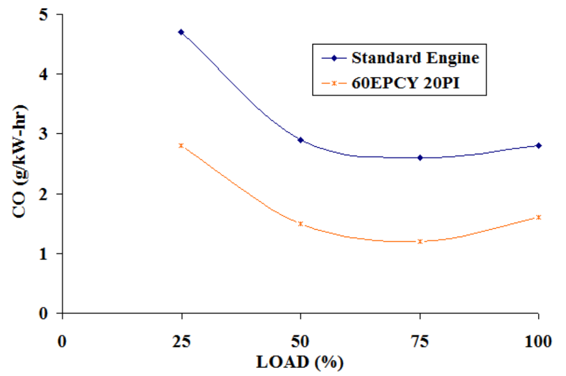

Figure 8.Comparison of carbon monoxide emission for different loads.

Figure 3 shows the variations of brake specific fuel consumption of standard engine and compared with 60EPCY 20PI coated combustion chamber. The specific fuel consumption is reduced by 15.89% for resin-PZT coated combustion chamber compare to standard engine. This may be due to increased temperature of the combustion chamber walls, which increases the temperature of the fuel issuing from the heated nozzle orifice resulting in the reduced fuel viscosity.

The variation of brake thermal efficiency with load for engine operating on 60EPCY 20PI coated combustion chamber and standard engine are shown in figure 4.It is significant that modified combustion chamber has higher efficiency than that of base line. This may be due to thermal resistance on the walls which cannot allow the heat energy to the coolant. The maximum brake thermal efficiency obtained for engine operating on 60EPCY 20PI coated combustion chamber and standard engine are 33.05 % and 28.49 %.

Figure 5 shows the comparison of Hydrocarbon emission for different loads. Formation of sac volume is not possible because of high compression temperature at the end of compression stroke so the fuel droplets stored in the tip of the nozzle also enhance the combustion in the 60EPCY 20PI coated combustion chamber which reduces hydrocarbon emission compared to standard engine. For modified combustion chamber and standard engine HC emissions are 0.23 g/kW-hr and 0.7 g/kW-hr at full load condition.

Figure 6 indicated the variation of oxides of nitrogen with load for 60EPCY 20PI coated combustion chamber and standard engine. NOx is generated mostly from nitrogen present in air and also from fuel. The inherent availability of nitrogen and oxygen in the fuel accelerates the formation of NOx. While observing the trends of modified combustion chamber, it is noticed that higher the combustion and maximum temperature in the combustion chamber which in turn results in higher NOx. With 60EPCY 20PI coated combustion chamber, the NOx level varies from 6.57 g/kWh at no load and 3.72 g/kWh at full load condition.

Figure 7 depicts the variation of exhaust gas temperature with load for 60EPCY 20PI coated combustion chamber and standard engine. It can be observed that when the combustion chamber is 60EPCY 20PI coated the combustion temperature is high which increases exhaust temperature. The increase in temperature is due to the better combustion of oxygenated fuels. The exhaust gas temperature for standard engine is 150^{o}C at no load and 460^{o}C at full load. With 60EPCY 20PI coated combustion chamber, the exhaust gas temperature increases to181^{o}C to 590^{o}C.

The measured CO emissions for 60EPCY 20PI coated combustion chamber and standard engine are shown in Figure 8. The reduction in CO emission is due to complete combustion and on local rich region found in the 60EPCY 20PI coated combustion chamber. With 60EPCY 20PI coated combustion chamber, the CO level varies from 2.8 g/kWh at no load and 1.6 g/kWh at full load condition.

5. Conclusion

A conventional contemporary diesel engine was converted to a 60EPCY 20PI coated combustion chamber diesel engine. The BSFC and emission were measured to determine the performance and emission characteristics of the engine. The following conclusions can be drawn from the experimental results.

60EPCY 20PI coated combustion chamber diesel engine shows better BSFC compared to conventional diesel engine. It is 15.89% reduced specific fuel consumption than the standard engine. NOx and Exhaust Gas Temperature are so high for 60EPCY 20PI coated combustion chamber diesel engine. Hydrocarbon emission was reduced drastically in 60EPCY 20PI coated combustion chamber diesel engine.

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