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Effect of Copper Coating on Extended Expansion SI Engine

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Abstract: In this research, a single cylinder engine with variable ER/CR ratio was analyzed for its performance when copper coating is done on the surface of cylinder head - piston combination. Copper element which can promote pre-flame reaction was coated on the surface of cylinder head and piston. ER/CR ratio (Expansion ratio/compression ratio) was varied with LIVCT (Late Inlet Valve Closing Time) and the load was regulated with LIVCT-VCR combination. Due to the catalytic effect of copper coating it was found that for the copper coated EE engine, the brake thermal efficiency was improved by 4% compared to standard engine operating at same conditions. The SFC of the copper coated engine was reduced by 0.8 kg per kw-h compared to that of standard engine. It was found that for ER/CR ratio equal to 1.5, the copper coated EE engine was giving best performance in terms of load and thermal efficiency. It was also seen that the lean misfire limit of the engine was extended up to 0.75.

Key words: Extended Expansion (EE), ER/CR, SFC, efficiency, lean misfire limit, Variable Compression Ratio (VCR)

INTRODUCTION

With the increasing trend of usage of petroleum products, it becomes necessary to use fuel in efficient manner in internal combustion engines. One such attempt to achieve fuel economy was extended expansion concept which dates back to 19th century. James Atkinson (John, 1988) introduced the concept of higher expansion to compression ratio (ER/CR), so that the advantage of extended expansion in terms of higher engine work output and reduced blow down losses can be achieved. When expansion ratio is more than the compression ratio it becomes extended expansion engine (George *et al*., 1989). It was theoretically proved that at part load conditions compared to otto, diesel and dual cycles the miller cycle (i.e., extended expansion cycle) gives better efficiency (Jorge *et al*., 2005). It was also established that delayed closing of inlet valve employed in EE Engine makes faster mixing of air-fuel mixture (Li *et al*., 2004).

There were lot of research work being carried out in the past in EE engine (Ma and Rajabu, 1988), however the effect of copper coating on EE engine was not tried yet. In this study performance comparison between an EE engine and copper coated EE engine has been done. Experiments were conducted on a modified single cylinder SI engine with variable ER/CR ratio. Initially performance tests were conducted with EE engine for different ER/CR values. Then copper was coated on the engine cylinder head-piston combination of EE engine. Performance test were conducted on the copper coated EE engine and results were compared with that of EE engine. The basic idea of using catalytic material copper (Beyerlein *et al*., 1988) is to improve the pre-flame reaction so that we can achieve lean burn combustion. From the emission point of view, the gradual leaning of the operating mixture can effect reduction in emission level (Hailin *et al*., 2005).

ENGINE MODIFICATION

Initially a water cooled single cylinder diesel engine with specification shown in Table 1 was converted into spark ignited gasoline engine by altering the fuel injection system and providing electronic ignition system.

Further to achieve extended expansion, we have to delay the inlet valve closing time. Hence in the standard camshaft only the inlet valve cam was modified leaving the exhaust valve cam untouched. The amount of delay in closing the inlet valve decides the ER/CR ratio for extended expansion. Figure 1 shows the valve-timing diagram for standard engine and for modified SI engine to operate on extended expansion with ER/CR ratios 1.5 and 2.

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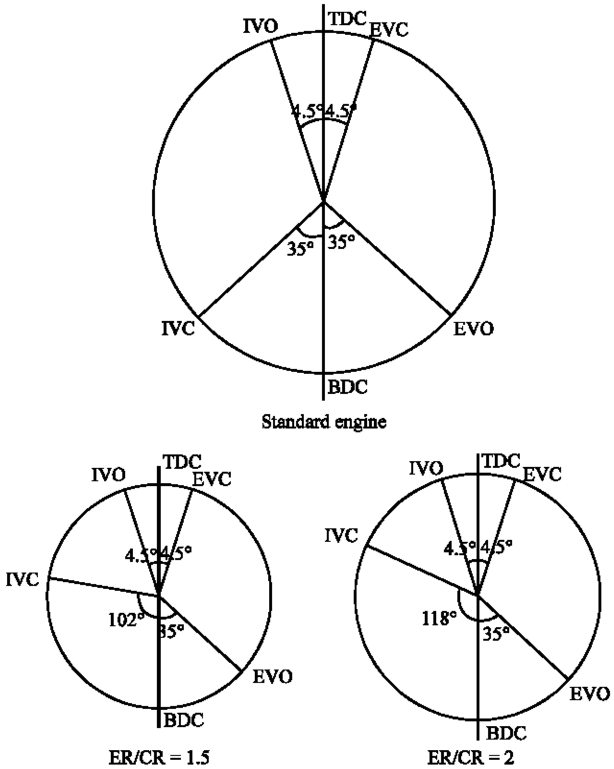

Fig. 1: Valve timing for standard engine and EE engine

Table 1: Specification of diesel engine before modification

Rated power	5 bhp
Rated speed (constant)	1500 rpm
Type of cooling	Water cooling
Compression ratio	16.5:1
No. of cylinders	1
ER/CR	1

To achieve an ER/CR ratio equal to 1.5 we have to delay the inlet valve closing by 67° i.e., inlet valve should close 102° aBDC. Similarly to achieve an ER/CR ratio of 2 we have to delay the inlet valve closing by 83° i.e., inlet valve should close 118° aBDC. Hence the Fig. 1 clearly shows the inlet valve closing time for corresponding ER/CR ratios. Other modification was done on piston crown. It was machined on top to have required peak pressure.

The technique used for depositing the copper catalyst material on cylinder head and piston combination was plasma coating. The surface of the cylinder head and piston combination was first thoroughly cleaned with emery paper of fine size and kerosene was used to wash away the minute particles of metal. Then copper up to a depth of 100 microns was deposited with high pressure plasma.

RESULTS AND DISCUSSION

Performance tests conducted with standard engine, EE engine and copper coated EE engine for different CR values clearly indicate the improvement in efficiency for copper coated EE engine.

Effect of copper coating on engine efficiency: Copper coating was done on cylinder head and on piston crown for the EE engine with optimized value of ER/CR ratio equal to 1.5. Due to catalytic effect of copper the performance test done on copper coated EE engine showed remarkable effect on brake thermal efficiency. Efficiency improvement for modified engine over standard engine is shown in Fig. 2 and 3.

It is observed that compared to standard engine, copper coated engine with ER/CR equal to 1.5 was having better thermal efficiency. Figure 2 indicates the improvement in efficiency of modified engine when CR is 8 as compared to the Standard Engine (ER/CR = 1) and EE

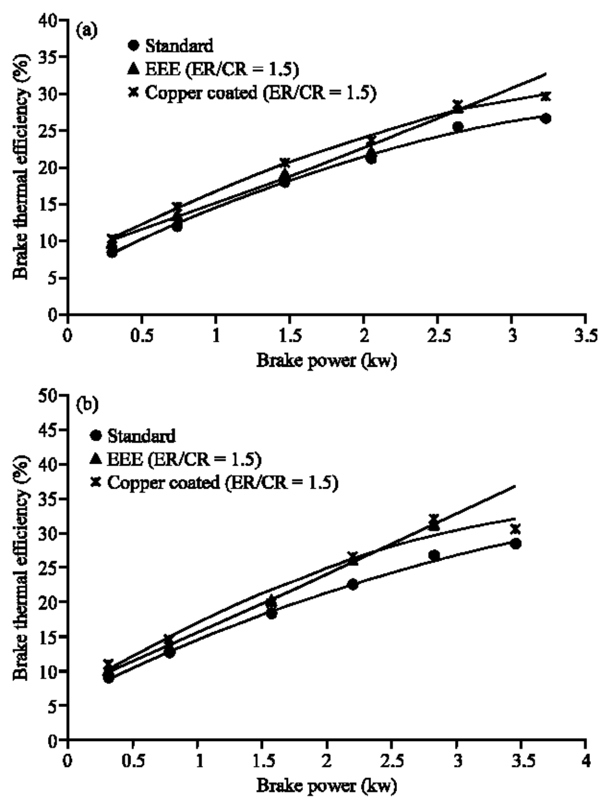

Fig. 2: Effect of copper coating on engine efficiency. a): Standard vs EEE and copper coated, CR = 8, speed 1400 rpm and b): Standard vs EEE and copper coated, CR = 8, speed 1500 rpm

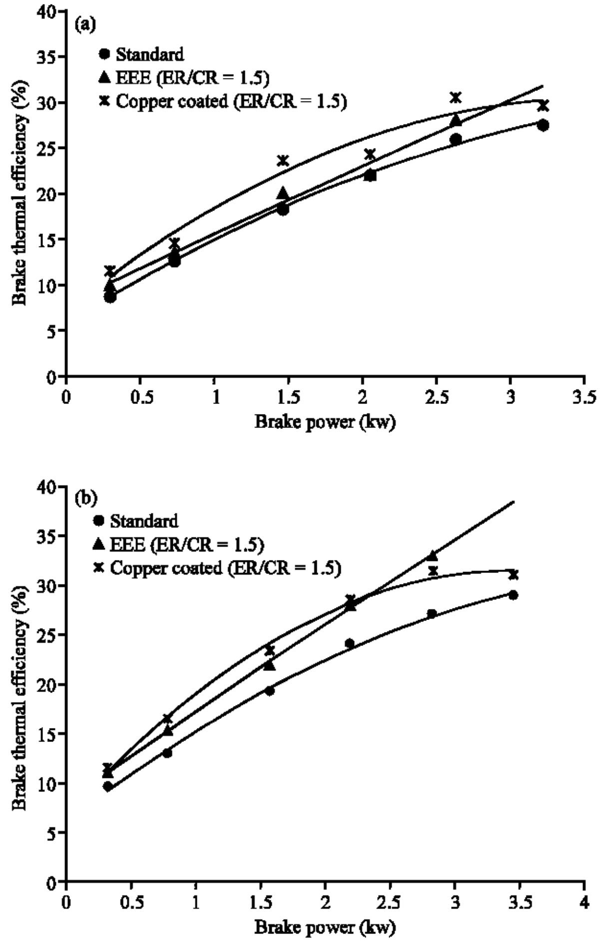

Fig. 3: Effect of copper coating on engine efficiency. a): Standard vs EEE and copper coated, CR = 9, speed 1400 rpm and (b) Standard vs EEE and copper coated, CR = 9, speed 1500 rpm

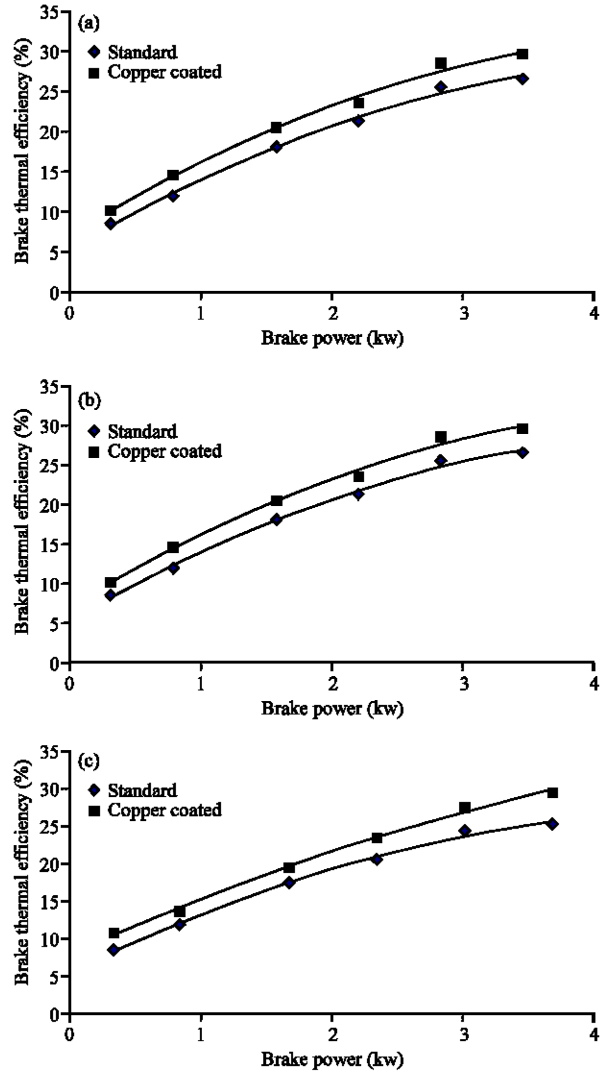

Fig. 4: Effect of speed on engine efficiency. a): Standard vs copper coated (ER/CR 1.5), speed = 1400 rpm CR 8, b): Standard vs copper coated (ER/CR = 1.5), speed = 1500 rpm, CR 8 and c): Standard vs copper coated (ER/CR = 1.5), speed = 1600 rpm, CR 8

engine (ER/CR = 1.5). Figure 2 clearly indicate that at speed 1400 and 1500 rpm, the part load efficiency of the modified engine is up by 4%. The copper coated EE engine with ER/CR = 1.5 is better than EE engine and Standard Engine.

The Fig. 3 compares the brake thermal efficiency of standard engine, EE engine (ER/CR = 1.5) and copper coated EE engine when compression ratio is 9. It is clear that the part load efficiency is higher for copper coated EE engine. Hence for compression ratio of 8 and 9 there is an improvement in part load brake thermal efficiency without the risk of knocking.

Effect of speed on engine efficiency: The effect of speed on engine efficiencies of a standard engine and copper coated EE engine is shown in Fig. 4 when CR value is 8.

The Fig. 4 clearly indicates that, for the compression ratio of 8, the copper coated EE engine has better part load efficiency. For a part load of 2.63 kw when speed is 1400 rpm and 2.826 kw when speed is 1500 rpm and 3.01 kw when speed is 1600 rpm, the gain in brake thermal efficiency is more. The increase in efficiency is 3% for a speed of 1400 rpm, 5.4% for a speed of 1500 rpm and 3.3% for a speed of 1600 rpm for part loads of 2.63 kw, 2.826 and 3.01 kw respectively. It is clear that speed of 1500 rpm would enhance the efficiency at part loads more effectively than 1400 and 1600 rpm. Similarly the Fig. 5

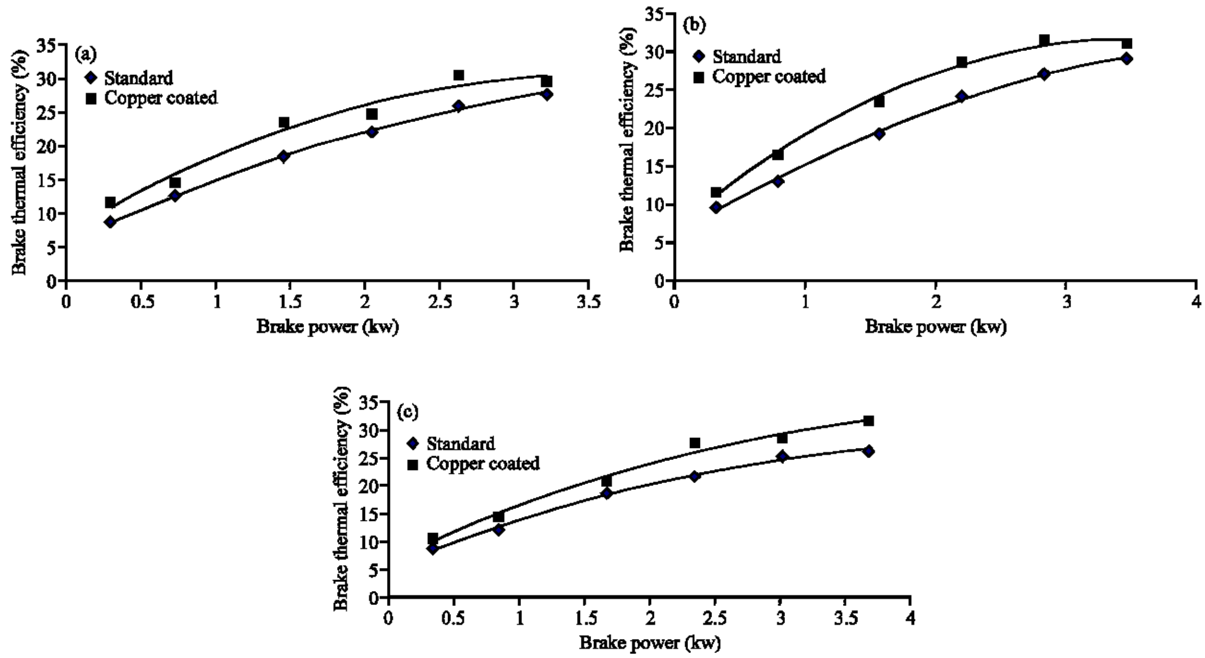

Fig. 5: Effect of speed on engine efficiency. a): Standard vs copper coated (ER/CR = 1.5), speed = 1400 rpm, CR 9, b) standard vs copper coated (ER/CR = 1.5), speed = 1500 rpm, CR 9 and c): Standard vs copper coated (ER/CR = 1.5), Speed = 1600 rpm, CR 9

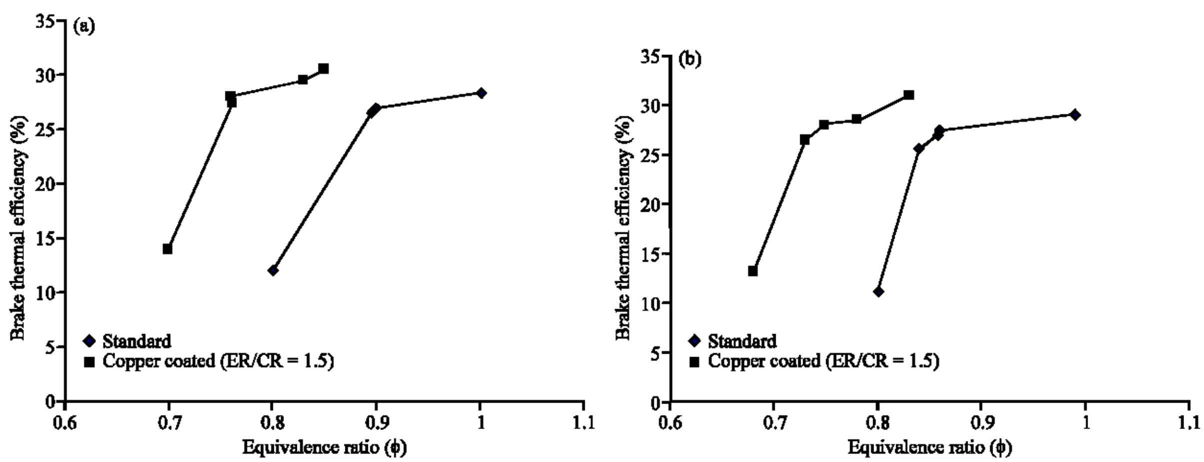

Fig. 6: Effect of equivalence ratio on engine efficiency. a): ϕ vs efficiency (CR = 8, speed = 1500 rpm) and b): ϕ vs efficiency (CR = 9, Speed = 1500 rpm)

shows the effect of speed on efficiency when CR value is 9.

For a speed of 1600 rpm the increase in part load efficiency is 6.1% at part load of 2.34 kw. For 1500 rpm the increase is 4.5% for a wide range of part load compared to 1400 and 1600 rpm.

Effect of equivalence ratio on engine efficiency: As performance tests were conducted on finding the lean misfire limit for copper coated EE engine, the effect of equivalence ratio on efficiency could be analyzed.

Figure 6 and 7 shows clearly the onset of lean misfire limit and it's effect on engine efficiency. It can be easily

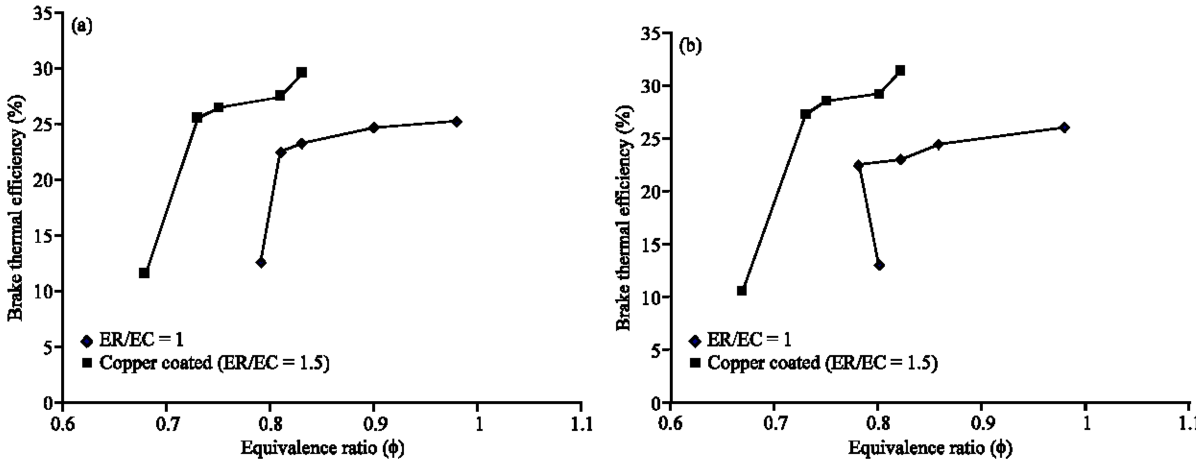

Fig. 7: Effect of equivalence ratio on engine efficiency. a): ϕ vs efficiency (CR = 8, speed = 1600 rpm) and b): ϕ vs efficiency (CR = 9, speed = 1600 rpm)

ascertained from the Figure 6 and 7 that, as the lean limit is reached the efficiency drops suddenly owing to low brake power output from the engine. It is quite clear that the thermal efficiency is more for copper coated EE engine than standard engine and also the lean limit is extended up to 0.76.

CONCLUSIONS

The above analysis explains lucidly the advantage of copper coating on cylinder head and piston of EE engine. Not only the brake thermal efficiency and SFC are improved for the EE engine, also the lean limit of the air fuel mixture is greatly extended to 0.75 for the EE engine implying the significance and advantages of lean burn. Hence the idea of copper coating on EE engine cylinder head and piston combination proves to be an advantageous trend towards fuel economy in internal combustion engines.

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