ABSTRACT

Nowadays, automobile systems play a vital part in life all over the world. Literature ascertains that 33% of the fuel energy available for heavy-duty vehicles are employed in overcoming friction due to engine, brakes, transmission, auxiliary equipment, and tires. Furthermore, roughly 20% of the losses arise from the engine and thus, every attempt to reduce frictional losses will have an instant influence on engine efficiency. Majority of mechanical frictional losses inside the engine originated by piston ring and cylinder liner assembly and bearings, amounts to approximately 65–70% of the total mechanical frictional losses. The conventional automobile components can be replaced by composite material in which two or more reinforcements are added into the matrix material to improve the strength and reduce the frictional losses. Recently, it has been found that nano-hybrid composite material gives better performance than a mono-reinforcement composite material. The lightweight nano-hybrid composite in automobile components not only saves fuel consumption but also decreases the emissions produced from the engine.

This research work aims to replace conventional cast iron cylinder liner (CL) with a new lightweight nano-hybrid composite cylinder liner (NL) to reduce the frictional losses and emissions and improve the performance of the engine. The systematic material selection procedure of analytic hierarchy process was used to select the matrix and reinforcement materials. New composites were prepared with nano-ZrO_2, micro-SiC ceramics, and micro-graphite solid lubricant reinforcements with Al6061 as matrix material. The controlled bottom pouring stir casting technique was used to make nano-hybrid composite samples.

Characterization was carried out to determine the tensile strength, hardness, coefficient of thermal expansion, thermal conductivity, corrosion and photomicrography study using field emission gun scanning microscope

(FEG-SEM). Taguchi method was adopted for the design of experiments to determine tribological properties such as wear and coefficient of friction. For this purpose, a reciprocating tribometer was designed and developed indigenously and the test results were analyzed with analysis of variance. A regression model was developed to predict the wear loss and coefficient of friction for Al6061 nano-hybrid composite samples equally reinforced with nano-ZrO_2, micro-SiC, and micro-Gr particles of 0, 0.75, 1.5, 2.25, and 3 by weight percentage under different operating conditions such as room temperature and high temperature of 125 °C and the conformation test was performed. Since for an engine cylinder liner, the coefficient of thermal expansion, coefficient of friction and mass loss by wear are more important parameters, the nano-hybrid composite material containing 6.75% by weight of combined reinforcement was found to be the most suitable material. The photo-micrographic examination of this sample also has shown more uniform bonding, without agglomeration although a nano-sized reinforcement has been added with matrix material. The combined reinforcement of 6.75% by weight with Al6061 matrix sample was identified to make new nano-hybrid composite cylinder liner (NL) similar to the present cast iron cylinder liner (CL) dimensions.

NL was machined using computer numerical control procedure and finished through honing operation, and new NLs were obtained. To minimize the manufacturing uncertainties, four liners (NL1, NL2, NL3, and NL4) were manufactured using the same procedure. The variations in weights were found to be negligible, with a maximum of variation of 0.25%. The performance, combustion, and emission characteristics of diesel engine were tested using the present CL and the newly manufactured NL at different loads. A four-stroke, direct-injection, water-cooled Kirloskar AV1 (3.75 kW power) engine was used as a test engine for this study. It had a cylinder bore of 80 mm, stroke length of 110 mm and a constant speed of 1500 rpm. In the NL-operated engine, brake thermal efficiency (BTE) was found to be comparatively higher than that of the present CL-operated engine at all-loads. This could be because nano- and micro-reinforcements play a major role because of their exceptionally high surface-to-volume ratio of the reinforcing phase with Al6061 matrix material. High temperature was maintained inside the combustion area because the possibility of complete fuel burning is high, which results in comparatively enhanced BTE, in-cylinder pressure, heat release rate, and exhaust gas temperature.

Emission test results showed that the use of NL reduced carbon monoxide (CO), hydrocarbon (HC), and smoke emissions compared to the use of CL. Oxides of nitrogen (NO_x) emission values indicated a marginal increase with the use of NL compared to the use of CL due to high temperature being maintained in the combustion chamber. The developed NL cost has been estimated and it shows marginal cost saving comparable to CL.

After running for 2000 h for a period of 1 year, at various load conditions, the engine fitted with the new NL was dismantled to conduct a teardown analysis. The internal parts were inspected and evaluated to investigate wear characteristics, breakage, and other damage as well as the accumulation of dirt, sludge, and carbon. No cracks were found both inside and outside of the NL. No foreign particles or Al matrix debris or reinforcement debris were observed in the engine oil. This again shows that the developed NL can be used as a replacement for the existing CL as it yields better performance and does not have detrimental effects.

Thus, this research work has shown that the newly developed NL has good potential to replace the presently used CL for achieving greater fuel economy and green environment. The fact that it can be used without any modification of the engine structure with weight saving of 43.75% is an added advantage.