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Enhancing Fuel Efficiency of Internal Combustion Engine through the Application of Nanostructured Aluminium Alloy in Pistons

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ABSTRACT
The automobile and motorsport industires are under immense pressure due to emission laws to reduce fuel consumption and alleviate the effects of global warming. This experimental study compared the performance of internal combustion engine pistons made of a newly developed nanostructured aluminium alloy (RSA-612) and conventional aluminium alloy 2618. The new alloy is expected to reduce piston mass which will reduce piston assembly frictional losses and lead to reduced fuel consumption. The new alloy has lower density and higher strength at elevated temperatures than conventional aluminum alloys, and the final machined piston was 13.5% lighter than the original piston. The limited engine testing carried out in this study showed that the new piston produced enhanced performance in certain engine operating conditions, whilst performing similarly or slightly worse in others. Further testing with the new piston is advised to assess engine performance across wider engine running envelope.

Keywords: Piston material, Piston, Spark ignition engine nanostructured aluminum alloy

INTRODUCTION
The automotive and motorsport industries have been under immense pressure due to emission control legislations to reduce fuel consumption and alleviate the effects of global warming (Blackmore & Thomas, 1977). Transport sector esepcially private transport is the largest contributor to emissions therefore improvement in this sector will lead to a bigger reduction in emissions. The automtoive industry responded to this challenge by reducing the over all mass of the vehicle and improving engine efficiency. Engine efficiency can effectively be enhanced by reducing losses in an engine. Besides thermodynamic losses, mechanical losses also play a significant role and the majority of these losses are caused by piston assembly (Merkle et al., 2012). It has been known that piston assembly is responsible for 30–40% (Kohashi et al., 2013) or 50% (Schwaderlapp et al., 2000) of the frictional losses in an engine.
The piston assembly friction is caused by a phenomenon called piston lateral acceleration/force (Kohashi et al., 2013). The lateral force is made of the components of gas and inertial forces (Adil et al., 2019; Norton, 2012) and the inertial force is dependent on the oscillating mass. The piston (Figure 1a) and the piston pin account for the greatest proportion of the oscillating masses. Any weight reduction undertaking must therefore start with these components. The motivation for the work presented in this paper is the superior mechanical properties at elevated temperatures exhibited by a newly developed aluminium based nanostructured alloy.

EXPERIMENTAL METHOD
The experimental work was carried out in the following 3 sections.

Microstructural Characterisation and Mechanical Properties of the Alloy
The detailed microstructural characterization of the new alloy can be found in (Adil, *et al*., 2023).

Finite Element Analysis of the Original and New Pistons
The modelling work carried out in this section was to establish a base finite element (FE) model for piston design and use it together with the new alloy's properties to design a new lightweight piston. The detailed finite

element analysis can be found in (Adil, *et al*., 2023; Adil, *et al*., 2019). The results presented in this work focused on the worst load case for the piston and the mechanical loads values are given in Table 1.

Table 1. Mechanical loads values in the maximum combustion load case.

Load	Value
Pressure	85.5 bar
Acceleration	14356 m/sec^2
Lateral Force	5626 N

Engine Testing

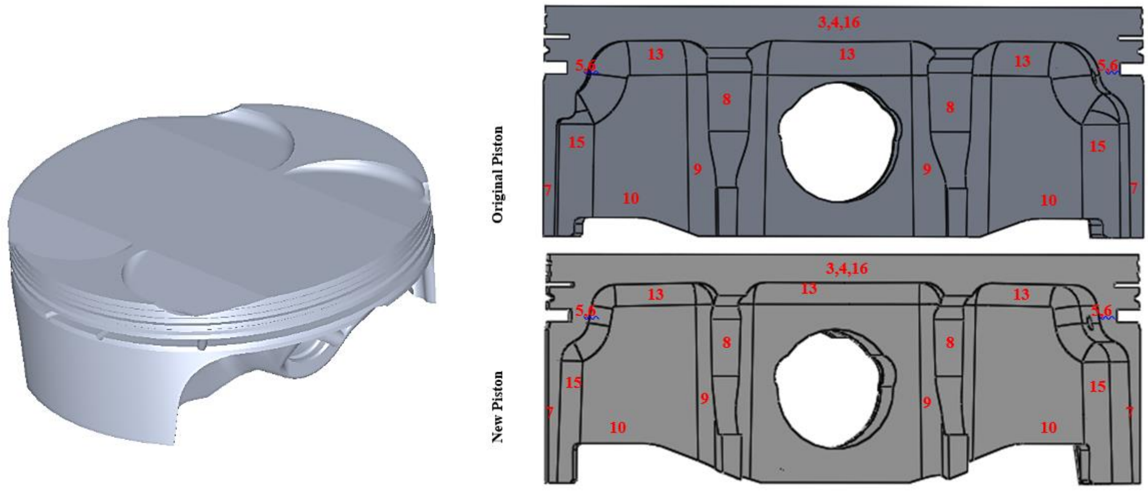
The engine tests were carried out with the original and new pistons. Measurements were taken under the same operating conditions in order to determine any gains or losses in the engine performance. More details about the engine test setup and testing are given in (Adil, *et al*., 2023).

RESULTS

Due to the number of pages restriction by the journal, not all results could be listed here. However, some of the critical results from each section of work are given below.

Finite Element Analysis results

The design approach was to reduce piston mass by thinning different sections of the piston (Figure 1b). This was feasible because the new alloy has higher strength.



a) **b)**

Figure 1. a) A model of the test piston **b)** Cross section and Comparison of original and new piston design.

Engine Test Results

The engine test results for brake specific fuel consumption vs. torque for engine speeds 3000 are given in Figure 2.

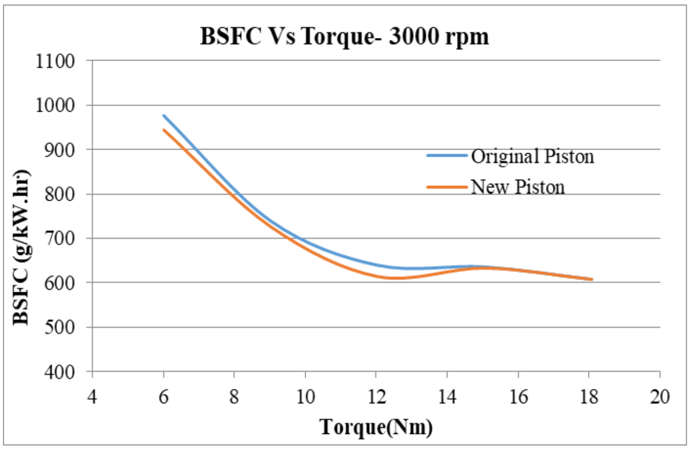


Figure 2. Comparisons of brake specific fuel consumption (BSFC) vs. torque at 3000 rpm

DISCUSSION

Finite Element Analysis of New Piston and Implementation of the new piston in the engine

In order for the new piston to be compatible with the existing engine components, the new piston had to be designed with a number of constraints. These constraints made it more challenging to reduce the mass as many sections of the piston could not be modified. These constraints were crown, skirt length & profile, pin hole profile etc. The different sections of the pistons that were made thinner to reduce mass can be seen in Figure 1b and they are numbered to make comparison of different features easier. The final machined piston was 13.5% lighter than the original piston.

Engine Test Results of Original and New Pistons

The results for 3000 rpm in Figure 2 indicated that the new piston was more fuel efficient compared to the original piston especially at lower torque. This may be attributed to the higher volumetric efficiency of the engine which leads to leaner operation of the engine with the new piston. For the same torque, the engine with higher volumetric efficiency will consume less fuel due to the availability of more Oxygen which reduces ignition delay hence converts more of the fuel energy to useful work (Birtok-Băneasă et al., 2017). Furthermore, higher volumetric efficiency in general is considered a desirable characteristic because it leads to higher power output and improves specific fuel consumption (Khaifullizan *et al.*, 2021; Pan *et al.*, 2015; Sher, 1998; Treeamnuk *et al.*, 2018).

The limited engine testing results presented in this work have shown that the new piston produces enhanced performance in certain operating conditions, whilst performing similarly or slightly worse in others. To ultimately determine whether the new lightweight piston would generate any sizeable difference in engine performance and/or efficiency across the wider engine running envelope, further work is needed.

CONCLUSION

The application of a newly developed aluminium based nanostructured alloy in pistons was assessed in this work to evaluate the potential mass reduction of the piston under consideration. The final machined piston from new alloy was 13.5% lighter than the original piston. It could not be conclusively said from the results if the new piston was more fuel efficient overall in all test conditions, but the new piston was more fuel efficient than the original piston at higher speeds and lower torques. At lower speed of 3000 rpm, the new piston was more fuel efficient in all torque values. Further work is advised to ultimately determine if the new alloy gives any significant performance gains in various engine performance envelop.

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REFERENCES

Adil, H., Audebert, F., Saporiti, F., Gerguri, S., Bonatesta, F., & Durodola, J. (2023). Microstructure and Mechanical Properties of an Al-Mg-Si-Cu Alloy for High Temperature Applications. *Material Science Research India*. https://doi.org/https://bit.ly/3Qd1I0d

Adil, H., Gerguri, S., Durodola, J., Bonatesta, F., Audebert, F., & Saporiti, F. (2023). Application of a Nanostructured Aluminium Alloy in Internal Combustion Engine Pistons for Mass Reduction. *International Journal of Automotive Science and Technology*.

Adil, H., Gerguri, S., Durodola, J., Fellows, N., Bonatesta, F., & Audebert, F. E. (2019). Comparative Study and Evaluation of Two Different Finite Element Models for Piston Design. *International Journal of Engineering Research and Applicationd*.

Birtok-Băneasă, C., Raţiu, S., & Hepuţ, T. (2017, 2017). Influence of intake air temperature on internal combustion engine operation. International Conference on Applied Sciences,

Blackmore, D. R., & Thomas, A. (1977). *Fuel economy of the gasoline engine: fuel, lubricant and other effects*. Macmillan.

Khaifullizan, M. N. N., Jaat, N., Abidin, S. F. Z., Darlis, N., & Zahari, I. (2021). Effect of Intake Air Temperature on Engine Performance and Fuel Consumption of Passenger Car. *Fuel, Mixture Formation and Combustion Process*, *3*(2).

Kohashi, K.-i., Kimura, Y., Murakami, M., & Drouvin, Y. (2013). Analysis of Piston Friction in Internal Combustion Engine. *SAE Int. J. Fuels Lubr.*, *6*(3), 589-593. https://doi.org/10.4271/2013-01-2515

Mahle, G. (2016). *Pistons and engine testing, Second edition*. Springer Vieweg.

Merkle, A., Kunkel, S., & Wachtmeister, G. (2012). Analysis of the Mixed Friction in the Piston Assembly of a SI Engine. *SAE Int. J. Engines*, *5*(3), 1487-1497. https://doi.org/10.4271/2012-01-1333

Norton, R. L. (2012). *Design of machinery: an introduction to the synthesis and analysis of mechanisms and machines, Fifth edition*. McGraw-Hill Higher Education.

Pan, W., Yao, C., Han, G., Wei, H., & Wang, Q. (2015). The impact of intake air temperature on performance and exhaust emissions of a diesel methanol dual fuel engine. *Fuel*, *162*, 101-110.

Schwaderlapp, M., Koch, F., & Dohmen, J. (2000). Friction reduction—the engine's mechanical contribution to saving fuel. FISITA World Automotive Congress,

Sher, E. (1998). *Handbook of air pollution from internal combustion engines: pollutant formation and control*. Academic Press.

Treeamnuk, T., Treeamnuk, K., & Papakae, S. (2018). *Influence of Intake Air Temperature on Performance of Small Gasoline Engine* The Asian Conference on Sustainability, Energy & the Environment 2018, Thailand. http://papers.iafor.org/wp-content/uploads/papers/acsee2018/ACSEE2018_41242.pdf