

# DEVELOPMENT OF AUTOMOBILE PISTON FROM ALUMINIUM ALLOY AND COCONUT SHELL ASH AS ADDITIVE

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## ABSTRACT

*The research investigated the use of coconut shell ash as reinforcement in aluminium alloy matrix for production of an automobile piston. Numerous studies have been carried out that established that piston failures were mostly as a result fatigue stress at the top head and gudgeoned pin areas of the piston. The present work investigated the production of piston that has optimum strength and fuel economy. A sample of piston was cast, using stir-casting process and machined to size from aluminium alloy and coconut Shell ash as additive. A 12-valve Toyota engine was used to determine the performance and effectiveness of the produced piston. The piston was put to use, and was found to be serviceable.*

*Key words: Coconut, Aluminium, Piston, Gudgeoned pin, Toyota, Engine*

## 1 INTRODUCTION

The availability of coconut shell is increasing every year worldwide, which is a hard lignocellulose Agra waste. Nigeria is one of the largest producer of coconut. But mostly the coconut shells are left out in the garbage or burnt as waste and produce large quantity of CO<sub>2</sub> and methane emission. [1]. The engine piston is a disc which reciprocates within a cylinder. It is moved by the fluid which enters the cylinder. The main function of a piston of an internal combustion engine is to receive the impulse from the expanding gas and to transmit the energy to the crankshaft through the connecting rod. The piston must also disperse a large amount of heat from the combustion chamber to the cylinder walls. The structure of the piston can be divided into two sections, which are the top section and the lower section Figure 1. The top section is known as the crown or barrel, while the lower section is called the skirt.

Research were carried out and showed that the coconut shell ash used in metal matrix composites has the potential of improving mechanical properties: hardness, tensile strength and improved density. This work try to produce a car piston from aluminium alloy with coconut shell ash as an additive for improved hardness and wear resistance. The presence of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and CaO in coconut shell ash confirmed from scanning electron microscopy suggest that, the fly ash can be used to reinforce aluminium alloy matrix [3, 4].

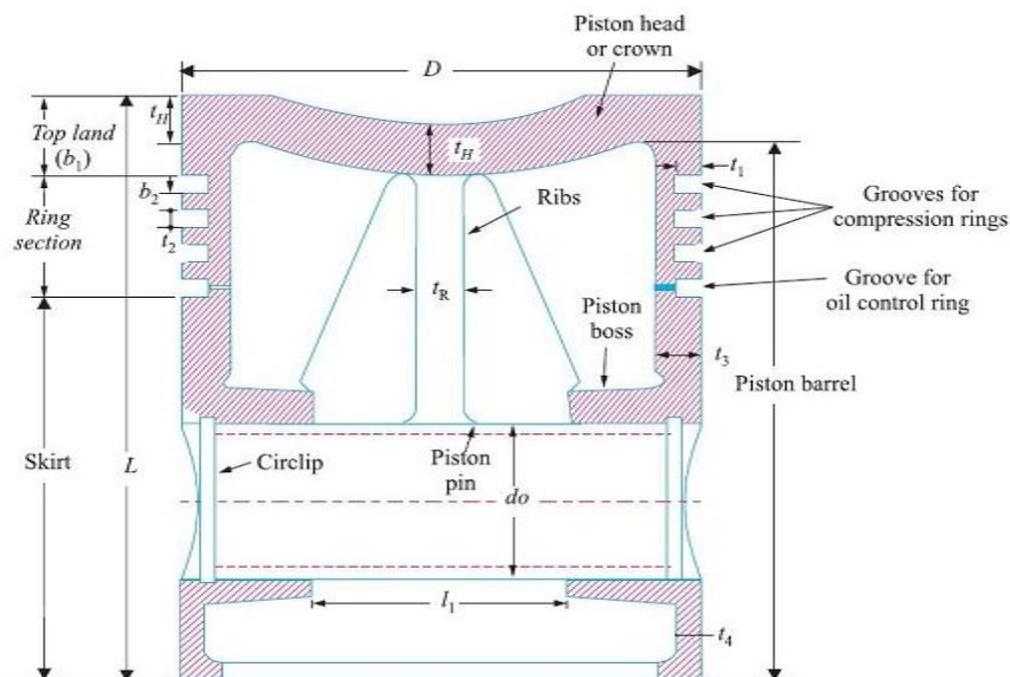


Figure 1. Cross-Section of a Piston [2]

## 2 MATERIALS AND METHODS

### 2.1 Materials

In addition to the piston design, material is a major element in the piston manufacture. The common material that is always used in the manufacture of piston is aluminium and cast iron. Nowadays, piston is made using aluminium alloy as the raw material, compared to cast iron in the early manufacturing of piston [5]. Steel or ceramic cast-in elements are used as local reinforcements to improve the high temperature mechanical properties and/or to control thermal expansion, that is, reduce the effects of different thermal expansion coefficients in contact areas with other materials. [6]. In the present research coconut shell ash was used (Table 1.) to improve the properties of aluminium alloy for piston production. Table 1 and 2 show the properties of aluminium alloy and chemical composition respectively.

Table 1. Properties of Aluminium 356-T7

Material	Aluminium 356-T7
Thermal Conductivity(W/m-K)	134
Density, (kg/m <sup>3</sup> )	2713
Poisson Ratio	0.35
Coefficient of thermal expansion A (/K)	18 x 10 <sup>-6</sup>
Modulus of Elasticity (GPa)	72.4
Ultimate Tensile Strength,(MPa)	172

Source: Budynas &amp; Nisbett (2014) [7]

Table 2. Chemical composition of Aluminium Alloy

Material	Al	Cu	Mg	Si	Zn	Fe	Ni
AL Alloy%	Balanced	4-5	0.45-0.65	16-18	1.5	1.3	0.1

Source: American Society for Testing and Materials (ASTM) [8]

Table 3. Analysis of coconut shell ash

Element	Al <sub>2</sub> O <sub>3</sub>	CaO	Fe <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	MgO	Na <sub>2</sub> O	SiO <sub>2</sub>	MnO	ZnO
%	15.6	0.57	12.4	0.52	16.2	0.45	45.05	0.22	0.3

Source: Poornesh *et al.* [3]

## 2.2 Methods

Analytical technique (particle size analysis) of the coconut shell ash was performed. The crushed coconut shell (CS) pieces were ground using a two disc grinder to obtain the powder which was sorted into different sizes using set of sieves arranged in descending order of grain fineness number. Transmission Electron Microscope (TEM) was used to measure the distribution of particle size. The coconut shell additive was added to the aluminium alloy at a percentage increment, and hardness test of samples produced were carried out.

## 2.3 Design Analysis

The piston crown was designed for bending by maximum gas forces  $P_z \max$  as uniformly loaded round plate freely supported by a cylinder.

The stress acting in MPa on piston crown:  $\sigma_b = M_b / W_b = P_z \max (r_i / \delta)^2$

Where  $M_b = (1/3) P_z \max$  is the bending moment, Nm;  $W_b = (1/3) r_i \delta^2$  is the moment of resistance to bending of a flat crown, m<sup>3</sup>;  $P_z \max = P_z$ , is the maximum combustion pressure, MPa;

$$\text{I. The crown inner radius, } r_i = D/2 - (s + t + d_t) \quad (1)$$

$$\text{II. The stress acting in MPa on piston crown } \sigma_b = \frac{M_b}{W_b} = P_{z \max} (r_i / \delta)^2 \quad (2)$$

$$p_{z \max} = 2 \text{ MPa}$$

$$\sigma_b = 2(27.7/6)^2 = 42.63 \text{ MPa}$$

III. Angular velocity: Cycle time:

$$\text{As engine rpm} = 800$$

$$t = 1/800 \text{ min}$$

$$t = 0.00125 \text{ sec}$$

$$\text{Angular Velocity, } \omega = \frac{2\pi \times \text{rpm}}{60} \quad (3)$$

IV. Linear Velocity:

$$\text{Linear Velocity} = \text{Angular Velocity} \times \text{radius} = 83.775 \times 36 = 3016.8 \text{ mm/s}$$

V. Heat Flow through the Piston Head (H):

The heat flow through the piston head is calculated using the formula [9].

$$H = 12.56 \times t_H \times K \times (T_c - T_e) / \text{sec} \quad (4)$$

Where

K=thermal conductivity of material which is 174.15W/mk

$T_c$  = temperature at centre of piston head in °C.\*

$T_e$  = temperature at edges of piston head in °C.

$t_H$  = piston thickness of piston head

Thickness of Piston Head ( $t_h$ )

VI. The piston thickness of piston head calculated using the following **Grashoff's formula**,

$$t_H = \sqrt{\frac{(3pD^2)}{(16\sigma_t)}} \text{ mm} \quad (5)$$

Where P = maximum pressure in N/mm; D = cylinder bore/outside diameter of the piston in mm;  
 $\sigma_t$  = permissible tensile stress for the material of the piston.

VII. Permissible tensile stress for the material of the piston:

Here the material is a particular grade of AL-Si alloy whose permissible stress is 50 Mpa-90Mpa.

Before calculating thickness of piston head, the diameter of the piston has to be specified.

The piston size that has been considered here has a L\*D, specified as 73.5\*72

Factor of safety F.O.S = 1.2

$$\sigma_t = \frac{\sigma_p}{F.O.S} = \frac{90}{1.2} = 75 \text{ MPa} \quad (6)$$

VIII. Thickness of Piston Head ( $t_h$ ):

$$t_h = 0.032 D + 1.5 = 3.8 \text{ mm}$$

IX. On the basis of the heat dissipation, the thickness of the piston head [9] is given by:

$$t_h = \frac{(C \times HCV \times m \times BP) \times 10^6}{12.56 \times K(T_c - T_e)} \quad (7)$$

X. Piston Rings:

$$\text{The radial width of the ring; } b = D \sqrt{\frac{3p_w}{\sigma_t}} \quad (8)$$

Radial Thickness of Ring ( $t_1$ )

Where D = cylinder bore in mm

$P_w$  = pressure of fuel on cylinder wall in N/mm<sup>2</sup>. Its value is limited from 0.025N/mm<sup>2</sup>

to 0.042N/mm<sup>2</sup>. For present material,  $\sigma_t$  is 90Mpa

$$t_1 = \frac{72\sqrt{3} \times 0.042}{90} = 2.69 \text{ mm}$$

XI. Minimum axial thickness ( $t_2$ ):  $t_2 = \frac{D}{(10 \times n_r)}$

Where  $n_r$  = number of rings

$$t_2 = \frac{72}{10 \times 3} = 2.4 \text{ mm}$$

XII. The thickness of the rings:  $t_2 = (0.7b \text{ to } b) = 0.7 \times 2.69 = 1.883 \text{ mm}$

XIII. Width of Top Land and Ring Lands: The width of the top land varies from

$$b_1 = t_H \text{ to } 1.2 t_H$$

Width of top land:

$$h_1 = t_h \text{ to } 1.2 t_h = 6.53 \text{ mm}$$

Width of other lands ( $b_2$ )

Width of other ring lands varies from

$$b_2 = 0.75t_2 \text{ to } t_2$$

XIV. Piston Barrel (skirt): Maximum Thickness of Barrel ( $t_3$ )

$$t_3 = 0.03 \times D + b + 4.5 \text{ mm}$$

Where  $b$  = Radial depth of piston ring groove,

Thickness of piston barrel at the top end:

$$t_3 = 0.03 \times 72 + 2.69 + 4.5 = 9.35 \text{ mm}$$

XV. Thickness of piston barrel at the open end:  $t_2 = (0.25 t_1 \text{ to } 0.35 t_1)$

$$= 0.35 \times 9.35 = 3.27 \text{ mm}$$

XVI. Length of the skirt:  $l_s = (0.6 D \text{ to } 0.8 D)$

$$= 0.8 \times 72 = 57.6 \text{ mm}$$

XVII. Length of piston pin in the connecting rod bushing

$$l_1 = 45\% \text{ of the piston diameter}$$

$$= 0.45 \times 72 = 32.4 \text{ mm}$$

XVIII. Piston pin diameter:  $d_o = (0.28 D \text{ to } 0.38 D)$

$$= 0.38 \times 72 = 27.36 \text{ mm}$$

The centre of the piston pin should be  $0.02 D$  to  $0.04 D$  above the centre of the skirt. Thus, the dimensions for the piston were calculated and these were used for modelling the piston. In the above procedure, the ribs in the piston were not taken into consideration, so as to make the piston model simple in its design, that is, one faced. In modelling a piston, considering all factors became a tedious process. Thus, a symmetric model was developed, using the above dimensions approximately.

## 2.4 Casting Process

The production of the composites was done by the double stir-casting method. Initially, Al-7% weight of alloy was charged into the graphite crucible furnace and heated to about  $750^\circ\text{C}$ , till the entire alloy in the crucible was melted and 2% by weight of iron powder was added. The reinforcement particles (CSA) were preheated to  $800^\circ\text{C}$  for one hour, before incorporation into the melt. After the metal was fully melted, 0.05wt% degassing tablets (hexachloroethane) were added to reduce the porosity. Simultaneously, 1% by weight of magnesium was added to the melt in order to enhance the wettability between coconut shell ash particles and the alloy melt. It was noticed that without the addition of magnesium, the particles of coconut shell ash were rejected. The stirrer made of stainless steel was lowered into the melt slowly to stir the molten metal during the stirring time. The stirring rate continued for another five minutes, even after the completion of particle feeding. The mixture was poured into the mould which was also preheated by exposure to direct flame, or in an oven, but preheating in an oven until the molten metal is ready for pouring was chosen and it is much more desirable [10]. Using this process, the cast piston was produced with 0, 3, 6, 9, 12 and

15% W CSA particle reinforced composites. A cast composite pistons were produced, as shown in Plate 3.3 [11].



Plate 1. Cast piston



Plate 2. Compressive Test

Plate 1 shows a cast piston that was roughly machined before finishing. The cast piston was subjected to compressive test, Plate 2, and the compressive load was 5.8 KN.

### 3 RESULTS AND DISCUSSION

Table 4. Hardness Test Results of the Composite Piston (BHN)

(%) coconut shell	1 <sup>st</sup> reading	2 <sup>nd</sup> reading	3 <sup>rd</sup> reading	Average (BHN)
0	63.00	64.00	63.50	63.50
3	67.00	68.90	69.00	68.30
6	69.50	68.90	69.00	69.13
9	70.00	69.50	70.50	70.00
12	76.00	75.50	75.20	75.40
15	78.50	78.60	78.80	78.60

It was noticed from the experiment that hardness of the composite increases with percentage increase of coconut shell. It was observed that higher percentage of coconut shell will lead to brittleness of the composite. The coconut shell ash has grain fineness number (GFN) of 76.06, and was considered to be fine since 100 GFN was ranked the finest. BS1377:2013.

#### 3.1 Performance Test

A Toyota model 12 valve engine was used in carrying out the performance test. The engine was assembled, serviced and then test run to determine the performance and effectiveness of the engine.

Petrol fuel of 100ml (0.1 litre) was poured into the fuel chamber and the engine allowed to run until the fuel in the chamber was consumed. The time taken to consume the fuel was 16.5 minutes and the rate of fuel consumption was determined. A 200ml (0.2litres) of fuel, using a calibrated glass measuring cylinder was poured into the engine and allowed to run and the time for the engine to consume the fuel was 24.5 minutes. Lastly, 300ml (0.3litres) of fuel was poured into the engine through the same channel and the engine allowed to run, it took the engine 30 minutes to completely consume the fuel.

$$\text{fuel consumption} = \frac{\text{vol of fuel in litres} \times 60 \times 60}{\text{time taken to consume fuel} \times \text{kW}} \quad (9)$$

Figure 2 shows the duration of fuel consumption in kw/h, when conventional and MMC pistons were used.

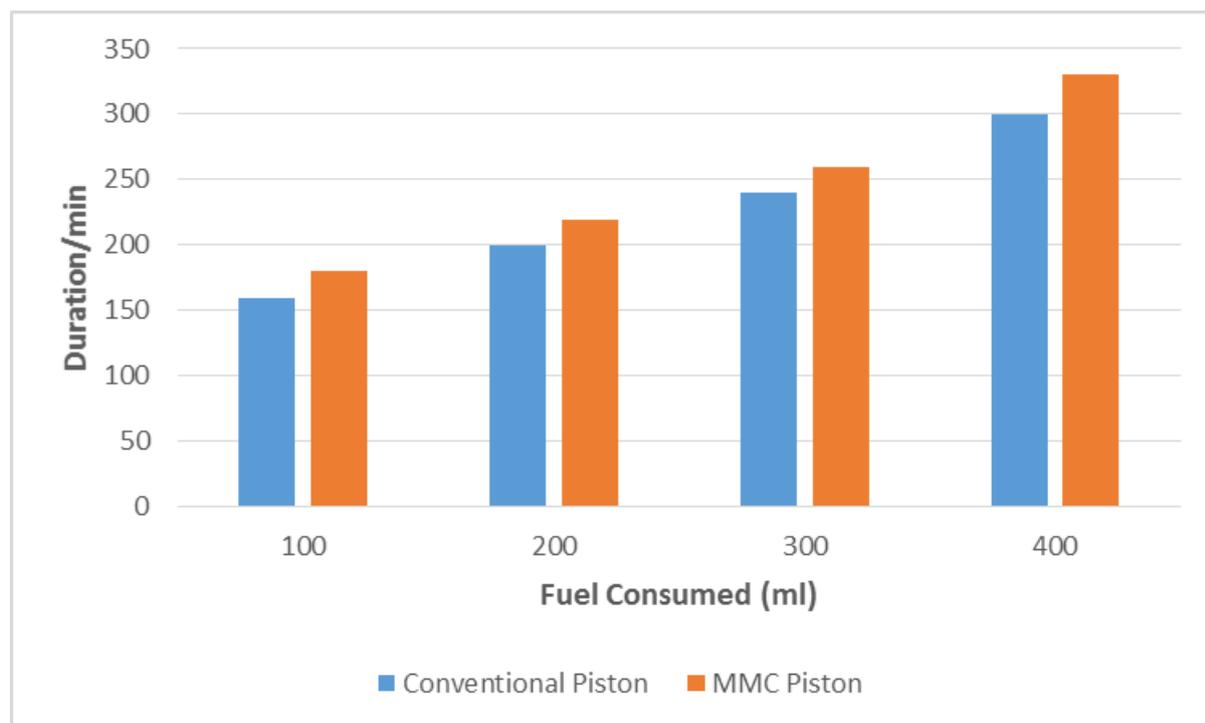


Figure 2. Performance evaluation for conventional and MMC Piston (ASTM)

#### 4 CONCLUSION

A car piston was produced, and the following conclusions have been drawn from the test. A physical piston model was cast from metal matrix composite (MMC), using stir casting. The cast piston was machined to obtain the piston rings grooves and gudgeoned pin bosses. A sample of the produced MMC piston was tested, using a 12-valve Toyota automobile engine to determine the performance and effectiveness of the device. The performance test showed that the engine fuel consumption, when using the MMC piston was lower, compared to the conventional piston, resulting in 0.34% fuel consumption/min. Hence the piston is capable of fuel consumption saving of 0.003 litre/min and it can be deduced that more improvement in combustion efficiency can be attained when using MMC pistons. The MMC piston has the desired mechanical properties (strength, hardness and wear resistance) at 15wt% coconut shell ash, with minimum density, but showed brittleness at higher percentage.

#### REFERENCES

1. Udhayasankar, R., Karthikeyan, B. (2015) A review on Coconut Shell Reinforced Composites. *International Journal of Chem Tech Research*, vol. 8, no. 11, pp. 624-637.
2. Khurmi, R.S, Gupta, J.K. (2004). A Text Book of Machine Design, S. Chand & Co., pp. 1132-1144.
3. Poornesh, M. Saldanha J. Singh J. Pinto G. (2017) Effects of coconut shell ash and SiC particles on mechanical properties of aluminium based composites: *American Journal of Material Science*, vol. 7, no. 4, pp. 112-115.
4. Rajesh P. V, Sriram M. P, Saravanan C. M and Daniel V. S (2018) 'Evaluation of Mechanical Properties and Machinability of A/6061 Hybrid Composite', *International Journal of Multidisciplinary and Current Research*, vol. 6.
5. Challen B. and Baranescu, R (2003). Diesel Engine Reference Book; Society of Automotive Engineers.
6. Röhrle, M. D. (2011). Pistons for Internal Combustion Engines, Verlag Modern Industry, European Aluminium Association

7. Budynas, R. G., Nisbett K. J. (2014) Shigley's Mechanical Engineering Design, *a Text book of Engineering Design*. (McGraw-Hill Series in Mechanical Engineering) 10<sup>th</sup> Edition, pp. 112-121.
8. American Society for Testing and Materials (ASTM) (200) ASTM D 638-99-2000 and 790-99-2000. ASTM Committee on Standards.
9. Venkata, C. R., Murthy, P.V, Murali, M.V and Rao G.M (2013). Design Analysis and Optimization of Piston using CATIA and ANSYS: *International Journal of Innovative Research in Engineering & Science*, vol. 1, pp. 41-51.
10. Callister A. (2013). Material Science and Engineering and introduction 4th Edition, USA, vol. 2, pp. 203-317.
11. Kasi, J. B., Prasad, K. S., Kumar, J. B., Raju, T. P. (2016) CNC Part Programming & Manufacturing of a Piston. *International Journal and Magazine of Engineering Technology, Management and Research*, vol. 3, Issue 8, pp. 89-95.