Chapter

# A New Lightweight Material for Possible Engine Parts Manufacture

*Akaehomen O. Akii Ibhadode and Raphael S. Ebhojiaye*

## Abstract

In the current drive for cleaner energy use, the application of lightweight materials in internal combustion engines becomes imperative as it makes for greater fuel efficiency which results in pollution reduction. This chapter reviews the materials being developed in this direction and then discusses a particularly new lightweight hybrid composite material made of palm kernel shell (PKS) and periwinkle shell (PS) particles as reinforcements in commercially pure aluminium matrix. The fabricated composite had significantly improved properties over the commercially pure aluminium and was used to produce a lightweight engine block. Preliminary performance test results show that the hybrid aluminium composite may be suitable for some engine parts manufacture such as an engine block. Weight analysis carried out on an existing engine shows that the use of this new material in the manufacture of the engine block, cylinder head, piston and connecting rod could give a potential weight reduction of over 25% when used in place of conventional materials. Also, the results show that potential energy cost saving of over 62% could be achieved when this new material is used. However, further work is needed to properly ascertain its areas of specific application.

**Keywords:** lightweighting, aluminium composite, palm kernel shell, periwinkle shell, engine block

## 1. Introduction

### 1.1 The internal combustion engine and the environment

An overwhelming majority of transport vehicles are driven by internal combustion (IC) engines which use fossil fuels as the propellant. Fossil fuel used in vehicles is known to be one cause of environmental degradation. The global need to stem environmental degradation, climaxed at the 2015 United Nations Climate Change Conference, COP 21/CMP 11 held in Paris, France. The Conference came up with the target of limiting global warming to below 2°C. This tells us that additional and more stringent measures are likely to be imposed on fossil fuels in the future. This will negatively impact on the use of internal combustion (IC) engines in vehicles. Even now, new targets on fuel economy are being set: 'by 2021, new cars in Europe should emit no more than 95 g/km of $CO_2$, representing a reduction of 40% compared with the fleet average of 158.7 g/km in 2007. At the same time, CAFÉ regulations in the US will require light vehicles to achieve 54.5 mpg (23.2 km/l) by 2025. These developments make manufacturing costs more important than ever. With approximately 87 million vehicles sold in 2015 and this number expected to rise to

115 million by 2030, introducing lightweight materials and innovative processes will enable car manufacturers to meet these ambitious targets' [1].

One method used by the automobile industry to tackle this challenge posed by new emission regulations is for IC engines to burn fuel more efficiently. Lightweighting, which is building lighter vehicles, is used to have better fuel efficiency [2].

### 1.2 Purpose of lightweighting

The main purpose of lightweighting vehicles is to increase fuel efficiency [3]. For example, while a conventional gasoline car weighing about 750 kg may have a fuel economy of 22 km/l, a Shell eco-marathon [4] urban-concept gasoline vehicle weighing about 45 kg may have a fuel efficiency of over 400 km/l. This vividly shows the benefit of weight reduction on fuel economy.

Other reasons for lightweighting include:

i. To achieve better vehicle performance to give better acceleration, braking and handling.

ii. To have greater load-carrying capacity to engine power ratio.

### 1.3 Methods of lightweighting

The methods of automobile lightweighting include:

i. The use of lighter materials such as high-strength steel, aluminium, magnesium, lightweight composites and plastics [5].

ii. The use of optimum structural designs such as boxlike geometries to achieve greater rigidity to weight ratio. **Figure 1** shows a car bumper with stacked-joined hexagonal lightweight pipes [6].

iii. The use of hot-forming techniques including hot-stamping to produce ultra-high strength parts such as used for reinforcements for vehicle doors, bumper beams, etc., which can reduce weight to the tune of 50% compared to cold-formed parts [1].

iv. 'Body-in-white' (BIW) technique in which the unpainted metal components are welded together to form the vehicle's body, which can account for approximately 50% of weight saving [1].

**Figure 1.**
*The use of stacked-joined hexagonal lightweight pipes for a car bumper [6].*

### 1.4 Lightweighting materials

**Table 1** shows the major types of lightweighting materials used in the automotive industry [7]. It shows that weight reduction could be as high as 70% when carbon fibre composites and magnesium are used to replace mild steel.

### 1.5 Fabricated metal composites

Lightweight engineering materials require high strength, long life, high wear and corrosion resistance. In the current drive for cleaner energy use, the application of lightweight materials in internal combustion engines becomes imperative as it makes for greater fuel efficiency which results in pollution reduction. Unfortunately, there are no naturally occurring engineering materials that perfectly possess all these properties at the same time. To achieve some of these qualities in a single engineering material, dissimilar materials with unique characteristics can be made together as alloys or composite materials to produce improved performance characteristics. 'Such fabricated composite materials find very wide application [8] in electronics, sporting goods, aerospace parts, consumer goods, marine and oil industries, automobile components like IC engine parts, etc. because of the high requirements in product performance and rise in global market demand of lightweight components' [9].

### 1.6 A new material for IC engine parts

Material selection for IC engine components has been one active area of research. Proper selection of materials for the production of IC engines is critical because of the high temperature and fatigue stresses the engine is subjected to. In selecting a suitable material for IC engine components, important parameters or factors such as the physical properties (i.e. melting temperature, hardness, creep and flow, corrosion, weight and vibration absorption) and mechanical properties (i.e. strength, strain, elastic modulus, ultimate tensile strength, yield strength, elongation, fatigue strength, pressure tightness and machinability) as well as availability and cost of the materials must be considered.

Palm kernel and periwinkle are common sources of foods and are harvested and processed in very large quantities in most parts of Southern Nigeria. However, their shells are disposed of indiscriminately giving rise to environmental challenges to communities where they are processed because palm kernel shell (PKS) and periwinkle shell (PS) do readily undergo biological degradation [10, 11].

| Lightweighting material | Mass reduction with respect to mild steel |
|---|---|
| Carbon fibre composites | 50–70% |
| Magnesium | 30–70% |
| Aluminium and its matrix composites | 30–60% |
| Titanium | 40–55% |
| Glass fibre composites | 25–35% |
| Advanced high-strength steel | 15–25% |
| High-strength steel | 10–28% |

**Table 1.**
*Comparison of different lightweighting materials (Adapted from [7]).*

Aluminium and magnesium alloys are commonly used as lightweight engineering materials, and they are gradually taking over from cast iron and steel in the automobile and aerospace industries and defence applications [12, 13]. To improve the properties of aluminium, they are usually alloyed with other very expensive elements like chromium, nickel, molybdenum, silicon, boron, vanadium, etc. However, these alloying metallic elements are expensive and difficult to source in most parts of the developing world such as Nigeria. This study is directed at exploring alternative substitute materials for production of metal matrix composites (MMC) that can be suitable for the production of automobile parts [14]. Thus, the purpose of the study is to develop a hybrid composite material with PKS and PS as the reinforcement particles in aluminium matrix, for the production of appropriate IC engine parts. In this work, the engine block is used as case study because it is particularly important in that it houses the power-producing chamber and forms the fixed point for all other members of the engine. It is hoped that this could be a cheaper alternative to existing aluminium alloy engine parts.

## 2. Methodology

### 2.1 Materials

The following materials were used:

#### *2.1.1 Commercially pure aluminium ingot*

Commercially pure aluminium pieces cut from an ingot with the composition shown in **Table 2** was used.

#### *2.1.2 Palm kernel shell (PKS)*

Palm kernel shell, a common agro waste (**Figure 2(a)**), was collected from a palm oil processing factory in Uselu Community in Benin City, Nigeria. The PKS was washed thoroughly with detergent and spread in the sun to dry. The dry shell was pulverised into powder of particle size 425 μm. The PKS powder is shown in **Figure 2(b)**. PKS is reported to have chemical properties which include 8.786% calcium oxide (CaO), 6.254% potassium oxide ($K_2O$), 54.81% silicon oxide ($SiO_2$), 6.108% magnesium oxide (MgO), 0.362% iron oxide, 11.40% alumina ($Al_2O_3$), 33% charcoal, 45% pyroligneous liquor and 22% combustible materials [15].

#### *2.1.3 Periwinkle shell (PS)*

The periwinkle shell (**Figure 3(a)**), another agro waste belonging to the pozzolanic group, is available in large quantities in the estuaries and mangrove swamp forest of the South-South region of Nigeria [16]. A large quantity of PS was sourced

| **Mg** | **Si** | **Mn** | **Cu** | **Zn** | Ti |
|---|---|---|---|---|---|
| 0.00118 | <0.03456 | 0.00058 | <0.00035 | 0.00058 | 0.00438 |
| Fe | Na | B | Sn | Pb | Al% |
| <0.09775 | 0.00118 | 0.00024 | 0.01160 | 0.00116 | 99.85 |

**Table 2.**
*Chemical composition of the commercially pure aluminium.*

(a) (b)

**Figure 2.**
*Palm kernel shell (PKS). (a) Broken shells and (b) 425 μm powder.*

(a) (b)

**Figure 3.**
*Periwinkle shell. (a) Shells and (b) 75 μm powder.*

from its dump site around New Benin Market in Benin City, Nigeria. The PS was soaked in a mixture of detergent and water for 24 h and later washed and spread in the sun to dry. The clean PS was then pulverised with an electrically driven crushing machine into a powder of particle size 75 μm as shown in **Figure 3(b)**. PS is reported to have a chemical composition of calcium content of $8.25 \times 10^3$ mg/100 g, potassium content of 5.50 mg/100 g, sodium content of 5.30 mg/100 g and phosphorus content of 2.55 mg/100 g [16].

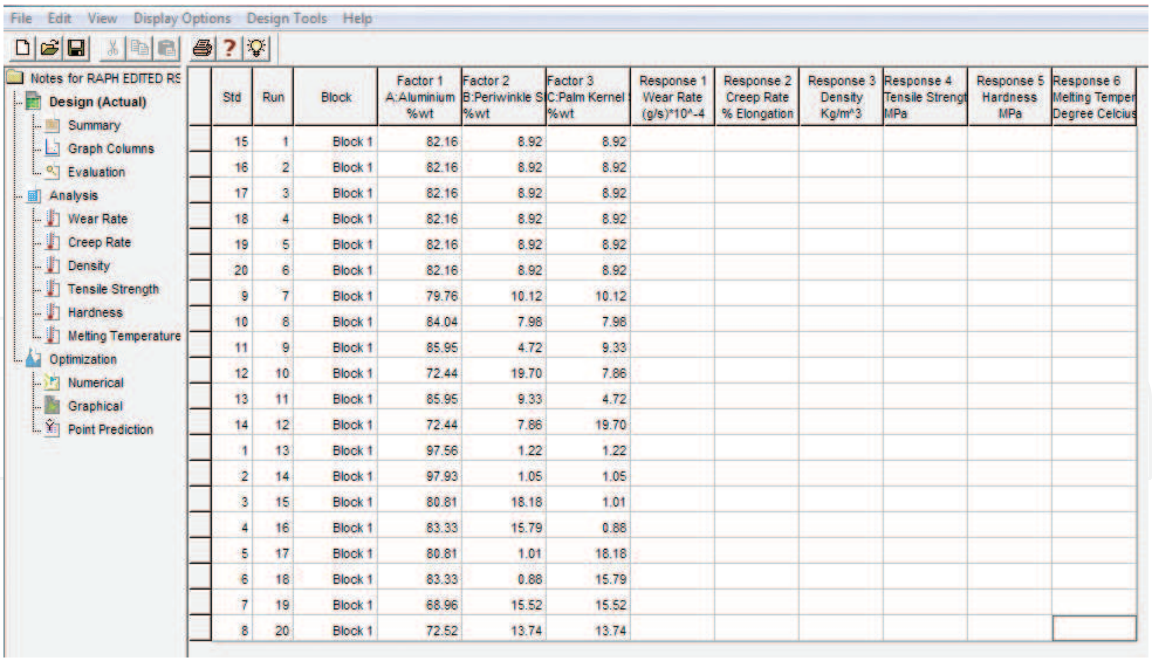
The hybrid aluminium composite material used in this study was made up of appropriate percentages of commercially pure aluminium and particular percentages of PKS and PS [14, 17].

### 2.2 Methods

The hybrid composite material of aluminium metal matrix using agro wastes of palm kernel shell (PKS) and periwinkle shell (PS) powder as the reinforcement agents was designed using the central composite design (CCD) of the response surface methodology (RSM). In order to aid homogenous mix of the reinforcement materials in the matrix, the hybrid composite was formulated and fabricated by stir casting [18, 19] process using a stir casting machine.

#### *2.2.1 Design of the experiment*

The experimental design for the study was done to optimise operating conditions (i.e. factor levels of the input variables) of the fabricated composite with respect to the predicted response parameters. The CCD method was selected because it allows the addition of axial runs which in turn allows the quadratic terms to be incorporated into the model. Three input variables were used in the design: pure aluminium ingot, PKS and PS. A total of six response variables were investigated: wear rate (g/s), creep rate (% elongation/h), density (kg/m$^3$), tensile




| Std | Run | Block | Factor 1 A:Aluminium %wt | Factor 2 B:Periwinkle S %wt | Factor 3 C:Palm Kernel %wt | Response 1 Wear Rate (g/s)*10^-4 | Response 2 Creep Rate % Elongation | Response 3 Density Kg/m^3 | Response 4 Tensile Strengt MPa | Response 5 Hardness MPa | Response 6 Melting Temper Degree Celcius |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 1 | Block 1 | 82.16 | 8.92 | 8.92 | | | | | | |
| 16 | 2 | Block 1 | 82.16 | 8.92 | 8.92 | | | | | | |
| 17 | 3 | Block 1 | 82.16 | 8.92 | 8.92 | | | | | | |
| 18 | 4 | Block 1 | 82.16 | 8.92 | 8.92 | | | | | | |
| 19 | 5 | Block 1 | 82.16 | 8.92 | 8.92 | | | | | | |
| 20 | 6 | Block 1 | 82.16 | 8.92 | 8.92 | | | | | | |
| 9 | 7 | Block 1 | 79.76 | 10.12 | 10.12 | | | | | | |
| 10 | 8 | Block 1 | 84.04 | 7.98 | 7.98 | | | | | | |
| 11 | 9 | Block 1 | 85.95 | 4.72 | 9.33 | | | | | | |
| 12 | 10 | Block 1 | 72.44 | 19.70 | 7.86 | | | | | | |
| 13 | 11 | Block 1 | 85.95 | 9.33 | 4.72 | | | | | | |
| 14 | 12 | Block 1 | 72.44 | 7.86 | 19.70 | | | | | | |
| 1 | 13 | Block 1 | 97.56 | 1.22 | 1.22 | | | | | | |
| 2 | 14 | Block 1 | 97.93 | 1.05 | 1.05 | | | | | | |
| 3 | 15 | Block 1 | 80.81 | 18.18 | 1.01 | | | | | | |
| 4 | 16 | Block 1 | 83.33 | 15.79 | 0.88 | | | | | | |
| 5 | 17 | Block 1 | 80.81 | 1.01 | 18.18 | | | | | | |
| 6 | 18 | Block 1 | 83.33 | 0.88 | 15.79 | | | | | | |
| 7 | 19 | Block 1 | 68.96 | 15.52 | 15.52 | | | | | | |
| 8 | 20 | Block 1 | 72.52 | 13.74 | 13.74 | | | | | | |

**Figure 4.**
*Computer interface of the preliminary design of experiment.*

strength (MPa), hardness (BHN) and melting temperature (°C). **Figure 4** shows the computer interface of the preliminary experimental design using the CCD.

### *2.2.2 Fabrication of the aluminium composite material*

The commercially pure aluminium ingot was cut into smaller sizes. The smaller pieces of the ingots were soaked with detergent and hot water at 50°C for 10 h and then washed thoroughly with a hard brush and later rinsed in clean water. The ingots were dried at about 70°C for 1.5 hrs. A digital electronic scale with an accuracy of 0.01 g was used to weigh the ingots into the various percentage weights as obtained from the design of experiment using CCD of RSM.

The crucible furnace was initially preheated to 100°C. The pure aluminium ingots that were measured for the different experimental specimen weights were preheated for about 1 h at a temperature of 450°C [20]. The PS and PKS reinforcement particles were also preheated to 250°C to remove moisture and oil contents [21]. For the first sample labelled A-1, aluminium ingot of 87.5 wt.% ~262.5 g was charged into the graphite crucible pot with 1 wt.% of magnesium powder [22, 23] as the wetting agent. The graphite crucible was then placed inside the crucible furnace and heated to a temperature of 750°C [13, 24, 25]. At that temperature the solid aluminium ingots had melted into molten form. The melt was allowed to cool in the furnace to a slurry form (semisolid state) at a temperature of about 600°C [25]. At that slurry temperature of the molten metal, the preheated PKS and PS particles were added and stirred manually for about 7 min with the stir casting machine. The PKS particles were charred into particles of black carbon due to the high temperature of 600°C at which the PKS particles were introduced into the molten matrix. The resultant composite mixture was further heated from the slurry state to the molten state at about 720°C [25] and mechanically stirred with the stir casting machine at 400 rpm for about 10 min to form a fine vortex [26]. The molten composite mixture was then poured into prepared permanent moulds made of mild steel to form the cast composite specimen. This process was repeated thrice for all the responses. Pure aluminium ingots without the addition of reinforcement materials were charged into the crucible pot to produce a molten form that was cast in the die mould. This was used as the specimen for the control of experiment. The specimens produced including the control specimens were tested for the six responses, and the values were recorded. The values obtained from the laboratory tests for the specimens were modelled and optimised to obtain the blend ratio using RSM.

## 2.3 Practical application of the developed composite material

### *2.3.1 Production of the engine block*

The developed composite material was used as engineering material to produce the engine block of a bush cutting machine shown in **Figure 5** in order to conduct practical application assessment on the material to ascertain its applicability in real-life situation. Performance test was carried out on the produced engine block.

The engine block was produced by casting and thereafter machined. The material was initially cast into a box dimension of 80 mm × 80 mm × 110 mm by the stir casting process. Thereafter, the cast material was machined using the centre lathe and milling machine. **Figure 6** shows the dimensions of the produced engine block.

**Figure 5.**
*The bought-out bush cutting machine.*

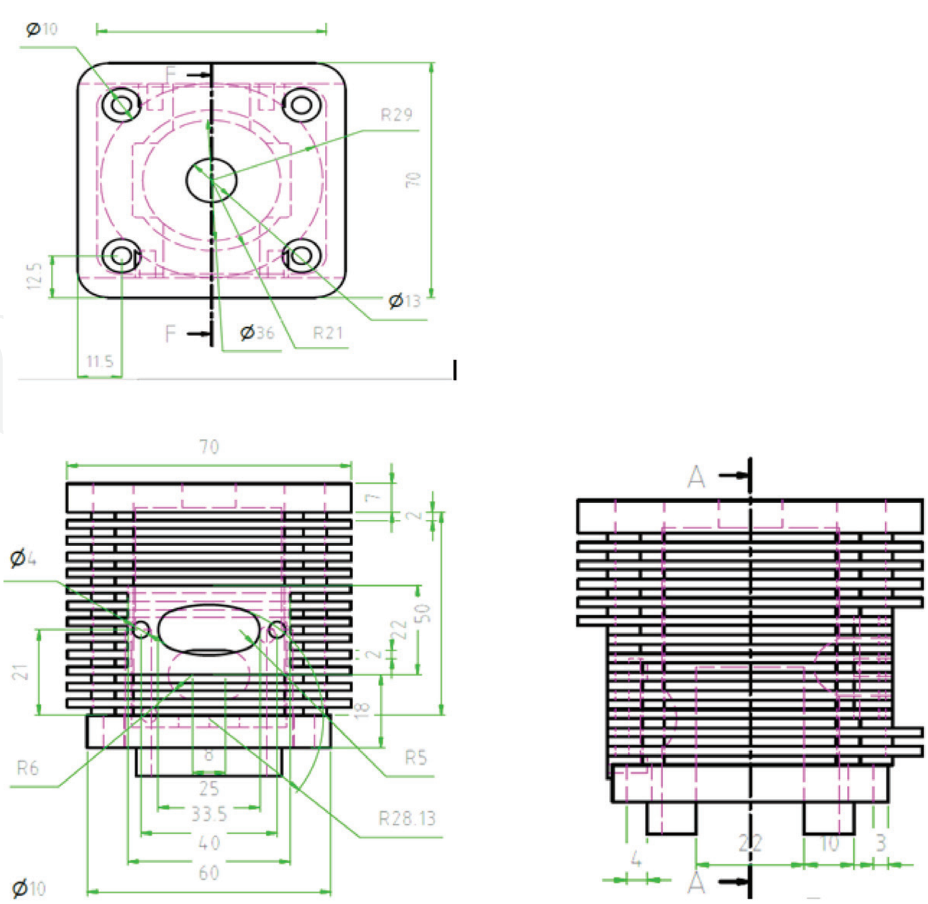



**Figure 6.**
*The engine block of the bush cutting machine.*

**Figure 7.**
*Produced engine block in bush cutting machine.*

#### *2.3.2 Performance test of the produced engine block*

The fabricated engine block and cylinder liner were assembled into the engine as shown in **Figure 7**. It was thereafter tested for 1 h. The temperature of the engine block was taken at 1 min intervals. This was repeated for the control cylinder block and liner. The bought-out bush cutting engine block was used as the control engine block.

#### *2.3.3 Lightweighting and cost saving analyses*

Lightweighting and energy cost saving analyses were carried out on an existing gasoline engine used for powering a newly designed lightweight utility vehicle. The engine is rated at 7.1 kW at 5500 rpm with a maximum torque of 18.0 Nm at 3500 rpm. The new material was hypothetically used to replace the conventional materials used for the engine block, cylinder head, piston and connecting rod. The potential weight reduction of the engine was then determined. The potential cost saving in energy was also determined.

## 3. Results and discussion

### 3.1 Optimal composition

#### *3.1.1 Design of experiments*

Ebhojiaye et al. [17] developed the hybrid composite material of palm kernel shell (PKS) and periwinkle shell (PS) particles as reinforcements in pure aluminium matrix. The central composite design (CCD) of the response surface methodology (RSM) was used to carry out the design of experiment (DoE) as shown in **Figure 4**. Stir casting method was used to fabricate the specimens. The design of experiments by the CCD gave 20 runs (experimental samples) as shown in **Table 3**. The runs were replicated three times each, bringing the total number of runs to 60 for each

| Std. | Run | Type | Factor 1 (aluminium, % wt) | Factor 2 (periwinkle shell, % wt) | Factor 2 (palm kernel shell, % wt) | Response 1 (wear rate (g/s) $10^{-4}$) | Response 2 (creep rate, % elongation/h) | Response 3 (density, kg/m$^3$) | Response 4 (tensile strength, MPa) | Response 5 (hardness BHN) | Response 6 (melting temperature, °C) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 1 | Centre | 82.16 | 8.92 | 8.92 | A1 | A2 | A3 | A4 | A5 | A6 |
| 16 | 2 | Centre | 82.16 | 8.92 | 8.92 | B1 | B2 | B3 | B4 | B5 | B6 |
| 17 | 3 | Centre | 82.16 | 8.92 | 8.92 | C1 | C2 | C3 | C4 | C5 | C6 |
| 18 | 4 | Centre | 82.16 | 8.92 | 8.92 | D1 | D2 | D3 | D4 | D5 | D6 |
| 19 | 5 | Centre | 82.16 | 8.92 | 8.92 | E1 | E2 | E3 | E4 | E5 | E6 |
| 20 | 6 | Centre | 82.16 | 8.92 | 8.92 | F1 | F2 | F3 | F4 | F5 | F6 |
| 9 | 7 | Axial | 79.76 | 10.12 | 10.12 | G1 | G2 | G3 | G4 | G5 | G6 |
| 10 | 8 | Axial | 84.04 | 7.98 | 7.98 | H1 | H2 | H3 | H4 | H5 | H6 |
| 11 | 9 | Axial | 85.95 | −4.72 | 9.33 | I1 | I2 | I3 | I4 | I5 | I6 |
| 12 | 10 | Axial | 72.44 | 19.70 | 7.86 | J1 | J2 | J3 | J4 | J5 | J6 |
| 13 | 11 | Axial | 85.95 | 9.33 | −4.72 | K1 | K2 | K3 | K4 | K5 | K6 |
| 14 | 12 | Axial | 72.44 | 7.86 | 19.70 | L1 | L2 | L3 | L4 | L5 | L6 |
| 1 | 13 | Fact | 97.56 | 1.22 | 1.22 | M1 | M2 | M3 | M4 | M5 | M6 |
| 2 | 14 | Fact | 97.93 | 1.05 | 1.05 | N1 | N2 | N3 | N4 | N5 | N6 |
| 3 | 15 | Fact | 80.81 | 18.18 | 1.01 | O1 | O2 | O3 | O4 | O5 | O6 |
| 4 | 16 | Fact | 83.33 | 15.79 | 0.88 | P1 | P2 | P3 | P4 | P5 | P6 |
| 5 | 17 | Fact | 80.81 | 1.01 | 18.18 | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 |
| 6 | 18 | Fact | 83.33 | 0.88 | 15.79 | R1 | R2 | R3 | R4 | R5 | R6 |
| 7 | 19 | Fact | 68.96 | 15.52 | 15.52 | S1 | S2 | S3 | S4 | S5 | S6 |
| 8 | 20 | Fact | 72.52 | 13.74 | 13.74 | T1 | T2 | T3 | T4 | T5 | T6 |

**Table 3.**
*Assigned letter codes to the response parameters.*

of the six responses considered, and 360 specimens were fabricated in all. Three experimental values were obtained for each of the 120 runs for the wear rate, creep rate, density, tensile strength, hardness and melting temperature. The average values were determined and recorded. Control specimens with 100 wt.% pure aluminium matrix, 0 wt.% of PKS and PS reinforcement particles were prepared. The results showed that the reinforcement particles had significant improvement on mechanical properties of the pure aluminium as shown in **Table 4** for hardness test of the various 20 fabricated composites and that of the control commercially pure aluminium.

*3.1.2 RSM analysis*

In optimising the results obtained for the six responses using the central composite design (CCD) of the response surface methodology (RSM), three of the responses [i.e. wear rate ($y_1$), creep rate ($y_2$) and density ($y_3$)] were minimised, while the other three responses [i.e. tensile strength ($y_4$), hardness ($y_5$) and melting temperature ($y_6$)] were maximised. The optimal equations obtained for the actual factors [commercially pure aluminium (A), periwinkle shell (B) and palm kernel shell (C)] for the six responses are shown in Eqs. (1)–(6).

1. Wear rate ($y$ 1)

$$y_1 = 25.021 - 0.503A - 0.315B - 0.278C + 0.00273AB + 0.00205AC + 0.00279BC + 0.00268\,A^2 + 0.00265B^2 + 0.00343\,C^2 \quad (1)$$

2. Creep rate ($y$ 2)

$$y_2 = 2303.565 - 49.151A - 14.268B - 9.448C + 0.137AB + 0.108AC - 0.039BC + 0.263A^2 + 0.179B^2 + 0.042\,C^2 \quad (2)$$

3. Density ($y$ 3)

$$y_3 = -4283.948 + 152.915A + 50.465B - 86.331C - 0.607AB + 0.925AC + 0.253BC - 0.839A^2 + 0.252B^2 + 0.035C^2 \quad (3)$$

4. Tensile strength ($y$ 4)

$$y_4 = -198.881 + 6.437A + 7.726B - 6.745C - 0.081AB + 0.088AC + 0.032BC - 0.036A^2 - 0545B^2 + 0.066C^2 \quad (4)$$

5. Hardness ($y$ 5)

$$y_5 = -115.362 - 0.774A + 6.128B + 29.139C - 0.180AB - 0.079AC - 1.159BC + 0.032A^2 - 0.548B^2 - 0.479C^2 \quad (5)$$

6. Melting temperature ($y$ 6)

$$y_6 = 475.599 + 9.379A - 4.784B + 17.014C + 0.119AB - 0.096AC - 0.109BC - 0.058A^2 - 0.219B^2 + 0.302C^2 \quad (6)$$

The result of the RSM analysis gave an optimal blend ratio of 80.98 wt.% aluminium, 13.55 wt.% periwinkle shell and 5.47 wt.% palm kernel shell particles. This optimum blend ratio when used to produce an engineering composite material

| Composite label | Diameter of indenter (D) mm | Diameter of indentation (d) mm | Load (Kg) | BHN (HBS 10/1000) |
|---|---|---|---|---|
| A5 | 10.00 | 2.08 | 1000 | 291.08 |
| B5 | 10.00 | 2.12 | 1000 | 280.07 |
| C5 | 10.00 | 2.11 | 1000 | 282.77 |
| D5 | 10.00 | 2.10 | 1000 | 285.49 |
| E5 | 10.00 | 2.08 | 1000 | 291.08 |
| F5 | 10.00 | 2.11 | 1000 | 282.77 |
| G5 | 10.00 | 3.20 | 1000 | 121.07 |
| H5 | 10.00 | 1.75 | 1000 | 412.54 |
| I5 | 10.00 | 2.54 | 1000 | 194.12 |
| J5 | 10.00 | 3.00 | 1000 | 138.00 |
| K5 | 10.00 | 2.77 | 1000 | 162.69 |
| L5 | 10.00 | 2.50 | 1000 | 200.48 |
| M5 | 10.00 | 3.00 | 1000 | 138.00 |
| N5 | 10.00 | 3.40 | 1000 | 106.86 |
| O5 | 10.00 | 1.98 | 1000 | 321.56 |
| P5 | 10.00 | 1.97 | 1000 | 342.86 |
| Q5 | 10.00 | 2.05 | 1000 | 299.75 |
| R5 | 10.00 | 2.13 | 1000 | 277.42 |
| S5 | 10.00 | 2.05 | 1000 | 299.75 |
| T5 | 10.00 | 2.50 | 1000 | 200.48 |
| U5 | 10.00 | 2.78 | 1000 | 98.50 |

**Table 4.**
*Results of hardness test of the fabricated composites and pure aluminium.*

will have the following properties: wear rate of $0.62 \times 10^{-4}$ g/s, creep rate of 19.09% elongation/h, density of 2598.62 kg/m$^3$, tensile strength of 94.04 MPa, hardness of 278.83BHN and melting temperature of 935°C. This solution that was selected with the aid of the design expert software 7.01 has a desirability value of 97.3%.

## 3.2 Properties of the fabricated aluminium composite

### *3.2.1 Chemical compositions*

**Table 5** shows the comparison of the chemical compositions of the as-received commercially pure aluminium with the fabricated aluminium composite. The as-received composition was given by the manufacturer, while that of the fabricated composite was determined in our laboratory using the EPA Method 3050B (concentrated HCl, $HNO_3$ and $HClO_4$). The results show that all the elements detected in the as-received sample increased in the fabricated composite (except for the ones that were not detected: boron and tin), while the aluminium decreased in the fabricated composite. However, the elements, cadmium, calcium, chromium and potassium, were added into the fabricated composite. The increase of elements and additions could have come from the palm kernel shell (PKS) and periwinkle shell (PS) as seen from Sections 2.1.2 and 2.1.3, especially for the elements silicon, calcium, potassium, iron and sodium.

| Element | As-received | Fabricated aluminium composite | Remark |
|---|---|---|---|
| Magnesium (Mg) | 0.00118 | 0.027 | Increased |
| Silicon (Si) | <0.03456 | 0.28 | Increased |
| Manganese (Mn) | 0.00058 | 0.19 | Increased |
| Copper (Cu) | <0.00035 | 0.02 | Increased |
| Zinc (Zn) | 0.00058 | 0.03 | Increased |
| Titanium (Ti) | 0.00438 | — | Not detected |
| Iron (Fe) | 0.09775 | 0.26 | Increased |
| Sodium (Na) | 0.00118 | 0.19 | Increased |
| Boron (B) | 0.00024 | — | Not detected |
| Tin (Sn) | 0.0116 | — | Not detected |
| Lead (Pb) | 0.00116 | 0.06 | Increased |
| Aluminium (Al) | 99.85 | 96.90 | Decreased |
| Cadmium (Cd) | — | 0.001 | Added |
| Calcium (Ca) | — | 0.11 | Added |
| Chromium (Cr) | — | 0.0001 | Added |
| Potassium (K) | — | 0.16 | Added |

**Table 5.**
*Chemical compositions of the as-received and fabricated composite samples.*

### *3.2.2 Physical and mechanical properties*

The optimum blend ratio obtained from the RSM analysis, when used to produce an engineering composite material, gave the properties as shown in **Table 6**. This is compared with properties of the control commercially pure aluminium tested under same conditions and those predicted by the RSM analysis. The table shows that there is improvement on properties of the fabricated aluminium composite over the control commercially pure aluminium. The creep rate, wear rate and density are reduced by 75.6, 78.2 and 3.4%, respectively, while the tensile strength, hardness and melting point are increased by 30.7, 184.8 and 31.4%, respectively. Except for density, these improvements are quite significant.

From the table, the values of the actual formulated hybrid aluminium composite and the values predicted from the RSM analysis are reasonably close, with all the absolute deviations of the predicted from the actual ones not greater than 10%. For example, the deviations are 5.8, 8.7, 0.7, 2.8, 0.6 and 3.9% for creep rate, wear rate, density, tensile strength, hardness and melting point, respectively.

Values of the above properties obtained from this research study (i.e. As-cast values) were compared with existing properties of aluminium alloys used for the production of engine block (i.e. As-used values). From **Table 5**, out of the six properties of the engine block examined, the book values of two of the As-used (or existing) engine block properties (i.e. wear rate and creep rate) were not readily available in the literature. However, the other four properties (i.e. density, tensile strength, hardness and melting temperature) were available [27, 28]. The value of density obtained in this study was found to be within an acceptable range with the book value. The value of tensile strength was below the range found in literature. However, it is hoped that with further research work, an appreciable tensile strength value which will fall within the range of values found in the literature

| Property | Commercially pure aluminium control | Formulated hybrid aluminium composite | Optimal solution values obtained from RSM (predicted values) | As-used values of existing engine blocks |
|---|---|---|---|---|
| Creep rate (% elongation/h) | 74.04 | 18.04 | 19.09 | Not available |
| Wear rate (g/s) | $2.61 \times 10^{-4}$ | $0.57 \times 10^{-4}$ | $0.62 \times 10^{-4}$ | Not available |
| Density (kg/m$^3$) | 2709.13 | 2617.39 | 2598.62 | 2570–2830 |
| Tensile strength (MPa) | 73.99 | 96.74 | 94.04 | 130–280 |
| Hardness (BHN) | 98.5 | 280.49 | 278.83 | 80–137 |
| Melting temperature (°C) | 685 | 900 | 935 | 645–710 |

**Table 6.**
*Physical and mechanical properties of the formulated hybrid aluminium composite [14].*

would be obtained. The value of the composite material hardness (As-cast value) was found to be far above the range of values of As-used (or existing) engine block. This shows that besides production of IC engine blocks, the developed composite material could also be used for the production of other engineering components where material hardness is of utmost importance. Again, the melting temperature of the developed composite material was found to be far higher than the range of values for aluminium engine blocks (As-used values) as currently used. The developed composite material therefore could withstand the high temperatures that exist within the combustion chamber of IC engines.

### 3.3 Performance test result of the produced engine block

The fabricated engine block and cylinder liner were assembled into the engine and tested for 1 h. The temperature of the engine block was taken at 1 min intervals. This was repeated for the control cylinder block and liner. The initial temperatures (i.e. before the engine was switched on) of the control engine block and the produced engine block were recorded as 25.6°C (room temperature).

**Figure 8** shows the temperature variations for each test. The fabricated engine block had a mean temperature of 151.7°C, while that for the control engine block was 156.9°C giving a deviation of 3.3% from the control value. The lower mean value of the fabricated engine block indicates that it may have a slightly lower heat dissipating ability than the control engine block.

This is expected as it is a fabricated material from aluminium, periwinkle shell and palm kernel shell, the last two being non-metallic materials with lower thermal conductivities. Heywood [29] stated that the combustion temperature within the combustion chamber of the IC engine is about 250°C. Despite this relatively lower heat dissipating ability, the developed hybrid composite material may still be regarded as a good heat conductor because within the first minute, it shot up the engine block temperature from the initial room temperature value of 25.6°C to about 80.7°C, showing an upsurge of 3.2 times the room temperature value. This is comparable to the 3.9 times for the control engine block. This heat conducting phenomenon is good for engine blocks so as to preserve their life span.

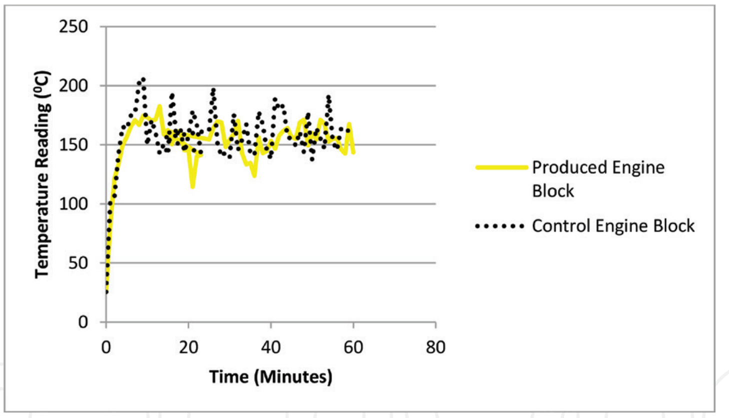



**Figure 8.**
*Temperature reading of produced against control engine blocks.*

### 3.4 Potential benefits of the new aluminium hybrid material

#### *3.4.1 Lightweighting*

A gasoline engine rated at 7.1 kW at 5500 rpm generating a maximum torque of 18.0 Nm at 3500 rpm used to power a new lightweight utility vehicle is considered. **Table 7** shows potential weight reductions if this new aluminium hybrid material were to be used as materials for the engine parts indicated, volume for volume. The table shows that:

i. The weight of the engine block is reduced by 63.03% if the new material were to replace the grey cast iron used.

ii. The weights of the cylinder head, piston and connecting rod will be reduced by 1.93, 2.13 and 6.37%, respectively, if the new aluminium hybrid material were to replace the aluminium alloys indicated.

iii. The weight reduction for the engine block, cylinder head, piston and connecting rod totalling 13.501 kg will be 48.37% if the new aluminium hybrid material were used to make these parts.

iv. The weight reduction for the whole engine weighing 25.75 kg will be 25.36% if the new material were used to make the engine block, cylinder head, piston and connecting rod.

The table also shows the comparison of weight reductions if the conventional aluminium alloy A356 and the new hybrid aluminium material were to be used to make the engine block. As the new material has a slightly lower density, it produces a slightly greater weight reduction of 1.99% over the A356 aluminium alloy. When all the above parts are made with their conventional aluminium alloy materials, the weight reduction will be 2.07% when the new aluminium hybrid material is used for the indicated engine parts.

These results show that lightweighting of the engine and consequently the vehicle powered by it will be achieved if this new aluminium hybrid material is used.

#### *3.4.2 Energy saving*

It is envisaged that the use of this new material in manufacturing engines will not only lead to lightweighting but also energy saving. If we consider melting in an

| Engine part | Material | Density (kg/m$^3$) [30] | Weight (kg) | Volume (m$^3$) | Weight of equivalent aluminium hybrid material (kg) (density = 2617 kg/m$^3$) | Weight reduction | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | (kg) | (%) (on individual parts) | (%) (on total parts) |
| Engine block | Grey cast iron | 7079 | 10.25 | 0.001448 (1448cm$^3$) | 3.789 | 6.461 | 63.03 | — |
| | Aluminium alloy (A356) | 2670 | (3.866) | 0.001448 (1448cm$^3$) | (3.789) | (0.077) | (1.99) | — |
| Cylinder head | Aluminium alloy (A356) | 2670 | 3 | 0.001124 (1124cm$^3$) | 2.942 | 0.058 | 1.93 | — |
| Piston | Aluminium alloy (A4032) | 2690 | 0.094 | 0.000035 (35cm$^3$) | 0.092 | 0.002 | 2.13 | — |
| Connecting rod | Aluminium alloy (A7075) | 2803 | 0.157 | 0.000056 (56cm$^3$) | 0.147 | 0.010 | 6.37 | — |
| Total | — | — | 13.501 (7.117) | — | 6.970 (6.970) | 6.531 (0.147) | — | 48.37 (2.07) |
| Whole engine | — | — | 25.75 | — | — | 6.531 | — | 25.36 |

**Table 7.**
*Potential lightweighting by the new aluminium hybrid material.*

induction furnace, the energy consumption for melting cast iron ranges from 550 to 575 kWh/ton, while that for melting light and solid aluminium scraps ranges from 500 to 625 kWh/ton [31].

Using the average values of the above energy ranges, we have that the:

i. Cost of energy required to melt the cast iron engine block in **Table 7** $= ((550 + 575\ \text{kWh})/2 \times (10.25\ \text{kg}/1000)) \times \$0.13/\text{kWh} = \$0.75$.

ii. Cost of energy required to melt the aluminium hybrid engine block in **Table 7** $= ((500 + 625\ \text{kWh})/2 \times (3.789\ \text{kg}/1000)) \times \$0.13/\text{kWh} = \$0.28$, where \$0.13/kWh is the cost of electricity.

The above shows that there could be an energy cost saving of 62.67% in melting which accounts for a significant part of the manufacturing cost, if the new aluminium hybrid material is used in place of cast iron in manufacturing the engine block.

### 3.5 Further work

This fabricated aluminium composite seems to present an interesting material which requires further work: while its tensile strength is about 53% less than the mean value for the commercially as-used, its hardness and melting points are 159 and 33% more than the mean values for the commercially as-used, respectively. While its tensile strength may further be improved, it could find uses not only for engine blocks but also for other engine parts such as parts of the linkage mechanism in the combustion chamber and other non-engine applications. Also, there is the need to determine its porosity due to these non-metallic combustible materials used as reinforcements.

## 4. Conclusion

The search for lightweighting materials for automobiles is a continuing process that opens up opportunities for development of new engineering materials. This work which is a part of this process has shown that agro wastes such as palm kernel shell (PKS) and periwinkle shell (PS) may be used as reinforcement materials for metal matrix composites giving good results for fabrication of some IC engine parts such as the engine block. This new material has the potential of lightweighting engines and giving significant energy cost saving in the manufacturing process. Due to the interesting properties it has, further work is necessary to determine additional and/or proper areas of application.

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## Author details

Akaehomen O. Akii Ibhadode[1*] and Raphael S. Ebhojiaye[2]

1 Shell Professorial Chair in Lightweight Engine Development, Federal University of Petroleum Resources Effurun, Warri, Nigeria

2 Department of Production Engineering, University of Benin, Benin City, Nigeria

*Address all correspondence to: ibhadode.akii@fupre.edu.ng

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