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# Evaluation of Optimized Carbonized Wheat Husk-Reinforced AA6061 Composite for Automotive Components Applications

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***Abstract:*** *In the pursuit of sustainable and lightweight materials for automotive applications, metal matrix composites (MMCs) have emerged as promising candidates due to their superior strength-to-weight ratios, enhanced wear resistance, and tailored mechanical properties. Aluminum-based composites, particularly those with AA6061 as the matrix, are widely recognized for their excellent corrosion resistance, weldability, and mechanical performance. However, there remains a need to improve the environmental sustainability, mechanical properties and lightweight properties of these materials through the incorporation of eco-friendly, sustainable, light and low-cost reinforcements. In this work, the reinforcement particulate, carbonized wheat husk (CWH) was gotten after pulverizing wheat husks to increase the surface area and charging it into a muffle furnace, subjected to a temperature of 900 $^0$C for 3 hours. Thereafter, AA6061 reinforced composites (AA6061-CWH) were produced using the stir casting method, optimized through the Taguchi's L9 orthogonal array. The composite developed at optimum parameters was then selected and compared with selected automotive components. The optimized AA6061-CWH composite offers a well-balanced mechanical profile. It delivers decent tensile strength, exceptional hardness, good impact resistance, and a lower density, making it an appealing material choice for a broad spectrum of automotive applications. Its application could support the automotive industry's ongoing pursuit of improved performance, efficiency, and sustainability through the use of affordable and eco-friendly materials.*

***Keywords****: Metal Matrix Composites, AA6061 Aluminum Alloy, Carbonized Wheat Husk, Agricultural Waste, Reinforcement*

## 1. INTRODUCTION

The demand for sustainable, high-performance materials in the automotive industry has significantly intensified in recent years, driven by the need to improve fuel efficiency, reduce emissions, and meet stringent environmental regulations [1]. In response, researchers and manufacturers have increasingly turned to metal matrix composites (MMCs) as viable alternatives to conventional metallic materials. MMCs, particularly those based on aluminium matrices, offer an attractive combination of high strength-to-weight ratios, enhanced wear resistance, and tunable mechanical properties that are highly beneficial for a wide range of automotive applications [2].

Among aluminium alloys, AA6061 stands out as a preferred matrix material due to its excellent corrosion resistance, good weldability, and favorable mechanical characteristics [3]. However, while AA6061 possesses many desirable attributes, further improvements are necessary to meet evolving industry demands–particularly in areas of sustainability, weight reduction, and cost-efficiency. These enhancements can be achieved by incorporating eco-friendly, lightweight, and inexpensive reinforcement materials into the matrix, contributing to both improved material performance and environmental sustainability.

Agricultural waste-derived reinforcements have garnered significant attention as sustainable and cost-effective alternatives to conventional ceramic reinforcements [4]. Several studies have demonstrated that incorporating such agro-waste derivatives into aluminium alloys enhances the mechanical properties of the resulting composites. For instance, Oghenevweta *et al.* [5], Atuanya *et al.* [6], Edoziuno *et al.* [7], and Suleiman *et al.* [8] reported notable improvements in mechanical performance when aluminium alloys were reinforced with carbonized maize stalk, breadfruit seed hull ash, palm kernel shell ash, and melon shell ash, respectively.

Wheat is a very important agricultural product, with approximately 772 million tonnes produced annually, of which 5-20% constitutes husks [9, 10]. Every year, large amounts of wheat husks are generated, but they have low economic value [11]. Despites the conspicuousness of wheat husks as agricultural waste, it has hardly been reported as reinforcement particulate used to reinforce aluminium matrix composites. Utilizing wheat husks as reinforcement will not only address the environmental challenges associated with agricultural waste disposal but also offers the potential to produce cost-effective and sustainable reinforcement particulates for aluminium-based composites.

In the present study, CWH was used to reinforce AA6061 at optimum processing parameters and the resulting composite was assessed to ascertain its suitability for automotive applications.

## 2. MATERIALS AND METHODS

### 2.1 Materials

The primary materials used in this experimental study were wheat husks and aluminium alloy (AA6061), both of which were locally sourced. The elemental composition of the AA6061 alloy, as specified in the manufacturer's test certificate, is presented in Table 1. Additional materials used in the study included hexachloroethane (as a degassing agent) and magnesium (to improve wettability).

Table 1: Chemical composition of AA6061

| Element | Mg | Si | Fe | Cu | Mn | Cr | Ni | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| Wt. (%) | 0.891 | 0.562 | 0.314 | 0.265 | 0.039 | 0.231 | 0.014 | 0.053 | 0.019 | Bal |

### 2.2 Preparation of Reinforcement Particulate:

Displayed in Figure 1 are the images of wheat husks and carbonized wheat husk (CWH). The wheat husks were initially washed and sun-dried for three days to minimize their moisture content. They were then ground using a hammer mill to increase their surface area. Afterwards, the pulverized husks were placed in a muffle furnace and heated at 900 ℃ for three hours to eliminate volatile substances. This temperature was selected to ensure the reinforcement remains thermally stable within the composite’s intended operating temperature range. The resulting material, referred to as CWH, was further ground and sieved using a stack of sieves arranged from coarse to fine mesh. The sieving process lasted 15 minutes, and particles smaller than 50 µm were collected, in line with the methodologies of Shanka *et al.* [12] and Usman *et al.* [13].


Figure 1: (a) Wheat husk (b) Carbonized wheat husk

### 2.3 Development of Carbonized Wheat Husk Reinforced AA6061 (AA6061-CWH) Composites

The AA6061-CWH composites were synthesized using the stir casting method. To identify the optimal processing conditions that yielded the most favorable combination of mechanical properties, the stir casting process was conducted under varied experimental parameters. The design of experiments was structured using Taguchi’s L9 orthogonal array (OA), incorporating three key processing variables: percentage composition (PC), melting temperature (MT), and stirring time (ST)-each evaluated at three distinct levels. The levels for PC were 5 wt%, 10 wt% 15 wt%. For MT the three levels chosen were 700 ℃, 750 ℃, 800 ℃ and for ST, 3 mins, 6 mins and 9 mins.

For each composite sample, AA6061 was first placed in a crucible and heated to a designated temperature based on the Design of Experiment (DOE) guideline. Heating continued until the alloy was fully melted. Meanwhile, the specified amount of reinforcement particles was preheated at 600 °C for one hour. This preheating step played a crucial role in preventing particle segregation, removing residual moisture, and forming a stable oxide layer on the particle surfaces, thereby improving their compatibility with the aluminum matrix.

Afterwards, 1 wt% of magnesium was added to the molten alloy to enhance the wettability between the carbonized wheat husk particles and the aluminum matrix. To remove entrapped gases, 1 wt% of hexachloroethane was also introduced as a degassing agent. The resulting mixture was then stirred mechanically using a stainless-steel stirrer at a fixed speed of 450 rpm. Stirring times, ranging from 3 to 9 minutes as defined by the DOE, were applied to ensure uniform distribution of the reinforcement particles throughout the melt. To ensure consistency and accuracy, each experiment was repeated three times.

### 2.4 Density Measurement of the Composites

The experimental density of each composite was determined by measuring the weight and volume of individual samples. A high-precision electronic weighing balance with a tolerance of ±0.1 mg was used to obtain accurate weight measurements, while a Vernier caliper was employed to measure the sample dimensions for volume calculation. The experimental density was then calculated by dividing the measured weight by the corresponding volume.

### 2.5 Investigation of Mechanical Properties of the Composites

Hardness testing was carried out on a total of ten samples (nine from the experimental runs and one control sample) using a Brinell Hardness Tester (Model: RBHT, Serial Number: 2011/202). Each sample was tested by making five random indentations with a spherical steel ball indenter under a load of 300 grams for 15 seconds, following ASTM E10 guidelines. For tensile testing, specimens were machined in accordance with ASTM E8M-13 standards. These tests were conducted using an Instron 3369 universal testing machine, operating at a loading rate of 5 mm/min. To enhance the reliability of the data, three specimens were tested for each experimental condition. Additionally, Charpy impact test samples with a V-notch at the center were prepared based on ASTM E23 specifications to assess the impact energy of the stir-cast AA6061-CWH composites.

### 2.6 Comparative Evaluation of CWH-AA6061 for Automotive Applications

This study adopted a comparative material evaluation approach to assess the suitability of optimized AA6061-CWH composite for various automotive components applications. The mechanical performance of the developed composite was systematically compared to that of commonly used aluminium alloys in the automotive industry, including AA6061, AA5182, AA319, AA4032, AA3003, and AA380. Key mechanical properties such as tensile strength, Brinell hardness (BHN), impact resistance, and material density were analyzed to establish the composite's performance profile.

The study focused on a selection of critical automotive components that widely employ aluminium-based materials due to their proven benefits in weight reduction, fuel efficiency, corrosion resistance, and overall vehicle performance. These components, which represent a cross-section of both structural and powertrain parts essential to modern automotive design and manufacturing, included cross members, hoods, doors, trunk lids, cylinder heads, pistons, control arms, brake calipers, radiators (with aluminium cores), and transmission casings.

## 3. RESULTS AND DISCUSSION

### 3.1 Densities of AA6061- CWH Composites

The densities of AA6061 reinforced CWH with different processing parameters as per the DOE are presented in Table 2. These results reveal that the density of the AA6061-CWH composite decreases as the amount of CWH in the alloy increases. Specifically, the density of the AA6061-CWH composite dropped from 2.72 g/cm³ at 0 wt% CWH addition to average of 2.61 g/cm³ at a 15 wt% CWH addition. This decrease occurred because CWH particles are less dense than the aluminum alloy (2.72 $g/cm^3$). This result is consistent with the findings of Hassan and Aigbodion [14]. The reduction in density indicates that the composites can be used to produce lightweight components. The lightweight property is highly sought in the automotive and aerospace industries which can in turn reduce energy consumption [15].

Table 2: Experimental densities of CWH particle-reinforced AA6061 Composites

| Sample No | Sample Designation | PC (%) | MT (°C) | ST (mins) | Experimental Density (g/cm³) |
|---|---|---|---|---|---|
| 1 | $C_1$ | 5 | 700 | 3 | 2.65 |
| 2 | $C_2$ | 5 | 750 | 6 | 2.64 |
| 3 | $C_3$ | 5 | 800 | 9 | 2.65 |
| 4 | $C_4$ | 10 | 700 | 6 | 2.62 |
| 5 | $C_5$ | 10 | 750 | 9 | 2.62 |
| 6 | $C_6$ | 10 | 800 | 3 | 2.63 |
| 7 | $C_7$ | 15 | 700 | 9 | 2.61 |
| 8 | $C_8$ | 15 | 750 | 3 | 2.61 |
| 9 | $C_9$ | 15 | 800 | 6 | 2.60 |
| 10 | $C_{10}$ | Control | | | 2.72 |

### 3.2 Evaluation of the Mechanical Properties of AA6061- CWH Composites

Figure 2 displays the tensile samples of the developed composites, while Figure 3 shows the tensile strength, hardness and impact energy values for nine AA6061-CWH composite samples along with the control sample. Among the developed AA6061-CWH composites, Sample $C_5$ exhibited the highest tensile strength, recording a 58.3% improvement over the unreinforced control, which had a tensile strength of 129.41 MPa. In contrast, Sample $C_9$ showed the least improvement, with only a 6.7% increase. The enhancement in tensile properties is attributed to the reinforcing effect of hard carbonized wheat husk (CWH) particles embedded within the soft and ductile aluminium matrix. These particles hinder atomic mobility and resist plastic deformation, thereby improving the mechanical strength of the composite. This strengthening mechanism aligns with the findings of Oghenevweta *et al*. [5], Atuanya *et al.* [6], Edoziuno *et al*. [7], and Suleiman *et al.* [8], who reported similar behavior using alternative agricultural waste reinforcements such as carbonized maize stalk, breadfruit seed hull ash, palm kernel shell ash, and melon shell ash.

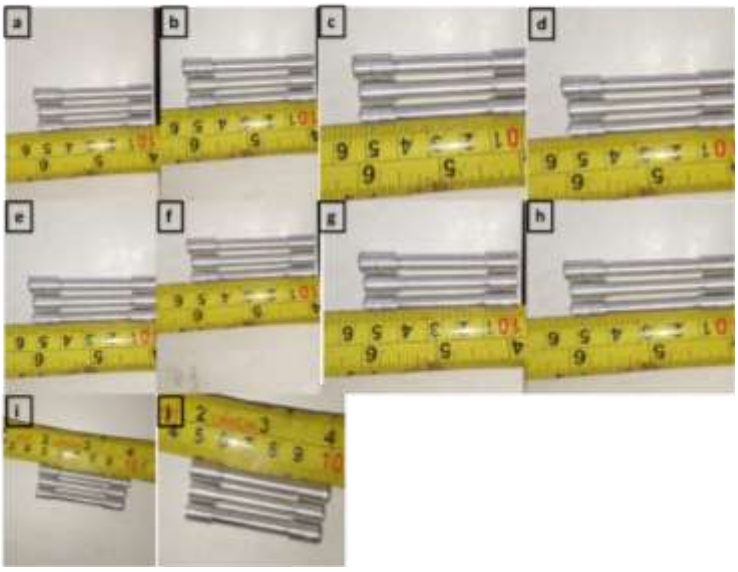

Figure 2: Tensile samples of AA6061-CWH produced at varied processing parameters

In terms of hardness, a similar trend was observed. Sample $C_5$ again achieved the highest hardness value, showing a 49.3% increase compared to the control. Conversely, Sample $C_9$ recorded the lowest hardness improvement, with a marginal increase of 0.2%. The overall increase in hardness across all composites is attributed to the incorporation of hard and brittle CWH particulates, which served as obstacles to plastic flow within the AA6061 matrix. These findings are in agreement with prior studies conducted by Osunmakinde *et al.* [16], Aynalem [17], and Lemine *et al.* [18], who also reported improved hardness in aluminium matrix composites reinforced with similar agro-waste materials.

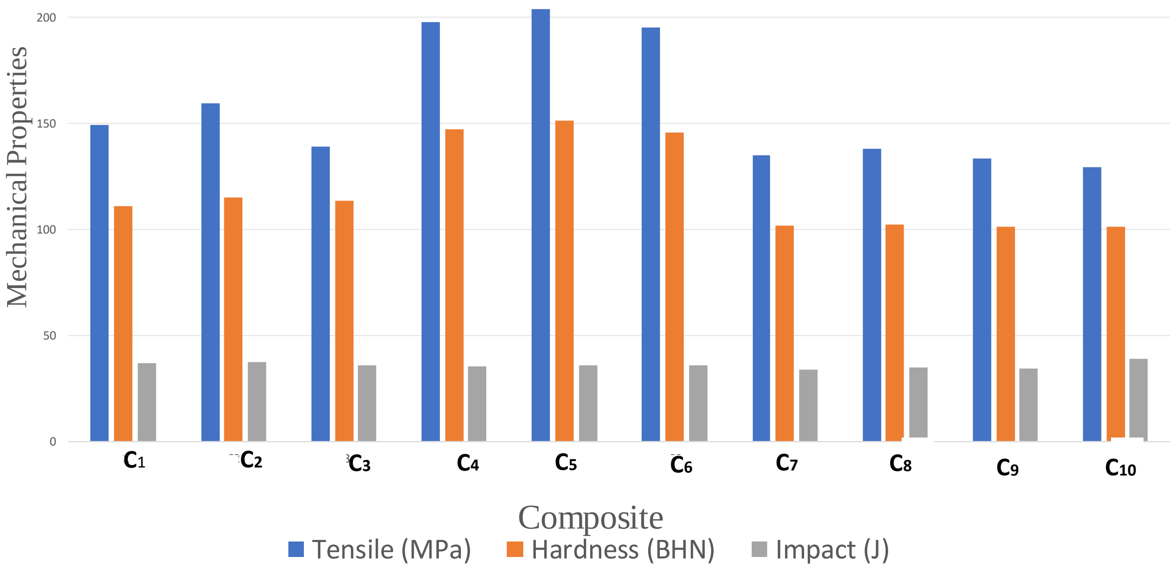


Figure 3: Variation of mechanical properties of AA6061-CWH composites

However, unlike the enhancements observed in tensile and hardness properties, the impact energy of the composites exhibited a slight decline. Sample $C_2$ showed the best impact resistance relative to the control, while Sample $C_9$ demonstrated the poorest performance. Analysis revealed that impact energy decreased progressively as CWH content increased from 5% to 15%, likely due to the inherently brittle nature of the CWH particles, which reduces the composite's ability to absorb energy during impact loading [19]. Despite this, ball milling the CWH particles to a fine size of 50 µm is believed to have helped to increase the interfacial surface area between the matrix and the reinforcement, minimizing the extent of reduction. The lowest impact energy observed showed only a 12.8% decrease, indicating that the particle size refinement played a mitigating role.

### 3.3 Confirmatory Results of Optimal Processing Parameters

The processing parameters for sample $C_5$, which demonstrated the most superior properties, were adopted to fabricate an additional composite to validate the optimization experiment. The outcomes of the confirmatory tests, conducted to verify the Taguchi optimization runs, are summarized in Table 4. These results revealed a 61.8% increase in tensile strength, a 59.8% enhancement in hardness, and a 3.1% reduction in impact energy compared to the control sample. This confirms that the composite produced under the optimized processing parameters exhibits significantly improved mechanical properties relative to the control.

### 3.4 Applicability of AA6061-CWH Composites

Table 4 presents the comparative properties of conventional automotive alloys and optimized AA6061-CWH composite across selected aluminium-based vehicle components. Each of the automotive parts considered has unique mechanical demands, and the materials used to make them must strike a balance between their mechanical properties, durability, weight, and cost. Commonly used aluminum alloys for the parts (such as AA6061, AA5182, AA319, AA4032, AA3003, and AA380) offer distinct mechanical properties tailored to their applications.

Table 4: Comparative properties of conventional automotive alloys and optimized AA6061-CWH composite across some vehicle components

| **Alternative (Automotive part)** | **Common Part Material** | **Tensile (MPa)** | **Hardness (BHN)** | **Impact (J)** | **Density ($g/cm^3$)** | **Source** |
|---|---|---|---|---|---|---|
| Cross Member | AA6061-T6 | 310-320 | 95-100 | 10-20 | 2.70 | [20] |
| Hood | AA5182 | 275-310 | 70-80 | 20-40 | 2.63-2.66 | [22] |
| Door | AA5182 | 275-310 | 70-80 | 20-40 | 2.63-2.66 | [22] |
| Trunk lid | AA5182 | 275-310 | 70-80 | 20-40 | 2.63-2.66 | [22] |
| Cylinder Head | AA319 | 220-280 | 80-100 | 4–8 | 2.74-2.75 | [23] |
| Piston | AA4032 | 380-420 | 120-140 | 10–15 | 2.75-2.80 | [24] |
| Control Arm | AA6061 | 129.41 | 101.34 | 39.04 | 2.72 | [24] |
| Brake Caliper | AA6061 | 129.41 | 101.34 | 39.04 | 2.72 | [25] |
| Radiator | AA3003 | 150-200 | 125 | 15-25 | 2.73-2.75 | [26] |
| Transmission Casing | AA380 | 190–230 | 80–100 | 3–6 | 2.75-2.78 | [27] |
| AA6061-CWH (Optimal) | - | 209.38 | 158.01 | 37.85 | 2.62 | |

The composite (AA6061-CWH) developed at optimized parameters has emerged as a potential alternative across multiple applications due to its impressive mechanical profile. Starting with structural components like cross members, AA6061-T6 is often favored because of its high tensile strength (310–320 MPa) and moderate hardness (95–100 BHN), with reasonable impact resistance (10–20 J)[20]. However, AA6061-CWH only falls short with a lower tensile strength of approximately 209 MPa, but significantly improved hardness at 158 BHN and excellent impact resistance at nearly 38 J. Moreover, its lower density (2.62 $g/cm^3$ compared to AA6061's 2.72 $g/cm^3$) makes it especially attractive for light weighting, a key objective in modern vehicle design [21].

For exterior body panels such as hoods, doors, and trunk lids, AA5182 is the industry standard [22], offering a good mix of strength (275–310 MPa), ductility, and impact resistance (20–40 J), with a relatively low density of 2.63–2.66 $g/cm^3$. CWH-AA6061, while slightly lower in tensile strength, matches closely in impact toughness and outperforms in hardness. This makes it a viable replacement, particularly when additional hardness or rigidity is desirable. For the engine components, different demands apply. Cylinder heads commonly use AA319, a cast alloy offering moderate tensile strength (220–280 MPa) and hardness (80–100 BHN), but relatively poor impact resistance (4–8 J) due to casting defects [23]. Pistons, on the other hand, are typically made from AA4032, a high-performance alloy with excellent strength (380–420 MPa), high hardness (120–140 BHN), and moderate impact resistance (10–15 J) [23]. These components endure high thermal and mechanical stresses; AA6061-CWH may not be a suitable replacement due to its lower tensile and uncertain thermal performance.

Components like control arms and brake calipers, which require a blend of strength, impact resistance, and wear tolerance, are often made from standard AA6061 [25]. AA6061-CWH offers significant improvements in hardness and impact energy while maintaining a slightly lower density, indicating its superior performance. For radiators, where corrosion resistance and moderate mechanical properties are important, AA3003 is used [26]. With its tensile strength (150–200 MPa), hardness of 125 BHN, and impact value of 15-25 J, AA6061-CWH surpasses it, potentially offering better durability if corrosion resistance can be matched. Lastly, transmission casings are typically cast from AA380, valued for its castability and decent strength (190–230 MPa), but it suffers from low impact resistance (3–6 J) [27]. AA6061-CWH offers significantly better mechanical performance.

AA6061-CWH demonstrates a well-balanced profile (moderate tensile strength, exceptionally high hardness, excellent impact resistance, and lower density), making it a strong candidate for replacing conventional materials in a number of structural, safety, and light weighting-focused automotive applications. While it may not be suitable for high-temperature or high-load engine parts like pistons or cylinder heads, it presents a compelling alternative in many other areas, aligning well with the automotive industry's goals of improved performance, affordable, lightweight, and fuel-efficient attributes.

## 4. CONCLUSIONS

In this study, AA6061 aluminium matrix composites reinforced with carbonized wheat husk were successfully developed, and the optimum processing parameters for their fabrication were established. The optimized composite developed at 209.38 MPa, 158.01 BHN and 37.85 J exhibited a well-balanced mechanical profile, including enhanced tensile strength, superior hardness, decent impact resistance, and reduced density compared to conventional aluminium alloys. These outstanding properties make the AA6061-CWH composite a promising, eco-friendly, and cost-effective material for a wide range of automotive applications. Its adoption could support the automotive industry's pursuit of lightweight designs, improved fuel efficiency, and sustainable material utilization.

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