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Influence of Agricultural Waste and Ceramic Reinforcement on the Hardness of Aluminium 7075 Hybrid Composites

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Abstract: Metal Matrix Composites offer superior mechanical properties compared to monolithic alloys, making them highly suitable for demanding engineering applications. This study investigates the mechanical behavior of an Aluminum 7075 alloy reinforced with Tungsten Carbide (WC) and Cow Dung Ash (CDA) fabricated via stir casting. The primary objective of this study was to evaluate the effect of hybrid reinforcement on the composite's hardness. The results indicated that the incorporation of WC and CDA significantly enhanced the hardness of the Al 7075 matrix. Specifically, the hybrid composite containing 3.5 wt.% WC and 1.5 wt.% CDA exhibited the highest hardness (35 HRB), representing a substantial improvement compared to the lower-WC compositions studied. These findings suggest that modifying Al 7075 with WC and CDA is a viable strategy for developing cost-effective high-strength composites.

Keywords: Cow Dung Ash (CDA), Hybrid Aluminum Metal Matrix Composite (HAMMC), Hardness, Stir Casting, Tungsten Carbide (WC).

1 INTRODUCTION

Aluminum 7075 is widely utilized in the aerospace and automotive sectors owing to its high strength-to-weight ratio. However, enhancing their surface properties and wear resistance remains a critical area of research. Metal Matrix Composites (MMCs) have emerged as a solution in which insoluble reinforcements are introduced into the matrix to improve tribological and mechanical performance [1]. Stir casting is preferred among fabrication techniques because of its cost-effectiveness and scalability. While synthetic ceramics such as SiC and Al_2O_3 are common reinforcements, there is growing interest in hybrid composites that utilize industrial or agricultural waste to reduce density and cost without compromising performance [2][3]. This study explores the hybridization of Al 7075 with Tungsten Carbide (WC), known for its extreme hardness, and Cow Dung Ash (CDA), a low-density sustainable reinforcement, to synthesize a novel hybrid composite.

Composites with hybrid aluminum metal matrices were produced to improve the composite characteristics above and beyond those of a single reinforcement. The hybrid metal matrix results from the combination of two or more synthetic ceramics in an aluminum matrix. Synthetic ceramics and industrial waste, such as fly ash, graphite, red mud, and other industrial waste, have been used to employ industrial waste with good results without compromising the composite properties. The addition of two synthetic ceramics to the matrix resulted in reduced ductility and increased fragility. Surface roughness increases with breakdown, and the weight of the composite materials increases due to the difference in particle and matrix densities. Given its typically tough character, synthetic pottery is commonly utilized as an abrasive for high-cost applications. One such solution is to employ agricultural waste to overcome these drawbacks.

To produce a hybrid aluminum metal matrix, agricultural waste is combined with synthetic ceramics. Agrarian waste has several advantages, including low cost, simple access, low density, and less pollution. Bagasse ash, groundnut shell ash, bamboo leaf ash (BLA), and rice husk ash (RHA) are a few examples of agricultural waste (BLA) [4]-[6]. The ash from palm kernel shells, corn cobs, maize stalks, shelled bean waste, and other materials have been studied.

Aluminum 7075 is widely used in aerospace applications because of its high tensile strength. In addition to its high hardness, improved impact and wear resistance, low specific density, low heat conductivity, and high stiffness, tungsten carbide has several advantages over aluminum for strengthening. CD Aash contains components such as SiO_2, Al_2O_3, Fe_2O_3, and MgO, which may enhance aluminum's properties [7]. The benefits of CDA integration include minimal cost, easy access, low density, and low pollution. This has led to efforts to enhance the CDA as the matrix's second line of strengthening. Aluminum 7075 is widely known for its high tensile strength and is often utilized in the automotive and aerospace industries [8]. In the automobile industry, alloy 7075 is used to manufacture pistons, brake calipers, wheels, and rockers. The percentages of reinforcements varied in the current investigation, and the effects were evaluated using mechanical behavior, such as hardness [9].

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The novelty of the present work lies in the combined use of a rigid ceramic reinforcement (WC) and an agricultural waste–derived reinforcement (CDA) in an Al7075 matrix, fabricated via a cost-effective stir-casting route. Unlike many earlier studies that focus solely on synthetic ceramic reinforcements or industrial by-products, this study demonstrates that a balanced hybrid reinforcement strategy can achieve significant hardness enhancement while maintaining sustainability and material cost considerations. The systematic variation of WC and CDA at a fixed total reinforcement content enables clear insight into the dominant strengthening contribution of WC in the hybrid system.

2 Materials and Methods

2.1. Material Selection

The matrix material used in this investigation was aluminum 7075 alloy. Table 1 shows the composition of Al 7075 based on the spectroanalysis. Natural pottery and WC were used to reinforce this investigation. Raw cow dung was gathered and dried in the sun for 3 days to remove the dung cake and to make it. The cake was divided into small parts to produce ash and burned in an open-air metal drum [10]-[11]. For two hours at 600°C in a muffle furnace to eliminate the carbonaceous elements included in the CD ash. In the current study, CDA with a size of less than 40 microns and WC with a size of less than 10-25 m were used. Table 2 shows how samples are prepared with various reinforcement weight percentages.

Table 1. Composition of Al 7075 based on the Spectroanalysis

Element	Zn	Cu	Mn	Mg	Fe	Cr	Ti	Si	Al
Weight%	5.4	1.42	0.12	2.42	0.42	0.21	0.11	0.13	Remaining

Table 2. Sample Preparation

Sample	Al7075 (wt%)	WC (wt%)	CDA (wt%)
S1	95	1.5	3.5
S2	95	2.5	2.5
S3	95	3.5	1.5

2.2. Experimental Setup and Fabrication Process

Hybrid metal-matrix composites were fabricated using the liquid metallurgy stir-casting technique. The Al 7075 alloy served as the matrix, whereas Tungsten Carbide (particle size 10–25 µm) and Cow Dung Ash (<40 µm) were used as reinforcements. The stir-casting procedure followed is depicted in Fig. 1.

Preparation of Reinforcements

Prior to casting, Cow dung ash was calcined at 600°C for 2 h to remove moisture and carbonaceous volatiles. Both WC and CDA particulates were preheated to 400°C in a separate muffle furnace (Fig. 1a & 1d). This preheating step is critical for removing surface moisture and reducing thermal shock when particles are introduced into molten metal, thereby improving wettability.

Melting and Stirring

The Al 7075 ingots were melted in a graphite crucible (Fig. 1a) using an electric resistance furnace (Fig. 1b). The melt temperature was raised to 800 ± 10°C to ensure varying fluidity (Fig. 1e). To enhance the wettability between the ceramic particles and metallic matrix, approximately 1 wt.% Magnesium (Mg) (as a wetting agent) was added to the melt; Mg scavenges oxygen and reduces surface tension, facilitating particle incorporation. A mechanical stirrer with SS316 blades (coated with alumina to prevent iron pickup) was introduced into the melt and rotated at 450 rpm.

Degassing and Pouring

To minimize porosity, the melt was degassed using hexachloroethane (C_2Cl_6) tablets, which were allowed to react for a few minutes, releasing chlorine gas that helped remove dissolved hydrogen and other entrapped gases from the melt, thereby improving the melt quality and reducing porosity. The preheated reinforcements were added slowly to the vortex created by the stirrer. The mixture was stirred for 10 min to ensure a homogeneous particle distribution. Finally, the composite slurry was poured into a preheated (300°C) permanent cast iron mold (Fig. 1f) to solidify and obtain the final cast specimens shown in Fig. 2.

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2.3. Testing methodology

Hardness tests, such as Brinell, Rockwell, and Vickers, are used to determine a material's hardness. ASTM E92 is the standard for Vickers hardness, E18 for Rockwell hardness, and E10 for Brinell hardness testing. In this study, a Rockwell hardness test was performed. The load applied was 100 kg for 30s, using a 1.587 mm-diameter steel ball indenter. Three indentations were made at room temperature, and the mean value was determined.

Fig. 1. Stir Casting Process. a) Al billets are transferred into the Crucible, b) Crucible is placed in the electric arc furnace, c) Reinforcement-1, d) Reinforcement-2, e) Melting and Stirring of AMMC, f) Heating the Permanent Mould to avoid the sudden solidification of the molten composite, g) Composites in the form of cylinders after solidification.

Fig. 2. Stir-Casted Composite Specimens

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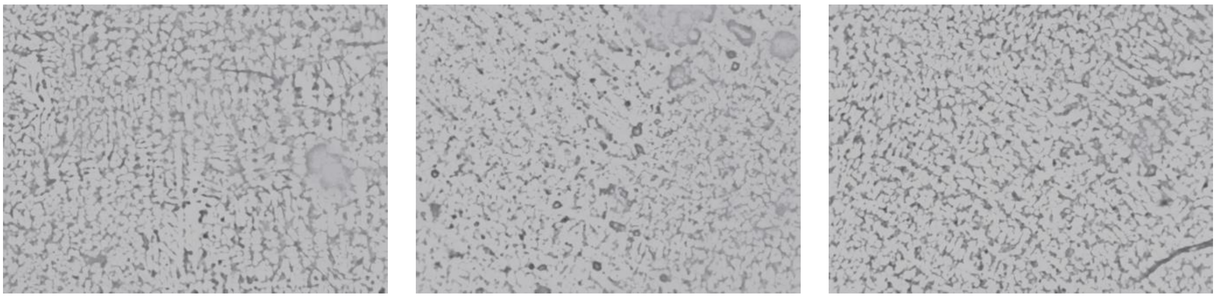
3 RESULTS AND DISCUSSION

3.1. Microstructural Analysis

The microstructural evolution of the Al 7075 hybrid composites was examined to validate the dispersion of the reinforcement. Fig. 3 presents the optical micrographs of samples S1, S2, and S3 [12]-[13]. The images reveal a reasonably uniform distribution of WC and CDA particulates within the Al 7075 matrix, with minimal agglomeration observed in Sample S3. The darker regions correspond to the CDA particles, whereas the angular bright phases correspond to the WC particulates. The absence of significant porosity or blowholes suggests that the degassing procedure and casting parameters (800°C melt temperature, 450 rpm stirring) were effective. The grain structure of the hybrid composite appeared to be more refined than that of the base alloy.

This can be attributed to the reinforcement of particles acting as nucleation sites during solidification, thereby restricting dendritic growth. The optical micrographs show a reasonably uniform distribution of WC and CDA particles in the Al7075 matrix, which enables efficient load transfer from the ductile alloy to the stiff reinforcements during indentation and contributes directly to the higher hardness of the WC-rich composition. The dispersed WC and CDA particles also act as heterogeneous nucleation sites during solidification, refining the grain structure and increasing the grain-boundary area, thereby further hindering dislocation motion and strengthening the matrix. In addition, the hard WC particles and finer CDA fragments served as effective dislocation pinning centers, reducing the ease of plastic flow beneath the Rockwell indenter. Together, these features—uniform particle distribution, grain refinement, and strong particle–matrix interfaces—synergistically limit plastic deformation under load and explain the progressive increase in hardness from S1 to S3 as the WC content increases, as reported in Section 3.2.



a) b) c)

Fig. 3. Optical Micrographs of Specimens a) Specimen S1, b) Specimen S2, and c) Specimen S3

3.2. Hardness

The Rockwell Hardness (HRB) of the fabricated composites is presented in Table 3. A clear trend of increasing hardness with higher Tungsten Carbide content was observed. Sample S3, which contained the highest fraction of WC (3.5 wt. %), exhibited the maximum hardness compared to Sample S1. The mean values for samples S1, S2, and S3 were 24.0 ± 0.8 HRB, 25.0 ± 0.8 HRB, and 35.0 ± 0.8 HRB, respectively. This enhancement is attributed to two primary mechanisms:

- Dispersion Hardening: The hard WC particles (approximately 2200 HV) acted as barriers to dislocation motion within the soft Al matrix.
- Orowan Strengthening: The presence of non-deformable ceramic particulates (WC and CDA) creates high-stress fields that restrain plastic deformation during indentation.

While CDA contributes to weight reduction, the dominant strengthening agent is WC reinforcement. The slight variation in hardness between S1 and S2 suggests that although CDA provides some reinforcement, the hardness is more sensitive to the WC volume fraction.

Table 3. Rockwell hardness of composites

Composites	Rockwell Hardness
S1	24.0 ± 0.8
S2	25.0 ± 0.8
S3	35.0 ± 0.8

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Table 4 presents a performance comparison of the proposed mechanism with methods reported in the literature. In some of the cited studies, the hardness scale (e.g., Rockwell, Vickers, and Brinell) and/or the exact base alloy reference condition (as-cast, heat-treated) are not explicitly reported. Consequently, the hardness values and percentage improvements compiled in the above table should be interpreted as indicative trends rather than strict one-to-one quantitative comparisons with the present work.

Table 4. Performance Analysis

Study	Reinforcement System	Hardness Value	Scale	% Improvement (as reported)
Current Study (S3)	Al7075 + 3.5% WC + 1.5% CDA	35.0 HRB	HRB	~45.8% (vs. S1)
B. S. Lovevanshi [6]	Al7075 + 2.5% CDA + 2.5% SiC	Hardness increased	—	32.72% (vs. base alloy)
M Girikonda [7]	Al7075 + 10% Al_2O_3 + 4% B_4C	Not specified	—	Optimized composition
S. Hariharan [8]	Al7075 + 2.5% TiO_2 + 5% SiC	Not specified	—	~40% (vs. base)
P. Sathiamurthi [9]	Al7075 + 8% B_4C + 1% ZrB_2	Not specified	—	8% (vs. base)

Despite differences in testing scales and reference conditions, the hardness improvement achieved in the present study is comparable to or exceeds that reported for several Al7075 hybrid composite systems, highlighting the effectiveness of WC as the primary strengthening phase even at relatively low reinforcement levels. Based on the experimental observations, the hardness enhancement mechanism in the Al7075–WC–CDA hybrid composites can be summarized as follows:

i) uniform dispersion of WC and CDA promotes effective load transfer during indentation;
ii) WC particles act as substantial barriers to dislocation motion through dispersion and Orowan strengthening;
iii) CDA particles contribute to grain refinement by serving as heterogeneous nucleation sites; and
iv) the combined presence of WC and CDA synergistically restricts plastic deformation under applied load.

From an engineering perspective, the observed hardness enhancement suggests that Al7075–WC–CDA hybrid composites may be suitable for applications requiring improved surface durability, such as lightweight automotive components, wear-resistant structural parts, and aerospace fittings where hardness is a critical design parameter. The use of cow dung ash as a partial reinforcement further supports sustainable material development by valorizing agricultural waste. The thing to note is that the present analysis focuses on macroscopic hardness response; micro-scale deformation mechanisms at the particle-matrix interface were not directly examined.

4 Conclusion

The investigation demonstrated that Al7075–WC–CDA hybrid composites fabricated via stir casting can achieve substantial hardness enhancement (approximately 45.8% increase for S3 relative to S1), indicating the strong contribution of WC to the strengthening of the hybrid system. Simultaneously, the scope of the present work is restricted to hardness evaluation, and other key mechanical and tribological properties, such as tensile strength, wear behavior, and detailed microstructural quantification (e.g., SEM–EDS), are not covered here. Quantitative porosity measurements and broader statistical validation (beyond the limited number of tested specimens) were also not included, which may influence the generalization of the results. Within these constraints, the findings support the view that combining agricultural waste–derived CDA with a hard ceramic, such as WC, is a promising and resource-efficient approach for enhancing the hardness of Al7075-based metal matrix composites.

The following conclusions are drawn from the investigation into Al 7075 reinforced with WC and Cow Dung Ash:

- Hybrid metal matrix composites were successfully fabricated using the stir casting technique with optimized parameters (800°C melt temperature, 450 rpm stirring speed).
- Microstructural analysis confirmed the uniform distribution of reinforcements and grain refinement in the matrix, thereby validating the effectiveness of the manufacturing process.
- The incorporation of WC significantly enhanced the hardness of the composites. Sample S3 (3.5% WC, 1.5% CDA) demonstrated a 45% improvement in hardness compared to Sample S1, reaching 35.0 ± 0.8 HRB.
- This study confirms that agricultural waste (CDA) can be effectively combined with synthetic ceramics (WC) to produce sustainable, high-hardness composites for industrial applications.

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ETHICS STATEMENT

This study did not involve human or animal subjects and, therefore, did not require ethical approval.

STATEMENT OF CONFLICT OF INTERESTS

The authors declare no conflicts of interest related to this study.

LICENSING

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