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Experimental Investigation On Mechanical Properties Of Fly Ash And Rice Husk Ash Reinforced Aluminium Alloy (AA8011) Hybrid Metal Matrix Composite

[1]Eeduru Dayakar, [2]Dr. P. Prasanna

[1]Post Graduate Student, [2]Associate Professor
Department of Mechanical Engineering
JNTUH University College of Engineering, Science and Technology Hyderabad, India

Abstract: This study explores the development and mechanical enhancement of AA8011 hybrid composites reinforced with Fly Ash, a by-product of coal combustion, and Rice Husk Ash, an agricultural residue. Both materials are considered cost-effective substitutes for more expensive reinforcements. These composites have promising applications in industries such as aerospace, automotive, and electrical engineering, including aircraft wings, fuselages, engine blocks, wheels, power cables, and transformer windings due to their enhanced mechanical properties. The composites were fabricated using stir casting, a cost-effective and efficient method that ensures uniform dispersion of the Fly Ash and Rice Husk Ash reinforcements within the aluminium matrix. Reinforcement levels were varied at three equal weight percentages (4%, 6%, and 8%) of Fly Ash and Rice Husk Ash. Mechanical testing revealed significant improvements in the aluminium metal matrix alloy's properties, with hardness increasing by approximately 15.63% and ultimate tensile strength by approximately 15.25% from 4% to 8% reinforcement, demonstrating the effectiveness of these reinforcements in enhancing the material's overall performance.

Keywords **- AA8011, Fly Ash, Rice Husk Ash, Stir Casting.**

1. INTRODUCTION

Aluminium matrix composites (AMCs) have emerged as promising materials in various industrial sectors due to their exceptional properties, such as low density, high strength-to-weight ratio, excellent thermal conductivity, and corrosion resistance. Among aluminium alloys, AA8011 is widely utilised in applications such as automotive components, packaging, and aerospace due to its outstanding formability and corrosion resistance. However, its relatively low hardness and strength limit its application in high-performance environments where superior mechanical properties are required. To address these limitations, the incorporation of reinforcements into the aluminium matrix has become a prevalent strategy for enhancing its properties. Hybrid composites, which incorporate more than one type of reinforcement, have demonstrated superior mechanical performance compared to single-reinforcement composites. Fly ash and Rice husk ash are two such reinforcements that have gained significant attention due to their availability, low cost, and environmental benefits. These materials, derived from industrial and agricultural waste, not only enhance mechanical properties but also contribute to sustainability by reducing the ecological footprint. Incorporating Fly Ash and Rice Husk Ash into the AA8011 matrix results in a hybrid composite with improved hardness, tensile strength, and thermal stability, making it an ideal candidate for advanced engineering applications.

2. MATERIALS

2.1 Matrix material

Aluminium alloy 8011 is a wrought alloy primarily composed of iron and silicon, known for its excellent deep-drawing properties. This modern alloy is widely used in various applications, including aircraft components (wings, fuselage), engine blocks, heat exchanger fins, power cables, and transformer windings. Its high strength-to-weight ratio also makes it suitable for structural components in the construction, automotive, and aerospace industries. The growing demand for these applications underscores the importance of research and development to further enhance its performance and utility. The Chemical Composition of AA8011 is shown in Table 1.

Table 1. Chemical Composition of AA8011 (in weight %)

Fe	Si	Cu	Mn	Mg	Cr	Al
0.74	0.52	0.12	0.45	0.27	0.02	Remaining

2.2 Reinforcement Materials

Fly ash is a coal combustion byproduct that is primarily composed of silicon dioxide (SiO_2) and calcium oxide (CaO), with variable compositions influenced by coal sources. Traditionally emitted into the atmosphere, Fly Ash is now regulated and contained, finding applications in construction (as a partial cement replacement, road subbases, and cement clinkers), agriculture, and manufacturing (bricks, tiles, and insulation). Its versatility extends to producing eco-friendly products like artificial reefs and wood fillers, promoting resource efficiency and waste management. The Chemical Composition of Fly Ash is shown in Table 2.

Table 2. Chemical Composition of Fly Ash (in weight %)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	Remaining
62.24	21.5	9.2	1.42	1.46	1.5	0.47	2.38	2.38

Rice husk ash obtained from rice milling residues is a lightweight material with an 85–97% silica content, offering enhanced hardness, thermal stability, and wear resistance. As a reinforcement in aluminium composites, Rice Husk Ash improves mechanical properties, including tensile strength and wear resistance, while maintaining low density. Its use supports sustainability by repurposing agricultural waste, making it a cost-effective alternative to synthetic materials. The Chemical Composition of Rice Husk Ash is shown in Table 3.

Together, Fly Ash and Rice Husk Ash contribute to developing advanced composites for industries, prioritising performance, cost savings, and eco-friendliness.

Table 3. Chemical Composition of Rice Husk Ash (in weight %)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5
82.14	1.34	1.27	1.21	1.96	0.17	0.14	2.09	6.44

3. METHODOLOGY

The fabrication of AA8011 aluminium alloy composites reinforced with fly ash and rice husk ash in equal proportions (4%, 6%, and 8% by weight) was accomplished using the stir casting method. The fabrication began with AA8011 aluminium alloy ingots, which were melted at a controlled temperature of 710°C in an induction furnace. The choice of 710°C ensured efficient and uniform melting of the aluminium alloy without overheating, which could lead to undesirable reactions or degradation of the alloy. To prepare the reinforcements, fly ash (FA) and rice husk ash (RHA) were carefully preheated to a temperature of 200°C in a muffle furnace. Preheating served multiple purposes: it effectively removed any moisture content present in the reinforcements, minimised the risk of gas formation when added to the molten aluminium, and enhanced the compatibility between the reinforcements and the aluminium matrix. The preheating step ensured that the reinforcements were dry, clean, and ready for incorporation into the molten alloy. Once the alloy was fully molten, the stirring process was initiated using a high-precision mechanical stirrer operating at 500 revolutions per minute (rpm). Stirring at this speed created a strong vortex within the molten alloy, which was essential for achieving uniform distribution of the reinforcements throughout the matrix. During the stirring process, argon gas was introduced into the system. Argon gas played a critical role by forming a protective atmosphere over the molten aluminium, thereby preventing oxidation and maintaining the alloy's quality. The stirring process was carefully maintained for 10 minutes to ensure thorough mixing and uniform dispersion of the reinforcements. The addition of the reinforcements was performed gradually and in small increments while stirring was ongoing. This incremental addition prevented clumping or settling of the reinforcements and promoted consistent integration within the molten matrix. The meticulous stirring and controlled addition of reinforcements resulted in a homogeneous composite with evenly distributed Fly Ash and Rice Husk Ash particles.

Figure 1. Induction furnace Figure

Figure 2. Mechanical Stirrer in molten metal

The prepared composite melt was then poured into a preheated cast iron die. The dimensions of the die were 300 mm × 170 mm × 16 mm, providing ample space to accommodate the composite for casting. The die was preheated to a temperature of 100°C before pouring the molten composite. Preheating the die helped minimise thermal shocks that could occur when the hot molten composite came into contact with a cold surface. Additionally, this step promoted better surface finish and reduced internal stresses within the cast samples.

Figure 3. Preheated cast iron die

Figure 4. Pouring molten metal into the die

After pouring the molten composite into the preheated die, it was cooled naturally under ambient conditions for uniform solidification. The cast composites were then prepared for mechanical and microstructural testing, ensuring high-quality AA8011 aluminium alloy composites with desired reinforcement proportions.

Figure 5. Composite samples after removing from the die

4. RESULTS AND DISCUSSION

After fabricating three composite compositions, the materials were precisely cut into specimens using Wire Electrical Discharge Machining (WEDM) to ensure a smooth surface finish suitable for testing. Initially, the hardness of the composite material was evaluated. Subsequently, the specimens were cut into tensile test dimensions by ASTM E8 standards to characterise the mechanical properties of the composite.

4.1. Hardness

Figure 11. Stir casted samples for hardness

Table 6. Stir-casted composite hardness results

Specimen Composition	Test values			Average Hardness (HRB)
	Test 1	Test 2	Test 3	
AA8011+4%(FA+RHA)	52	55	53	53.33
AA8011+6%(FA+RHA)	61	58	56	58.33
AA8011+8%(FA+RHA)	62	61	62	61.66

Hardness, measured here using the Rockwell B scale (HRB), reflects the material's resistance to surface indentation and wear. The composite shows a progressive increase in hardness values with higher reinforcement percentages: 53.33 HRB for 4% reinforcement, 58.33 HRB for 6%, and 61.66 HRB for 8%. This upward trend can be attributed to the uniform distribution of hard FA and RHA particles within the softer AA8011 matrix. The hardness increased by approximately 9.38% from 4% to 6% reinforcement and 15.63% from 4% to 8% reinforcement, demonstrating a significant improvement with higher reinforcement levels.

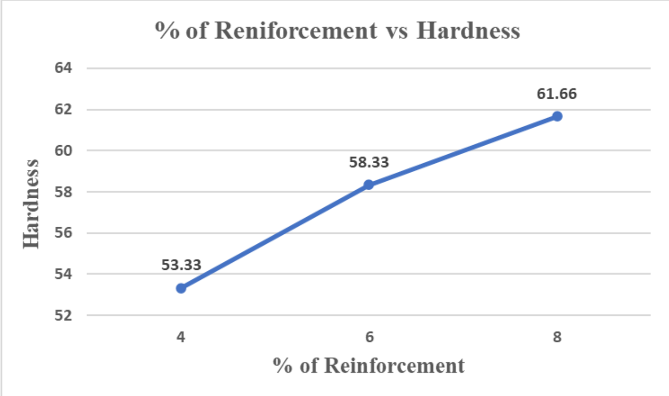

Figure 4.1 Graph of Percentage of Reinforcement vs Hardness

Increasing Fly Ash and Rice Husk Ash reinforcement reduces interparticle spacing, restricts dislocation movement and enhances hardness. The ceramic-like hardness of the reinforcements further strengthens the composite, distributing forces effectively to minimise deformation. This results in a denser, harder, and more wear-resistant composite with higher reinforcement levels.

4.2 Tensile Strength

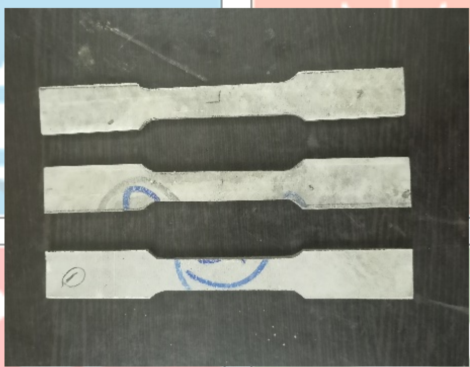

Figure 14 Stir casted tensile test specimens

Figure 15 Stir casted specimens after tensile test

Table 7. Stir-casted composite tensile test results

Specimen Composition	Ultimate Tensile Strength (MPa)	Percentage of Elongation (%)	Yield Stress (MPa)
AA8011+4%(FA+RHA)	115.97	13.16	45.85
AA8011+6%(FA+RHA)	123.81	10.70	49.75
AA8011+8%(FA+RHA)	133.68	5.45	54.91

Tensile testing was conducted using a Universal Testing Machine (UTM) to evaluate the composite's mechanical properties. Tensile properties, including ultimate tensile strength (UTS), percentage elongation, and yield strength, reveal how the composite behaves under load-bearing conditions. With an increase in reinforcement, there is a noticeable improvement in UTS and yield strength, paired with a reduction in elongation. For 4% reinforcement, UTS, elongation, and yield strength are 115.97 MPa, 13.16%, and 45.85 MPa, respectively; at 6% reinforcement, UTS increases to 123.81 MPa, elongation decreases to 10.70%, and yield strength rises to 49.75 MPa; finally, at 8% reinforcement, UTS reaches 133.68 MPa, elongation further reduces to 5.45%, and yield strength peaks at 54.91 MPa.

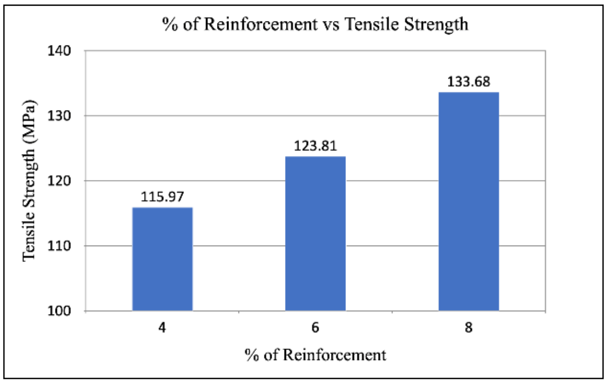

Figure 4.2 Graph of Percentage of Reinforcement vs Tensile Strength

The addition of FA and RHA reinforcement enhances the composite's UTS and yield strength by improving load-carrying capacity and resisting plastic deformation. The particles create a stiff reinforcing network, uniformly distributing stress and increasing strength. However, increased reinforcement reduces elongation due to the brittle, non-deformable nature of FA and RHA, which limits the matrix's flexibility and ductility. This trade-off results in a composite that is stronger but less stretchable.

4. CONCLUSION

The tensile strength and hardness of a hybrid AA8011 composite reinforced with varying weight percentages of fly ash and Rice husk ash (4%, 6%, and 8%) were investigated. Hybrid AA8011 matrix composites were successfully fabricated using the stir-casting method. An increase in Fly Ash and Rice Husk ash reinforcement contributed significantly to the hardness of the AA8011 composite, with the 8% reinforcement composite reaching the highest hardness value of 61.66 HRB. This represented a notable improvement, enhancing the base alloy's hardness by approximately 15.6%. The ultimate tensile strength of the hybrid composite also improved with increasing reinforcement content, with an observed maximum increase of 133.68 MPa for the AA8011/8% FA+RHA composite.

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