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Utilization of rice husk ash waste and scrap aluminum as composite materials fabricated by evaporative casting

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This article contributes to:

Highlights:

- Aluminum composites were made using waste materials like aluminum scrap and rice husk ash (RHA) with an evaporative casting method.
- Key factors such as composition, casting temperature, and styrofoam thickness affected properties like hardness and porosity.
- The study shows that waste materials can be used to create cost-effective and eco-friendly composites for industry.

Abstract
To achieve environmental sustainability, the integration of waste materials into new production processes is essential. This study investigates the development of aluminum matrix composites (AMCs) reinforced with rice husk ash (RHA) using the evaporative casting method. This study focuses on the effects of aluminum scrap-RHA composition, casting temperature, and styrofoam pattern thickness on key physical and mechanical properties such as fluidity length, surface roughness, hardness, and porosity. The composite material from aluminum scrap electrical cables and rice husk ash was heated in a furnace at a temperature of 900 °C for 2 hours with a sieve size of 200 mesh. The pattern material is styrofoam from electronic equipment packaging. The molding sand used is local silica sand with a sieve size of 60 mesh. The melting furnace uses a crucible furnace type with used oil as fuel. The independent variables were Al-RHA composition (100:0, 95:5, 90:10) %, pouring temperature (650 °C, 700 °C, and 750 °C), and Styrofoam pattern thickness (1, 2, 3, 4, 5, 6, and 10) mm. The results showed that the pouring temperature and the composition ratio of Al-RHA affected the fluidity length, surface roughness, hardness, and porosity, showcasing the potential of using waste materials in cost-efficient and environmentally sustainable composites for various industries.

Keywords: Scrap Al-RHA composite; Evaporative casting; Physical Properties; Mechanical properties; Fluidity

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1. Introduction

In the manufacturing industry, the utilization of waste materials to produce new materials is a crucial step toward sustainability [1], [2]. To enhance environmental sustainability, the use of industrial and agricultural waste has become a primary focus in the development of new materials [3]–[8]. Rice Husk Ash (RHA) is a by-product of rice milling rich in silica, abundant, and inexpensive

[9]–[11]. The use of agricultural waste, particularly RHA, represents an innovative, environmentally friendly solution in various industrial applications, especially in the development of aluminum matrix composites (AMC). By incorporating RHA into composites, industries can reduce their dependence on non-renewable conventional raw materials and minimize the amount of waste generated from agricultural processes [12]. The integration of RHA into aluminum composites aligns with the principles of the circular economy, where waste materials are transformed into valuable resources [13]. RHA-reinforced scrap aluminum composites offer a promising solution as they have the potential to reduce industrial waste while utilizing available resources. Using scrap aluminum in this process not only promotes recycling but also helps reduce production costs and environmental impact.

Innovations in composite production through evaporative casting offer environmentally friendly alternatives, with the economic value of scrap holding a high potential for enhancing environmental sustainability through the utilization of residual/waste materials. Evaporative casting, also known as Lost Foam Casting (LFC), is a unique casting technique that uses patterns made of styrofoam embedded in a sand mold. The styrofoam evaporates when molten metal is poured into the mold, allowing the formation of complex components with tight tolerances and minimal post-processing. The production of Al-RHA composites using this method offers advantages such as fast processing time, practicality, energy efficiency, and waste reduction. By reducing the waste produced from traditional casting processes and utilizing materials that are typically considered useless, this method supports the principles of the circular economy [14]. This process reduces energy consumption since it does not require intensive heating to remove the pattern, which is often one of the main cost drivers in composite production [15]. The use of styrofoam in evaporative casting offers significant economic benefits. Styrofoam is an inexpensive and easily accessible material, which reduces overall production costs [16]. However, the challenge lies in adjusting process parameters, such as pouring temperature and composition ratio, to achieve consistent results with good surface quality and desired mechanical properties. In evaporative casting, precise mold filling is critical to achieving the desired microstructure and mechanical properties [17].

RHA is well-known for its high silica content, which has the potential to enhance the physical and mechanical properties of composite materials, such as corrosion resistance, hardness, and wear resistance. AA7075 aluminum reinforced with RHA particulates increased the tensile strength and hardness [18]. The aluminum and RHA composition is a critical variable that affects the physical and mechanical characteristics of the composite. The proportion of RHA in the aluminum matrix can influence properties such as hardness and surface roughness, while the pouring temperature affects the homogeneity of the mixture. Increasing RHA content tends to increase the surface roughness, hardness, and porosity [19]. Therefore, the balance of scrap aluminum composition with RHA needs to be optimized to achieve the desired mechanical properties without compromising casting quality. However, the exact proportion must be determined to optimize these benefits without increasing porosity or reducing the fluidity length resulting from the casting process. Adding RHA to scrap aluminum is expected to improve hardness and reduce surface roughness due to the reinforcing role of silica in the aluminum matrix.

Incorporating RHA into aluminum composites can also affect fluidity. RHA, as a particulate material, can influence the flow characteristics of molten aluminum. The particle size and distribution of RHA play a crucial role in determining the overall fluidity of the composite. Small and well-distributed RHA particles can improve fluidity, while excessive or poorly distributed RHA can hinder the flow [20]. The fluidity length of the composite is important for assessing the material's ability to fill the mold during the casting process, which is directly related to the pouring temperature and material composition. Findings suggest that increasing the pouring temperature improves fluidity, allowing complex molds to be filled and resulting in better surface finishes [21]. The presence of RHA can also affect surface roughness. While RHA can enhance the mechanical properties of the composite, its particulate nature can lead to increased surface roughness if not evenly distributed. Studies show that achieving a balance between RHA content and pouring temperature is crucial to optimizing surface finish [20]. The addition of hard RHA particles provides a protective barrier against wear mechanisms [13], [22]. Ahmed et al. [23] demonstrated that mechanical properties, such as hardness and corrosion resistance of aluminum alloys, can be effectively modified by adding alloying elements such as Magnesium (Mg), Copper (Cu), and Zinc (Zn), which is analogous to the effects observed with RHA in aluminum composites. Studies have shown that these composites can be effectively used in the manufacture of components such as cylinder liners, pistons, and connecting rods, which require high wear resistance and durability

[24]. The inclusion of RHA in the aluminum matrix can significantly improve the wear resistance, which is very important for applications requiring high durability and toughness [25].

The mechanical properties of RHA-reinforced AMC make it suitable for applications in high-performance environments, thus expanding its use in critical engineering applications [26]. The high silica content in RHA not only contributes to hardness but also enhances the toughness of the composite by providing better energy absorption characteristics during deformation. This is particularly beneficial in applications where the material is subjected to dynamic loads, such as in automotive and aerospace components [27]. The addition of RHA can also affect the porosity of aluminum composites. While RHA can improve mechanical properties, higher RHA content can lead to increased porosity due to poor compaction during processing. This highlights the importance of optimizing RHA content to achieve the desired balance between mechanical performance and porosity [20].

The pouring temperature during the casting process is a critical factor in determining quality as it affects the microstructure of the resulting composite. Higher temperatures can facilitate a more homogeneous mixture of RHA in aluminum, potentially increasing fluidity length and reducing surface defects. Composites produced at higher temperatures exhibit superior mechanical properties due to the reduction of defects and porosity in the final product [28], [29]. However, excessively high temperatures can lead to the formation of adverse microstructural defects, such as hot cracking, which diminishes the composite's mechanical strength. Conversely, too high a pouring temperature can cause the degradation of RHA, reducing its reinforcing effectiveness. The optimal pouring temperature must be carefully controlled to balance the benefits of increased fluidity and the preservation of reinforcing material properties [30], [31]. Temperature affects the solidification rate of the composite, which can alter the material's toughness. Slower cooling rates, typically associated with lower pouring temperatures, can enhance the toughness of the composite, leading to improved impact resistance. Lower pouring temperatures can result in increased surface roughness due to incomplete mold filling and surface irregularities [28], [29]. Conversely, rapid cooling can produce a more brittle microstructure, reducing impact strength [29], [30]. Hardness and surface roughness are critical indicators of mechanical performance, especially in applications requiring high resistance to abrasion and mechanical stress. The pouring temperature affects the fluidity length, surface roughness, hardness, and porosity of Al-RHA composites [19]. Higher pouring temperatures can reduce the viscosity of molten aluminum, allowing trapped gases to escape more easily, reducing porosity. However, if the temperature is too high, it can lead to excessive gas formation, resulting in increased porosity [30], [31].

This research differentiates from previous studies by utilizing Rice Husk Ash (RHA), an agricultural waste product, as a novel reinforcement in Aluminum Matrix Composites (AMC), enhancing mechanical properties like hardness and corrosion resistance. It employs the sustainable evaporative casting technique, or Lost Foam Casting (LFC), which allows for intricate component shapes with reduced waste and energy usage, supporting circular economy principles. The study emphasizes both environmental and economic sustainability by integrating low-cost scrap aluminum and styrofoam, optimizing key parameters such as pouring temperature, RHA concentration, and styrofoam pattern thickness to achieve the best balance between mechanical properties and manufacturing efficiency. This meticulous optimization addresses challenges such as porosity and surface roughness, expanding the potential applications of RHA-reinforced AMC in high-performance industries like automotive and aerospace, which require materials that withstand significant wear and dynamic loads. The novelty of this research lies in its integration of Rice Husk Ash (RHA) with scrap aluminum using evaporative casting to produce cost-effective, sustainable, and mechanically enhanced composites suitable for high-performance applications.

2. Materials and Methods

2.1. Materials

The materials used in this research include scrap aluminum and RHA as the composite alloy composition, recycled styrofoam from electronic packaging as the pattern, and silica sand as the mold material in the casting process. The mold frame was made from plywood. Scrap aluminum from electrical cables was sourced from scrap collectors in Banjarbaru, South Kalimantan. The electrical cables were cleaned of contaminants and then cut into 20 cm lengths (**Figure 1a** and **Figure 1b**). The rice husks were purchased from a rice mill in Martapura, South Kalimantan. The styrofoam was obtained from recycled electronic packaging at the Faculty of Engineering, Lambung Mangkurat University, Banjarbaru City. The silica sand was purchased from a sand seller in Martapura, South Kalimantan. The sand was cleaned of impurities and then sieved to pass through a 60-mesh screen (**Figure 1c**).

Figure 1. The materials used in this study: (a) Electrical cable before cuting, (b) Electrical cable cut to 20 cm; and (c) Silica sand

2.2. Preparation of RHA

The rice husks (**Figure 2a**) were cleaned of impurities and then subjected to combustion at around 400 °C for 1.5 hours, resulting in black ash (**Figure 2b**). The combustion temperature was measured with a Benetech infrared thermometer, model GM1850, with a temperature range of 200–1850 °C. The ash was then ground and sieved to pass through a 200-mesh screen. The ash was subsequently heated in a furnace at 900 °C for 2 hours, resulting in white ash (**Figure 2c**). The furnace used was a B-ONE model BFNC-2012 with a temperature range of 200–1200°C. This white ash was used as the reinforcing material in the aluminum matrix composite.

Figure 2. Rice husk ash (RHA); (a) Rice husks, (b) Rice husks after burning at 400°C, (c) Rice husk ash after heating at 900°C for 2 hours

2.3. Pattern and Mold Frame Preparation

In this evaporative casting process, the pattern material for the product specimens was made from recycled styrofoam from electronic packaging (**Figure 3a**). The styrofoam was cut (**Figure 3b**) using an electric cutter into sizes (thickness x width x length) as follows: (1) 1 x 10 x 40 mm, (2) 2 x 10 x 40 mm, (3) 3 x 10 x 40 mm, (4) 4 x 10 x 40 mm, (5) 5 x 10 x 40 mm, (6) 6 x 10 x 40 mm, (7) 10 x 10 x 40 mm, and (8) 20 x 20 x 40 mm. The standard used in making patterns to measure fluidity using the Qudong Wang Method. This method has the advantage that the 8 existing grooves will get the same distribution of liquid metal flow because the down channel is in the middle of the mold [32]. The styrofoam pieces were then assembled with foam glue into the planned pattern (**Figure 3c**). The mold frame (**Figure 3d**) was made of plywood and used to hold the sand in place during the pouring of molten metal into the mold.

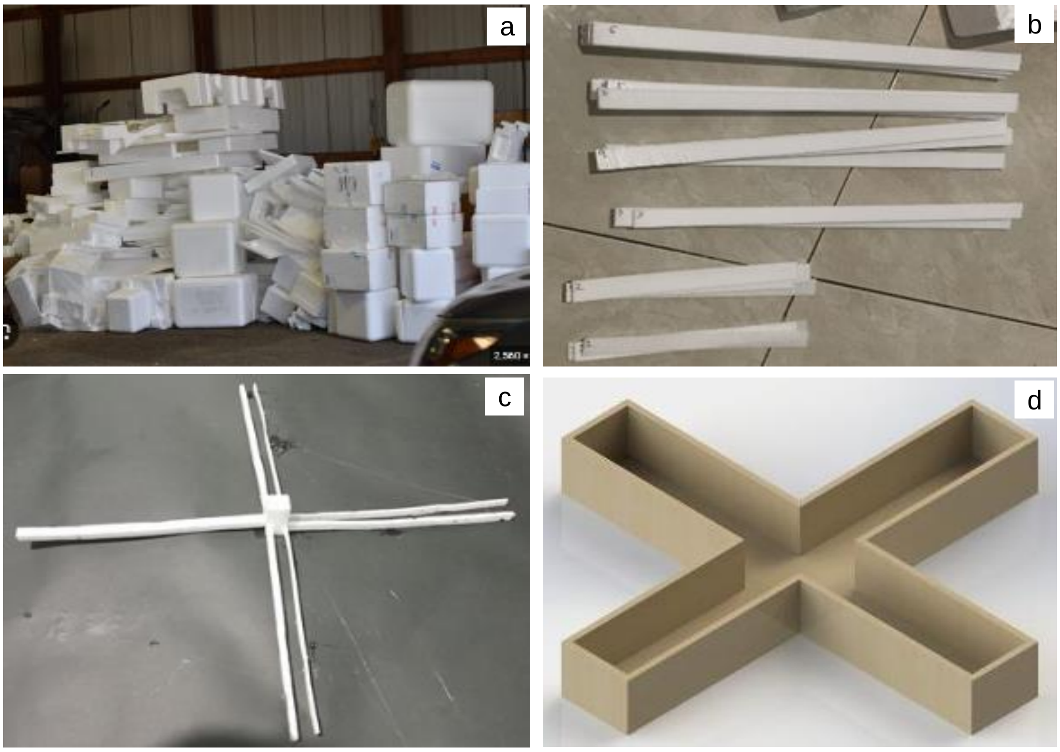

Figure 3. Pattern and mold frame; (a) Recycled styrofoam from electronic packaging, (b) Styrofoam being cut, (c) Styrofoam assembled into the planned pattern, (d) Mold frame

2.4. Experimental Procedure

The experimental procedure involved melting aluminum in a crucible furnace with varying pouring temperatures (650 °C, 700 °C, and 750 °C). The molten aluminum was then mixed with RHA at ratios of 100:0%, 95:5%, and 90:10%. The mixture was stirred at 150 rpm for 20 minutes to ensure homogeneous distribution of RHA particles in the aluminum matrix. The Al-RHA mixture was then poured into a styrofoam pattern embedded in silica sand. The pattern thickness varied (1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, and 10 mm). The shape and size of the styrofoam patterns are shown in **Figure 3a** When the molten metal was poured into the mold with the styrofoam pattern embedded in the sand, the styrofoam burned off, allowing the mold cavity to be filled, resulting in the desired shape. The composite was left to solidify in the mold for 30 minutes, after which it was removed, cleaned, and prepared for testing and further analysis.

2.5. Energy Dispersive X-Ray Spectroscopy (EDX) Testing on Scrap Aluminum and RHA

Figure 4a and **Table 1** show the results of EDX testing, which presents the X-ray intensity spectrum generated by each element in the sample. The highest intensity peak corresponds to the energy associated with aluminum (Al K = 82.9% by weight), indicating that aluminum is the main element in this sample. Smaller peaks indicate the presence of oxygen (O K = 14.6% by weight), and very small peaks indicate the presence of iron (Fe K = 2.5% by weight).

Figure 4b and **Table 2** show the EDX test results for RHA, displaying the X-ray intensity spectrum generated by each element in the sample. The highest intensity peaks correspond to oxygen (O K = 63.6% by weight) and silicon (Si K = 35% by weight), indicating that these two elements are the main components of the material. Smaller peaks are seen for magnesium (Mg K = 0.4% by weight) and potassium (K K = 1.0% by weight), indicating their presence in smaller amounts. The EDX testing device used was the FEI, Model: Inspect-S50 (FEI Company-United States).

The difference between weight percent and atomic percent in the context of these tables relates to how the composition of elements in a material is quantified. Weight percent (wt%) indicates the fraction of the total mass of the sample contributed by each element. This measure shows what portion of the total weight of the compound is made up of each constituent element. While atomic percent (at%) represents the fraction of the total number of atoms contributed by each element. This measure shows the proportion of atoms of each element in the sample compared to the total number of atoms.

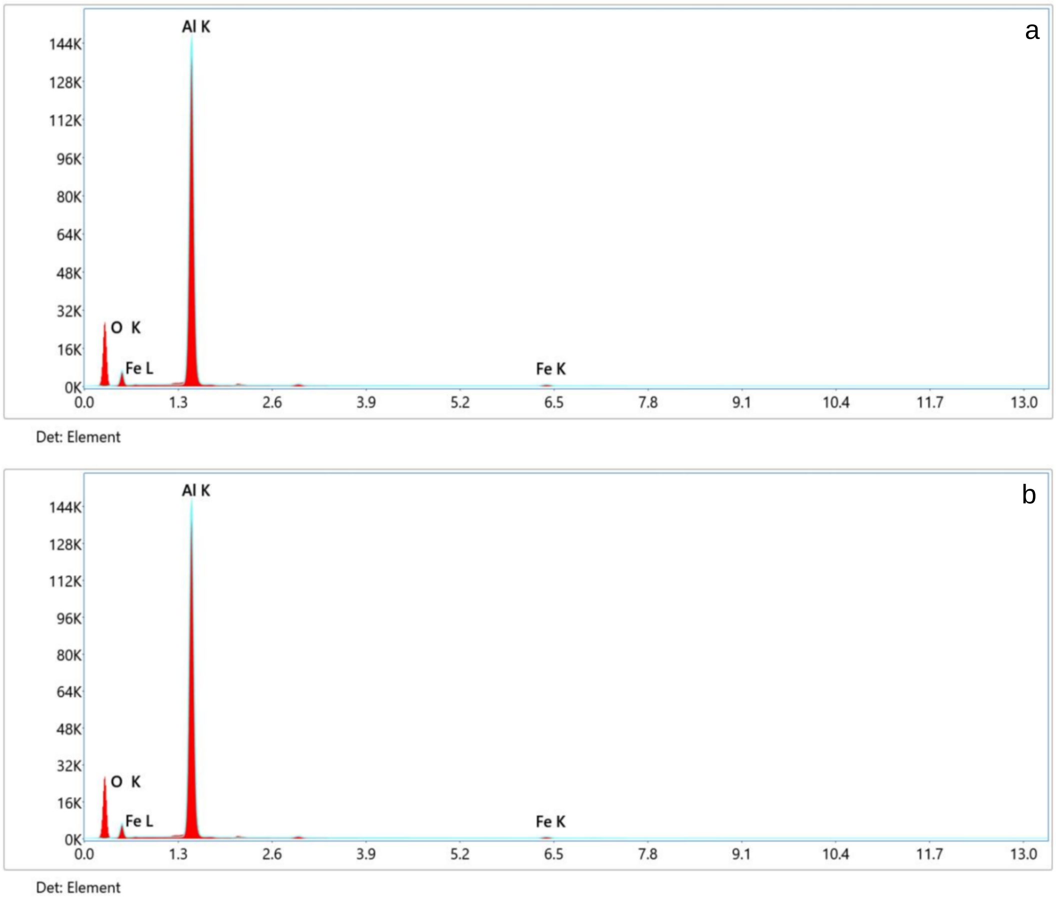

Figure 4. Energy dispersive X-Ray spectroscopy (EDX) on raw materials: (a) scrap aluminum electrical cable; (b) RHA

Table 1. EDX test results for scrap aluminum electrical cable composition

Element	Weight (%)	Atomic (%)
O K	63.6	75.6
Mg K	0.4	0.3
Si K	35.0	23.7
K K	1.0	0.5

Table 2. EDX Test results RHA composition after Heating at 900°C (2 hours)

Element	Weight (%)	Atomic (%)
O K	2.7	4.5
Al K	97.3	95.5

2.6. Composite Testing

Fluidity length, surface roughness, Brinell hardness (HB), and porosity were measured using standard testing methods. Fluidity length, surface roughness, Brinell hardness (HB), and porosity were measured using standard test methods. fluidity length is measured as the maximum distance of the molten metal traveled to fill the mold cavity before solidifying. The fluidity length is measured with a caliper from the boundary channel to the maximum length of the fully formed product. The method in the fluidity test uses the Qudong model. This method can not only measure the fluidity length but can also measure the effect of different mold cavity thicknesses. This method has the advantage that the 8 existing grooves will get the same distribution of molten metal flow because the descending channel is in the middle of the mold [32].

Surface roughness testing is based on ASTM D441 Method C standard, where the test uses a Krisbow type KW 06-303 surface roughness tester. Composite hardness testing uses a MITECH MH600 brand hardness tester with a Brinell (HBN) scale ASTM E8 standard. The percentage value of porosity is carried out using a pycnometer test with the ASTM E 252-84 standard. Porosity is assessed by measuring the density of the composite and comparing it to the theoretical density. This is done by weighing wet and dry specimens and then calculating the percentage.

3. Result and Discussion

This study tested the physical and mechanical properties of Aluminum composites with RHA using evaporative casting techniques, including fluidity length, surface roughness, hardness and porosity. Fluidity length and porosity were measured to determine the integrity and efficiency of mold filling, while surface roughness and hardness were assessed to measure the ability and quality of the composite finish. The results of surface roughness, hardness, and porosity tests are shown in **Table 3**.

Table 3. Surface roughness, hardness, and porosity test results for Al composite

Al : RHA Composition (%)	Pouring Temperature (°C)	Surface Roughness (µm)	Hardness (HB)	Porosity (%)
100:0	650	6.56	24.7	3.7
	700	9.97	24.9	5
	750	10.84	26.3	2.7
95:5	650	8.80	27	3.7
	700	10.71	27.4	2.3
	750	10.96	27.8	3.7
90:10	650	9.36	28.2	1.7
	700	10.87	29.6	1.3
	750	10.99	29.9	1

3.1. Fluidity Length

Table 4 presents the results of the fluidity length test of aluminum (Al) and RHA composites at various mixture ratios (100:0%, 95:5%, 90:10%), pouring temperatures (650 °C, 700 °C, 750 °C), and styrofoam pattern thickness (1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 10 mm). The composite fluidity length graph is shown in **Figure 5**.

Table 4. Fluidity test results for composites

Al : RHA Composition (%)	Pouring Temperature (°C)	Pattern Thickness (mm)						
		1	2	3	4	5	6	10
100:0	650	1.57	42.50	55.20	81.56	90.20	143.30	176.67
	700	2.50	56.20	80.20	93.50	101.7	158.19	182.06
	750	2.67	56.40	86.70	104.25	135.25	170.21	205.00
95:5	650	1.67	48.50	58.05	92.50	100.85	151.70	181.14
	700	2.67	56.20	83.30	105.15	107.15	162.30	185.23
	750	3.93	56.80	87.26	108.67	143.67	175.08	205.50
90:10	650	1.82	50.30	60.32	90.20	110.08	150.16	186.04
	700	2.74	56.70	83.23	103.45	118.50	173.25	192.60
	750	4.20	56.05	89.32	108.3	142.67	195.33	210.25

Based on **Table 4** and **Figure 5**, the test data show the fluidity length of scrap aluminum and RHA composites produced using the evaporative casting method. Several key factors appear to influence the fluidity results of this composite. The following is a systematic and comprehensive analysis of the effects of pouring temperature, Al-RHA composition, and styrofoam pattern thickness. The pouring temperature affects the fluidity length, surface roughness, hardness, and porosity of Al-RHA composites [19]. The fluidity length of the composite increases with the pouring temperature for all compositions and pattern thicknesses. For example, at a 100:0 composition with a pattern thickness of 6 mm, the fluidity length increased from 143.3 mm at 650 °C to 158 mm at 700 °C and 170 mm at 750°C. This indicates that the viscosity of the molten metal decreases as the pouring temperature increases, allowing the molten metal to flow further before solidifying. The findings suggest that increasing the pouring temperature improves fluidity, allowing complex molds to be filled and achieving a better surface finish [21]. At higher temperatures, the material's viscosity tends to decrease, enhancing the material's ability to flow into the mold. Conversely, too low a temperature can increase viscosity, resulting in difficulty filling the mold optimally [33]. Good

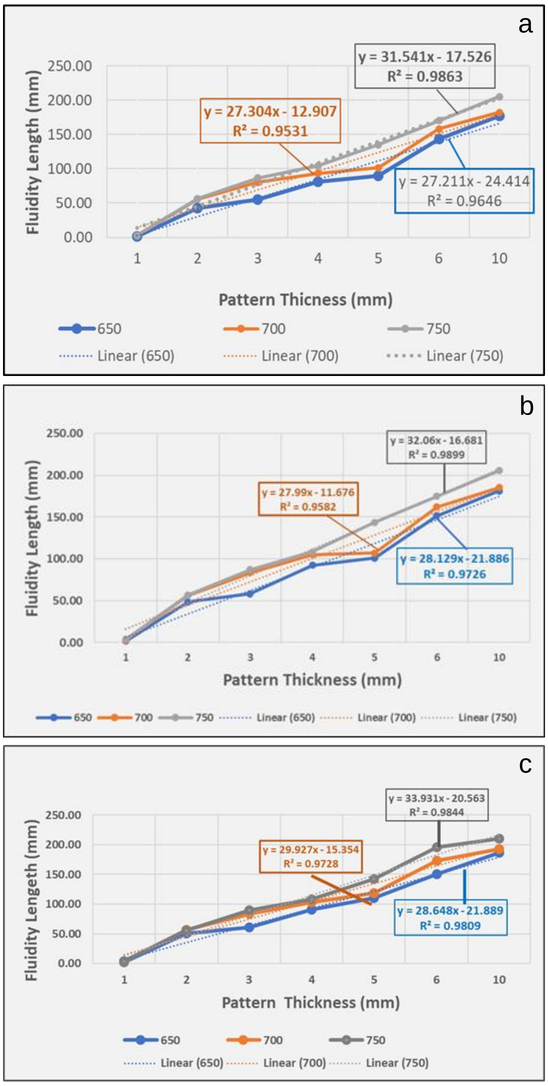

Figure 5. Fluidity length of the aluminum (Al) and RHA composite at different mix ratios, (a) 100:0%, (b) 95:5%, (c) 90:10%

fluidity ensures that the mold is evenly filled, reducing the likelihood of defects such as porosity and voids.

With the addition of RHA (from 0% to 10%), the fluidity length generally increased at the same pouring temperature and pattern thickness. For example, at a pouring temperature of 750 °C and a pattern thickness of 6 mm, the fluidity length increased from 170 mm at 100:0% composition to 175 mm at 95:5% and to 195 mm at 90:10%. This indicates that adding RHA enhances the fluidity length. RHA may affect the thermal properties of the mixture, such as thermal conductivity and heat capacity. If RHA reduces the thermal conductivity of the mixture, this could cause the molten metal to retain its temperature for a longer period, thereby reducing the freezing rate during casting, which indirectly increases fluidity. Incorporating RHA into aluminum composites can also affect fluidity. As a particulate material, RHA can influence the flow characteristics of molten aluminum. Small and well-distributed RHA particles can improve fluidity, while excessive or poorly distributed RHA can hinder flow, leading to defects in the final casting [29].

The thickness of the styrofoam pattern plays a crucial role in determining fluidity length. As shown in Figure 6, fluidity length increases with the pattern thickness across all compositions and pouring temperatures. For example, at a 100:0 composition and a pouring temperature of 650 °C, the fluidity length increased from 0 mm at a 1 mm pattern thickness to 196.67 mm at a 10 mm thickness. This can be interpreted as thicker patterns allowing slower temperature reduction during the pouring process, providing more time for the molten metal to flow before the styrofoam pattern fully decomposes. Conversely, thinner patterns accelerate the solidification of molten metal, reducing fluidity length because the material does not have sufficient time to flow completely before solidifying. In fluidity studies on A356 aluminum alloys in the lost foam casting process [34], results showed that thickness variation could affect the fluidity behavior of the alloy.

There is a clear interaction between pouring temperature, composition, and pattern thickness. Higher temperatures generally mitigate the negative effects of RHA addition on fluidity. At larger thicknesses, the reduction in fluidity caused by the addition of RHA seems to be more moderate. For example, at a 10 mm thickness and a pouring temperature of 750 °C, the fluidity length for the 90:10 composition was 255 mm, indicating that under these conditions, the molten metal was still able to flow well despite the higher RHA content.

The fluidity length of the composite increases with the pouring temperature for all compositions and pattern thicknesses. For example, at a 100:0 composition with a pattern thickness of 6 mm, the fluidity length increased from 143.3 mm at 650 °C to 158 mm at 700 °C and 170 mm at 750 °C. This indicates that the viscosity of the molten metal decreases as the pouring temperature increases, allowing the molten metal to flow further before solidifying. The findings suggest that increasing the pouring temperature improves fluidity, allowing complex molds to be filled and achieving a better surface finish [21]. At higher temperatures, the material's viscosity tends to decrease, enhancing the material's ability to flow into the mold. Conversely, too low a temperature can increase viscosity, resulting in difficulty filling the mold optimally [31]. Good fluidity ensures that the mold is evenly filled, reducing the likelihood of defects such as porosity and voids.

3.2. Surface Roughness

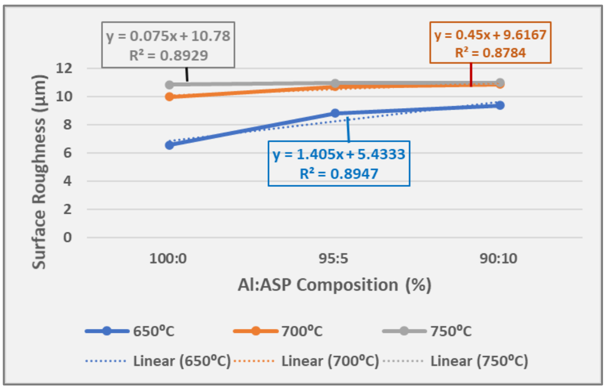

Figure 6. Surface roughness for Al-RHA composites

Figure 6 shows the graph of surface roughness for the aluminum (Al) and RHA composites at different mix ratios (100:0%, 95:5%, 90:10%) and pouring temperatures (650 °C, 700 °C, 750 °C). Based on the data presented in **Table 3** and **Figure 6**, the test results on surface roughness of scrap aluminum RHA composites indicate several trends and patterns that can be analyzed based on the influence of pouring temperature and material composition.

Increasing the pouring temperature leads to increased surface roughness. For instance, for the 100:0 composition, surface roughness increased from 6.56 µm at 650 °C to 9.97 µm at 750 °C. This can be explained by the fact that at higher temperatures, the molten metal has lower viscosity, allowing it to flow more rapidly and fill the mold; however, this can also increase turbulence, leading to greater surface defects. Higher temperatures may also influence the cooling rate, which can affect the formation of microstructures and result in surface roughness or porosity as the metal solidifies. However, too high of a pouring temperature can cause oxidation or other surface imperfections, negatively impacting surface quality [17], [20].

Adding RHA tends to increase surface roughness overall. For instance, at a pouring temperature of 750 °C, surface roughness increased from 9.97 µm at a 100:0 composition to 10.99 µm at a 90:10 composition. This suggests that RHA particles may not disperse evenly in the aluminum matrix or may cause heterogeneity during solidification, both of which could lead to increased roughness. RHA particles may also act as nucleation sites for the formation of pores or cause inclusions that increase the composite's surface roughness. Although RHA can enhance the composite's overall mechanical properties, its particulate nature can lead to increased surface roughness if not evenly distributed [35]. Studies have shown that a balance must be achieved between pouring temperature and RHA content to achieve optimal surface finishes.

There is an interaction between pouring temperature and Al-RHA composition. Higher pouring temperatures exacerbate the effect of increased RHA on roughness. At high temperatures, the impact of RHA addition on surface roughness becomes more significant. This may be because, at higher temperatures, the interaction between RHA particles and the aluminum matrix increases, further affecting the composite's surface quality. Compositions with higher RHA content are more sensitive to changes in temperature than composites consisting solely of aluminum, suggesting that RHA may alter the matrix's physical properties, affecting flow and solidification behavior. From the analysis of the test data, pouring temperature and RHA composition significantly impact the surface roughness of Al-RHA composites. Research shows that balancing RHA content and pouring temperature is crucial for optimizing surface finish [20], [29]. Increasing pouring temperature generally raises surface roughness, while adding RHA further increases roughness, particularly at higher temperatures.

3.3. Hardness

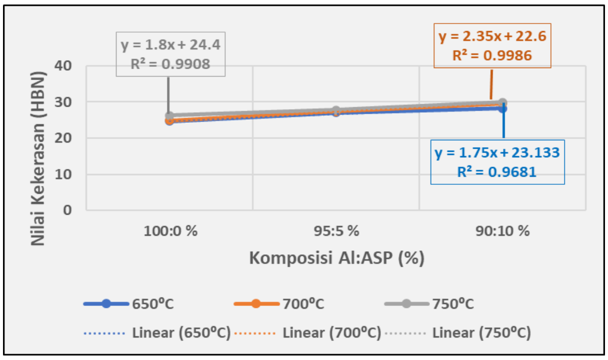

Figure 7. Hardness for Al-RHA composites

Figure 7 shows the graph of hardness for the aluminum (Al) and RHA composites at different mix ratios (100:0%, 95:5%, 90:10%) and pouring temperatures (650 °C, 700 °C, 750 °C). Based on the data presented in **Table 4** and **Figure 7** on the hardness of scrap aluminum and RHA composites, several patterns can be identified regarding the effects of pouring temperature and material composition on hardness (HB). Hardness increases with higher pouring temperatures for all compositions. The higher the pouring temperature, the harder the material tends to become [36]. For example, in the 100:0 composition, hardness increased from 24.7 HB at 650 °C to 26.3 HB at 750 °C. This increase can be attributed to changes in the microstructure resulting from higher pouring temperatures, which may cause faster cooling or other changes in crystal morphology. Higher pouring temperatures may facilitate the formation of finer microstructures, which are associated with increased hardness [37], [38]. However, excessive pouring temperatures can degrade RHA, reducing its reinforcing capability [35].

Adding RHA consistently increases the composite's hardness at each pouring temperature tested. For example, at a pouring temperature of 750 °C, hardness increased from 26.3 HB at a 100:0 composition to 29.9 HB at a 90:10 composition. This indicates that RHA acts as a reinforcement in the aluminum matrix, likely increasing the material's resistance to plastic deformation due to the dispersion of RHA particles that strengthen the matrix. Composites with higher RHA content show increased hardness, although there is a threshold beyond which further RHA additions may not yield additional benefits [29]. Increasing RHA content in composites generally enhances mechanical properties such as tensile strength, compressive strength, and stiffness. This is due to the increased interaction between the polymer matrix and RHA particles, which can improve load distribution within the material [33].

At a 100:0 composition, the increase in hardness from 650°C to 750 °C is about 1.6 HB. Similar increases are seen in the 95:5 and 90:10 compositions, with hardness increasing by approximately 1.1 HB and 1.0 HB, respectively, from the lowest to the highest temperatures. Adding RHA results in a more significant hardness increase than just raising the temperature. For example, changing the composition from 100:0 to 90:10 at 650 °C increases hardness by 4.2 HB. This shows that RHA's reinforcing effect is most effective at higher pouring temperatures, possibly due to better RHA distribution and more optimal interaction with the aluminum matrix at higher temperatures. The data indicate that both pouring temperature and RHA composition significantly and positively impact the hardness of Al-RHA composites. Higher temperatures and the addition of RHA effectively increase hardness, with RHA serving as a highly effective reinforcement in the aluminum matrix. Increasing the temperature not only affects the morphological and crystalline properties of the aluminum matrix but also facilitates better interaction between RHA and aluminum, resulting in higher hardness.

3.4. Porosity

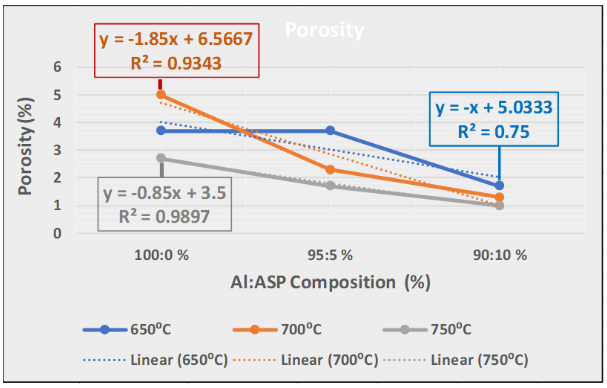

Figure 8. Porosity for Al-RHA composites

Figure 8 shows the graph of porosity for the aluminum (Al) and RHA composites at different mix ratios (100:0%, 95:5%, 90:10%) and pouring temperatures (650 °C, 700 °C, 750 °C). Based on the data presented in Table 4 and Figure 9 on the porosity of scrap aluminum and RHA composites, an analysis was conducted to understand the influence of pouring temperature and material composition on composite porosity. This is important because porosity in composite materials can significantly affect mechanical properties such as strength, hardness, and fatigue resistance.

The data show that the composite with a composition of 100:0% has a porosity level that tends to be stable as the temperature increases from 650 °C to 750 °C. In contrast, the composites with compositions of 95:5% and 90:10% show a decrease in porosity as the pouring temperature increases from 650 °C to 700 °C, followed by an increase in porosity at 750 °C. In particular, the graph for the 95:5% composition shows a sharper decreasing trend compared to the 90:10% composition. This pattern indicates that adjusting the pouring temperature can significantly affect the porosity of the composite, with the potential to optimize the quality of the composite through proper control of the pouring temperature within the studied temperature range. Pouring temperature plays an essential role in determining porosity levels. Higher temperatures can reduce porosity by allowing trapped gases to escape more effectively during the casting process. However, if the temperature is too high, it can lead to increased gas formation and subsequent porosity [35]. Excessive pouring temperatures can lead to the formation of gas, which increases porosity and negatively affects the composite's mechanical properties [17], [38].

With the addition of RHA (from 0% to 10%), composite porosity consistently decreases at each pouring temperature level. For instance, at a pouring temperature of 750 °C, porosity decreased from 2.7% at a 100:0 composition to 1% at a 90:10 composition. This may occur because RHA particles act as reinforcements, improving distribution in the matrix and minimizing porosity formation during solidification. Adding RHA can affect porosity; while it may improve mechanical properties, higher RHA content can lead to increased porosity due to poor compaction during composite powder processing [39]. This highlights the importance of optimizing RHA content to achieve the desired balance between mechanical performance and porosity [29]. However, there is a limit to increasing RHA content, where beyond a certain point, mechanical properties may decrease due to reduced density and increased porosity. Increased porosity may result from the evaporation of trapped water in the RHA or due to incomplete chemical reactions during the casting process.

There is a clear trend of interaction between pouring temperature and composition: the combination of higher temperatures and RHA addition results in the lowest porosity, indicating that higher temperatures facilitate better distribution and integration of RHA into the aluminum matrix, leading to a more compact structure with fewer voids. The data show that both higher pouring temperatures and the addition of RHA positively impact the porosity of Al-RHA composites. Increasing the temperature helps reduce porosity by improving the fluidity of molten metal and its ability to fill the mold efficiently.

4. Conclusion

This study evaluated the effects of the composition ratio of scrap aluminum (Al) and rice husk ash (RHA), pouring temperature, and styrofoam pattern thickness on the mechanical and physical properties of the composites, such as fluidity length, surface roughness, hardness, and porosity. The findings showed that pouring temperature and Al-RHA composition affected the fluidity length, surface roughness, hardness, and porosity.

1. As the pouring temperature increased, the fluidity length and hardness of the composite increased, while the porosity decreased. However, at a composition of 95:5, the porosity decreases as the temperature increases from 650 °C to 700 °C, but increases again at a temperature of 750 °C. Meanwhile, for the 100:0 composition, porosity increases as the temperature increases from 650 °C to 700 °C but decreases at a temperature of 750 °C. Increasing the pouring temperature also caused the surface roughness of the composite to increase.
2. The addition of RHA to the aluminum (Al) matrix increased the fluidity length and hardness of the composite. However, the addition of RHA also caused the surface roughness to increase, while the porosity of the composite decreased.
3. The fluidity length increased with the increase in pattern thickness, at all variations of Al-RHA composition and pouring temperature.

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Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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References

[1] J. L. Manalu, F. Tjhay, T. Kristoforus, and S. Aritonang, “Synthesis and In Vitro Testing of Mg-6Zn-xHAp Biocomposites from Beef Bone as Biodegradable Bone Implant Material,” *Journal of Mechanical Engineering Science and Technology (JMEST)*, vol. 8, no. 2, p. 410, Nov. 2024, doi: 10.17977/um016v8i22024p410.

[2] S. M. B. Respati, H. Purwanto, I. Fakhrudin, and P. Prayitno, “Tensile Strength and Density Evaluation of Composites from Waste Cotton Fabrics and High-Density Polyethylene (HDPE): Contributions to the Composite Industry and a Cleaner Environment,” *Mechanical Engineering for Society and Industry*, vol. 1, no. 1, pp. 41–47, 2021, doi: 10.31603/mesi.5252.

[3] R. Reinaldo and D. Setyanto, “The Potential of Ramie Fiber as Reinforcement in Calcium Carbonate-Filled Polyester Resin Matrix Composites for Roofing Applications,” *Journal of Mechanical Engineering Science and Technology (JMEST)*, vol. 8, no. 2, p. 363, Oct. 2024, doi: 10.17977/um016v8i22024p363.

[4] M. R. F. Putra, H. Isworo, M. N. Yasin, and R. Subagyo, “Friction Modeling of Composite Brake Pads with Ulin Wood Powder (Eusideroxylon zwageri),” *Journal of Mechanical Engineering Science and Technology (JMEST)*, vol. 8, no. 2, p. 520, Nov. 2024, doi: 10.17977/um016v8i22024p520.

[5] A. B. D. Nandiyanto, D. N. Al Husaeni, R. Ragadhita, M. Fiandini, D. F. Al Husaeni, and M. Aziz, “Resin matrix composition on the performance of brake pads made from durian seeds: From computational bibliometric literature analysis to experiment,” *Automotive Experiences*, vol. 5, no. 3, pp. 328–342, 2022, doi: 10.31603/ae.6852.

[6] M. Afiefudin, R. D. Widodo, and R. Rusiyanto, “Fabrication and Characterization of Asbestos Free Brake Pads Composite using Elaeocarpus Ganitrus as Reinforcement,” *Automotive Experiences*, vol. 6, no. 2, pp. 359–371, Aug. 2023, doi: 10.31603/ae.9367.

[7] A. Kholil, R. Riyadi, S. T. Dwiyati, E. A. Syaefuddin, R. H. Pratama, and Y. D. R. Putra, “Natural Fiber Composites from Coconut Fiber, Wood Powder, and Shellfish Shell of Centrifugal Clutch Materials,” *Automotive Experiences*, vol. 5, no. 2, pp. 111–120, 2022, doi: 10.31603/ae.6040.

[8] N. L. Indrayani, R. Sadiana, F. D. Ekawati, Y. Handoyo, H. Maulana, and D. N. Dayana, “Experimental study of variations in fiber types and volume fractions of unsaturated polymer resin (UPR) composites on the mechanical and physical properties of the material,” *BIS Energy and Engineering*, vol. 1, pp. V124019–V124019, 2024, doi: 10.31603/biseeng.59.

[9] A. B. D. Nandiyanto *et al.*, “The effects of rice husk particles size as a reinforcement component on resin-based brake pad performance: from literature review on the use of agricultural waste as a reinforcement material, chemical polymerization reaction of epoxy resin, to experiments,” *Automotive Experiences*, vol. 4, no. 2, pp. 68–82, 2021, doi: 10.31603/ae.4815.

[10] A. B. D. Nandiyanto, D. F. Al Husaeni, R. Ragadhita, and T. Kurniawan, “Resin-based Brake Pad from Rice Husk Particles: From Literature Review of Brake Pad from Agricultural Waste to the Techno-Economic Analysis,” *Automotive Experiences*, vol. 4, no. 3, pp. 131–149, 2021, doi: 10.31603/ae.5217.

[11] M. Khafidh *et al.*, “A Study on Characteristics of Brake Pad Composite Materials by Varying the Composition of Epoxy, Rice Husk, Al2O3, and Fe2O3,” *Automotive Experiences*, vol. 6, no. 2, pp. 303–319, 2023, doi: 10.31603/ae.9121.

[12] M. Geissdoerfer, P. Savaget, N. M. P. Bocken, and E. J. Hultink, “The Circular Economy – A new sustainability paradigm?,” *Journal of Cleaner Production*, vol. 143, pp. 757–768, 2017, doi: 10.1016/j.jclepro.2016.12.048.

[13] G. Arora and S. Sharma, “A review on monolithic and hybrid metal–matrix composites reinforced with industrial-agro wastes,” *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 39, no. 11, pp. 4819–4835, 2017, doi: 10.1007/s40430-017-0910-x.

[14] P. Ghisellini, C. Cialani, and S. Ulgiati, “A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems,” *Journal of Cleaner production*, vol. 114, pp. 11–32, 2016.

[15] I. D. Robertson *et al.*, “Rapid energy-efficient manufacturing of polymers and composites via frontal polymerization,” *Nature*, vol. 557, no. 7704, pp. 223–227, 2018, doi: 10.1038/s41586-018-0054-x.

[16] J. Joustra, B. Flipsen, and R. Balkenende, “Circular Design of Composite Products: A Framework Based on Insights from Literature and Industry,” *Sustainability*, vol. 13, no. 13, p. 7223, 2021, doi: 10.3390/su13137223.

[17] M. Ding, J. Song, and L. Honghui, “Effect of Pouring Temperature on Typical Structure of Thin-Walled ZL105A Alloy Casting,” *Materials and Manufacturing Processes*, vol. 29, no. 7, pp. 853–863, 2014, doi: 10.1080/10426914.2014.880472.

[18] O. O. Joseph, J. O. Dirisu, J. Atiba, S. Ante, and J. A. Ajayi, “Mechanical, and corrosive properties of AA7075 aluminium reinforced with rice husk ash particulates,” *Materials Research Express*, vol. 10, no. 11, p. 116520, 2023, doi: 10.1088/2053-1591/ad0dd3.

[19] R. Siswanto, R. Subagyo, M. Tamjidillah, M. Mahmud, and M. S. I. Setiawan, “Identifying the influence of pouring temperature, Al-RHA composition, and pattern thickness on the properties of Al-RHA composites produced by evaporative casting,” *Eastern-European Journal of Enterprise Technologies*, vol. 5, no. 12 (131), pp. 39–49, 2024, doi: 10.15587/1729-4061.2024.310274.

[20] S. D. Saravanan and M. S. Kumar, “Effect of Mechanical Properties on Rice Husk Ash Reinforced Aluminum Alloy (AlSi10Mg) Matrix Composites,” *Procedia Engineering*, vol. 64, pp. 1505–1513, 2013, doi: 10.1016/j.proeng.2013.09.232.

[21] Suyitno and Sutiyoko, “Effect of Pouring Temperature and Casting Thickness on Fluidity, Porosity and Surface Roughness in Lost Foam Casting of Gray Cast Iron,” *Procedia Engineering*, vol. 50, pp. 88–94, 2012, doi: 10.1016/j.proeng.2012.10.011.

[22] T. Sarıyer and Ç. Kaya, “Agricultural wastes in climate change mitigation,” *JOURNAL OF GLOBAL CLIMATE CHANGE*, vol. 1, no. 1, pp. 15–20, 2022, doi: 10.56768/jytp.1.1.03.

[23] M. S. Ahmed, M. S. Anwar, M. S. Islam, and M. Arifuzzaman, “Experimental study on the effects of three alloying elements on the mechanical, corrosion and microstructural properties of aluminum alloys,” *Results in Materials*, vol. 20, p. 100485, 2023, doi: 10.1016/j.rinma.2023.100485.

[24] E. O. Oyedeji, M. Dauda, S. A. Yaro, M. Abdulwahab, and A. Nathaniel Oyedeji, “Analysis of Al–Mg–Si alloy reinforced with optimal palm kernel shell ash particle and its impact on dynamic properties for sounding rocket application,” *Functional Composites and Structures*, vol. 5, no. 4, p. 45001, 2023, doi: 10.1088/2631-6331/acd48f.

[25] R. Yadav, A. Islam, and V. Kumar Dwivedi, “Wear and microstructure analysis of aluminium based composite using eggshell and rice husk ash as reinforcement,” *World Journal of Engineering*, vol. 21, no. 1, pp. 186–193, 2022, doi: 10.1108/wje-05-2022-0186.

[26] Z. Seikh, M. Sekh, G. Kibria, R. Haque, and S. Haidar, “Density, Hardness, and Wear Responses of Rice Husk Ash Reinforced Aluminium Composites,” *Materials Science Forum*, vol. 1074, pp. 67–78, 2022, doi: 10.4028/p-78710r.

[27] T. Hasan, M. A. Wadud, M. H. Niaz, M. K. Uddin, and M. S. Islam, “Fabrication and Characterization of Rice Husk Ash Reinforced Aluminium Matrix Composite,” *Malaysian Journal on Composites Science and Manufacturing*, vol. 14, no. 1, pp. 34–43, 2024, doi: 10.37934/mjcsm.14.1.3443.

[28] A. Seshappa, K. Prudhvi Raj, B. Subbaratnam, U. Pranavi, N. srihithagunapriya, and S. Chhabra, “Investigations of Al-Manufacturing while 7075/RHA/Al_2O_3 Composite by Squeeze Casting Approach",” *MATEC Web of Conferences*, vol. 392, p. 1027, 2024, doi: 10.1051/matecconf/202439201027.

[29] A. H. Mohamed Ariff, O. Jun Lin, D.-W. Jung, S. Mohd Tahir, and M. H. Sulaiman, “Rice Husk Ash as Pore Former and Reinforcement on the Porosity, Microstructure, and Tensile Strength of Aluminum MMC Fabricated via the Powder Metallurgy Method,” *Crystals*, vol. 12, no. 8, p. 1100, 2022, doi: 10.3390/cryst12081100.

[30] S. Essa Salih, B. Hashim, and H. Mahmood Al-tamimi, “The Mechanical and Thermal Properties of Polymer Hybrid Composite Reinforced by Rice Husk Ash at Different Conditions,” *Engineering and Technology Journal*, vol. 32, no. 9, pp. 2119–2133, 2014, doi: 10.30684/etj.32.9a2.

[31] A. Cañadilla, A. Romero, and G. P. Rodríguez, “Sustainable Production of Powder Metallurgy Aluminum Foams Sintered by Concentrated Solar Energy,” *Metals*, vol. 11, no. 10, p. 1544, 2021, doi: 10.3390/met11101544.

[32] W. Qudong *et al.*, “Study on the fluidity of AZ91+xRE magnesium alloy,” *Materials Science and Engineering: A*, vol. 271, no. 1–2, pp. 109–115, 1999, doi: 10.1016/s0921-5093(99)00185-9.

[33] S. Kumar, P. Kumar, and H. S. Shan, “Effect of evaporative pattern casting process parameters on the surface roughness of Al–7% Si alloy castings,” *Journal of Materials Processing Technology*, vol. 182, no. 1–3, pp. 615–623, 2007, doi: 10.1016/j.jmatprotec.2006.09.005.

[34] M. Divandari, V. Jamali, and S. G. Shabestari, “Effect of strips size and coating thickness on fluidity of A356 aluminium alloy in lost foam casting process,” *International Journal of Cast Metals Research*, vol. 23, no. 1, pp. 23–29, 2010, doi: 10.1179/174313309x449291.

[35] A. Y. Awad, M. N. Ibrahim, and M. K. Hussein, “Effects of Rice Husk Ash–Magnesium Oxide Addition on Wear Behavior of Aluminum Alloy Matrix Hybrid Composites,” *Tikrit Journal of Engineering Sciences*, vol. 25, no. 4, pp. 16–23, 2018, doi: 10.25130/tjes.25.4.04.

[36] R. Siswanto, Ma’ruf, A. M. Mukti, and R. Subagyo, “The effect of pure temperature and pressure on alloy hardness of Al-6.7% Cu using squeeze casting method,” *IOP Conference Series: Materials Science and Engineering*, vol. 1034, no. 1, p. 12173, 2021, doi: 10.1088/1757-899x/1034/1/012173.

[37] C. H. Fan, Z. H. Chen, W. Q. He, J. H. Chen, and D. Chen, “Effects of the casting temperature on microstructure and mechanical properties of the squeeze-cast Al–Zn–Mg–Cu alloy,” *Journal of Alloys and Compounds*, vol. 504, no. 2, pp. L42–L45, 2010, doi: 10.1016/j.jallcom.2010.06.012.

[38] J. W. Wang, J. X. Zhou, S. Q. Tang, F. M. Chu, and Y. S. Yang, “Effects of Casting Temperature on as Cast Microstructure and Tensile Properties of AS31-Sr Alloy,” *Advanced Materials Research*, vol. 915–916, pp. 583–587, 2014, doi: 10.4028/www.scientific.net/amr.915-916.583.

[39] F. Gillani, M. Z. Khan, and O. R. Shah, “Sensitivity Analysis of Reinforced Aluminum Based Metal Matrix Composites,” *Materials (Basel, Switzerland)*, vol. 15, no. 12, p. 4225, Jun. 2022, doi: 10.3390/ma15124225.