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Assessment of eggshell and $CaCO_3$ reinforced recycled aluminium green metal matrix

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ABSTRACT

Purpose: In this study, an environmentally friendly metal matrix was prepared, and the influence of eggshell powder and $CaCO_3$ particles on the tensile strength and hardness of recycled aluminium were assessed.

Design/methodology/approach: A matrix made of recycled aluminium was employed. Calcium carbonate and eggshells served as the study's reinforcing materials. Separately, weight percentages of 2, 4, and 8% of eggshell and calcium carbonate were used. The samples were made by sand-casting.

Findings: The results showed that both eggshell and calcium carbonate positively affect the hardness, yield, and ultimate tensile strength of recycled aluminium. The hardness values were improved as the percentage of the eggshell increased. The maximum hardness was achieved at 2% calcium carbonate. Similarly, the highest improvement of yield strength was for 2% $CaCO_3$ addition, while the highest tensile strength was obtained at 8% eggshell addition.

Research limitations/implications: To get better results, it would be desirable to use finer eggshells than those utilized in this study.

Practical implications: Composites made with an aluminium matrix exhibit exceptional mechanical and physical characteristics. The most challenging obstacle to overcome is the cost of metal matrix composites. Eggshells are a by-product that could be employed as a lightweight, affordable form of reinforcement. One way to get rid of this by-product, improve composite characteristics, and lower the cost of aluminium composite is to use eggshells.

Originality/value: A comparative investigation was carried out to determine the effects of adding agricultural by-product eggshell, and commercial $CaCO_3$ reinforcement material on the characteristics of recycled aluminium matrix integrated 425 μm sized eggshell and $CaCO_3$ separately as a reinforcement material to create a metal matrix that is beneficial to the environment.

Keywords: Green aluminium composites, Reinforcement of recycled aluminium, Aluminium-eggshells composite, Lightweight composite, Al-$CaCO_3$ composite

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PROPERTIES

1. Introduction

Recently, industries have demanded the use of lightweight materials. The lightweight material is essential since industries have physical restrictions that are frequently impossible to overcome easily. Additives are one of the technologies that could help with the issue of producing stronger yet lighter materials. Composites with a metal matrix are metals that have additional materials added to them for reinforcement. Reinforcements are commonly used to improve the base metal's characteristics, such as hardness, tensile, fatigue strength, etc. Composites with metal matrix, which have a lot of applications in the automotive and manufacturing industries, are attracting increased attention from researchers. As a base metal in metal matrix composites, aluminium and its alloys have gotten much attention because of their high specific strength [1,2]. The cost of the composite, which is determined by the reinforcing and matrix materials, is the most challenging aspect of metal matrix composites. As a result, the demand for low-cost reinforcements has increased [3]. For this reason, research on low-cost, lightweight composites is at the forefront [4].

Chicken eggshell is an agricultural by-product containing mainly 94% $CaCO_3$ and 6% other materials. It is mainly disposed of in landfills, which severely influences the environment. According to previous studies, the eggshell might be used as a cheap, lightweight filler [5,6].

Chaithanyasai et al., 2014 [3], integrated 106 µm sized eggshells into an aluminium matrix using powder metallurgy. They examined the dispersion of the eggshell in the aluminium matrix by scanning electron microscope (SEM) in addition to other physical and mechanical properties. They found that the incorporation of eggshells improved the hardness after adding eggshells by up to 14% by weight. Moreover, the integration of eggshells decreased the density of the resulting composite. Dwivedi et al., 2016 [7], studied the development of AA2014 alloy with carbonized eggshell composite. They investigated the optimum parameters to prepare the composite and assessed the mechanical properties of the resulting composite. Their results suggested that electromagnetic stir casting was a good composite fabricating method. Additionally, their results revealed that there was a good bond between aluminium and eggshell. Moreover, the hardness, tensile and fatigue strength were enhanced as a result of the addition of a 5% carbonized eggshell with lower density.

Agunsoye et al., 2016 [8], developed an aluminium ceramic composite by integrating 2-12% of $CaCO_3$ of sizes 100 and 150 µm into an aluminium matrix. They evaluated the microstructure and mechanical properties of the resulting composite. Their results revealed that samples with eggshells of size 100 µm performed better than the samples with $CaCO_3$ sized 150 µm.

Dwivedi et al., 2017 [9], assessed the physical and mechanical characteristics of Al-eggshells, Al- $CaCO_3$, and Al-SiC metal composite. In comparison to eggshell particles, results found that adding SiC reinforcement particles to Al alloy increased hardness and heat-treatable characteristics. Although, after adding SiC particles to the Al alloy, porosity and overall cost rose. When compared to SiC particles, using carbonized eggshells as reinforcing in the Al matrix produced enhanced physical features at a lower cost, according to their findings.

Sharma and Dwivedi, 2017 [10], evaluated an aluminium metal matrix composite composed of aluminium-eggshell-silicon carbide (SiC) by studying microstructural, physical, and mechanical properties. Their results showed improvement in specific strength reduction in porosity for the Al-2.5% SiC-7.5% carbonized eggshell sample. Murugana et al., 2018 [11], prepared metal composite with and without eggshell using stir casting. The combination of Al and eggshell particles improved overall mechanical properties compared to Al 6061 alloy. The results indicated that the integration of eggshell enhanced the mechanical properties, namely hardness and tensile strength.

Sakthi Balan et al., 2020 [2], evaluated the tensile strength and the corrosion resistance of Al7075- glass fibre and eggshell composite, prepared by stir casting. The presence of eggshell enhanced the corrosion resistance of the composite as it acted as a corrosion inhibitor. Moreover, the tensile strength improved due to the presence of glass fibre.

W.T. Rashid and K. Rashid, 2021 [12], established a comparative study to determine how eggshell size and addition percentage affected the aluminium matrix's hardness. They integrated 0-12% of eggshell with different sizes ranging from 100 to 679 µm. Their results revealed that increasing the weight percentage accompanied by finer powder improved the hardness values. The maximum hardness value was achieved at the 12% weight percentage of the eggshell with 100 µm.

This study used eggshell powder and $CaCO_3$ to reinforce the recycled aluminium matrix. This research aims to examine and compare the consequences of eggshell powder and $CaCO_3$ particles on the microstructures, tensile strength, and hardness of recycled aluminium.

2. Materials and methods

Recycled aluminium was used as a matrix obtained from a kitchen cabinet factory. The reinforcement materials used in this study were eggshells and calcium carbonate. Eggshell was collected from household trash, while calcium carbonate was obtained from the local market.

Eggshells were rinsed in water to eliminate any undesired material before being dried in the sun. Using a mixer grinder, the dry eggshells were crushed. The powder was then sieved for 15 minutes and passed through the No. 40 mesh. The No. 40 mesh in the U.S. Standard mesh size is a 425 µm sieve opening.

The composite prepared in this investigation was made of recycled aluminium as a matrix reinforced by eggshells and $CaCO_3$ independently with different reinforcement materials weight ratios of 2, 4, and 8%. The sample's designation and content are illustrated in Table 1.

Table 1.
Samples designation

Aluminium without addition
Aluminium with adding (2%) of eggshell
Aluminium with adding (4%) of eggshell
Aluminium with adding (8%) of eggshell
Aluminium with adding (2%) of $CaCO_3$
Aluminium with adding (4%) of $CaCO_3$
Aluminium with adding (8%) of $CaCO_3$

Fig. 1. Casting process

Depending on the reinforcement utilized, several production techniques are used when using a matrix of aluminium to produce products with a variety of intended functions [13]. In this study, the samples were made using the sand-casting method. Recycled aluminium cans were melted in a crucible furnace at about 690°C ±5°C and cast into bars, Figure 1. The reinforcement materials were added with different percentages of 2, 4, and 8% by weight, which were mixed manually. For mechanical characteristics testing, the cast bars were formed into specified sizes. The chemical composition of recycled aluminium and aluminium composite samples was examined by the ministry of industry and minerals, engineering inspection and lab department.

Rockwell hardness tests were used to evaluate the effect of adding eggshells and calcium carbonate to recycled aluminium. The specimen was cut into the required size, as shown in Figure 2. The specimen was initially loaded with a small force of 10 kg.f in the Rockwell hardness test. Then a major load was applied.

Fig. 2. Hardness test specimens

For the tensile test, which was done according to ASTM B557-15 [14] the specimens were machined into the required shape and size to assess the tensile strength, Figure 3. After that, the ends of the specimens were clamped into a 600 KN tensile testing machine (Instron). The specimens were pulled through their axis until failure occurred.

Fig. 3. Tensile test specimens

3. Results and discussion

3.1. Chemical composition test

The element content in the recycled aluminium, Al-eggshell, and Al-$CaCO_3$ samples were listed in Table 2.

Table 2.
Chemical composition results

	Recycled Al without addition	Al with 4% $CaCO_3$	Al with 4% eggshell
Si%	0.581	0.364	0.317
Fe%	0.791	0.676	0.619
Cu%	0.0664	0.0260	0.0229
Mn%	0.0325	0.0222	0.0238
Mg%	0.977	0.263	0.218
Cr%	0.0759	0.0154	0.0187
Ni%	0.0622	0.0093	0.0053
Zn%	0.210	0.0602	0.0512
Ti%	0.0886	0.0177	0.0209
V%	0.0356	0.0134	0.0146
Pb%	0.12	0.0332	0.0065
Al%	Bal.	Bal.	Bal.

As listed in Table 2, the main alloying elements were Mg, Fe, and Si, which were about 0.9, 0.79, and 0.581, respectively, for the recycled aluminium. Their weight percentages were 0.26, 0.67, and 0.36 for the alloy containing $CaCO_3$. While their percentages were 0.218, 0.67, and 0.317 for the aluminium alloy containing eggshells.

3.2. Mechanical properties

The Rockwell hardness values increase as the percentage of eggshells increases, as seen in Figure 4. The hardness increases from 29.5 HR to 40.47 HR for 8% eggshell addition. The improvement ranged between 6% and 14% according to the amount of eggshell used (2% or 4%). Additionally, both a 4 and an 8% addition of calcium carbonate increases the hardness of recycled aluminium to about 19.9%. However, the addition of 2% calcium carbonate resulted in the highest hardness value, which was 49.9 HR, as opposed to 29.5 HR for the control sample. These results agree with Agunsoye et al., 2016 [8]. Their results revealed that adding eggshells improved the hardness, and the highest hardness achieved by Agunsoye et al., 2016 [8], was at 12% of eggshell addition with 100 µm size.

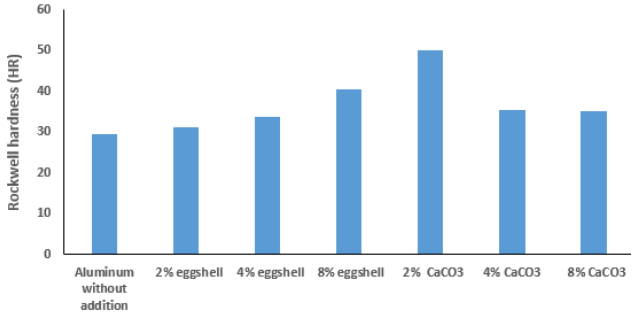

Fig. 4. Rockwell hardness

The ultimate tensile strength and yield strength are shown in Figure 5. The addition of eggshell and calcium carbonate enhanced the tensile and yield strength. The highest tensile strength was obtained at 2% eggshell addition with 132.8 N/mm^2 compared with 89.4 N/mm^2 for the recycled aluminium without addition. Tensile strength increased by 20.5% and 39.6% for the 4 and 8% eggshell addition. While the improvement percentages for the addition of 2% and 4% $CaCO_3$ were 17% and 21.7%, respectively. Tensile strength drops to almost the same level as the control sample upon the addition of 8% $CaCO_3$. These findings agree with Murugana et al., 2018 [11]. Similarly, the yield strength improved after the addition of eggshell and calcium carbonate with different percentages. The highest improvement was for 2% $CaCO_3$ addition which was 97 N/mm^2 as compared with 50 N/mm^2 for the control sample. While the yield strength was 68.9 after the addition of 8% of $CaCO_3$. The results of the mechanical properties agree with Agunsoye et al., 2016 [8]. The existence of refractory phase particles formed by calcium inside the aluminium alloy matrix further contributes to the Al composites' increased tensile strength and hardness. Finer grains have more grain boundaries, making dislocations more difficult to move [15]. It is expected that better hardness, yield and ultimate tensile strength values would be achieved when using finer eggshell powder and calcium carbonate [8,12].

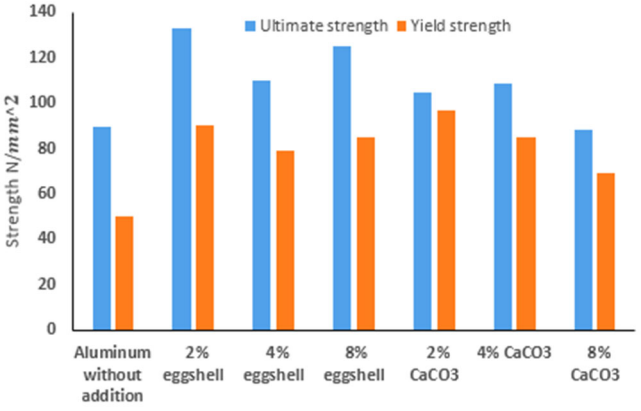

Fig. 5. Ultimate tensile strength and yield strength

4. Conclusions

The experiments in this study were performed to evaluate the mechanical properties of recycled aluminium matrix integrated 425 µm sized eggshell and commercial $CaCO_3$ independently as a reinforcement material. The findings of the study lead to the following conclusions:

- The Rockwell hardness values rise as the proportion of eggshells rises, reaching a maximum of 37% for the

addition of 8% eggshells. The highest hardness value was obtained, nevertheless, when 2% calcium carbonate was added.

- Both eggshell and calcium carbonate contribute to the improvement of the recycled aluminium's ultimate tensile and yield strength. At 2% eggshell addition, the maximum tensile strength was attained. Similarly, the yield strength improves when varying eggshell and calcium carbonate percentages are added. 2% of $CaCO_3$ showed the greatest improvement in yield strength. Compared to previous research, it would be better to use finer eggshells than the size used in this study to get better results.

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