J. Inst. Eng. India Ser. D (July–December 2021) 102(2):317–330
https://doi.org/10.1007/s40033-021-00292-z

ORIGINAL CONTRIBUTION

Development of Aluminium Based Composite by Utilizing Industrial Waste and Agro-Waste Material as Reinforcement Particles

Anas Islam[1] · Shashi Prakash Dwivedi[2] · Rajat Yadav[1] · Vijay Kumar Dwivedi[1]

Received: 9 June 2021 / Accepted: 12 September 2021 / Published online: 25 September 2021

Abstract The inclusion of agricultural wastes in aluminium-based metal matrix composites (AMMC) is gaining popularity because this will strengthen particulate matter present in AMMC, improving the composite materials' structural characteristics. Furthermore, by putting such agro-industrial residues to good use, not just save money on manufacture, but also lessen the environmental pollution. The synthesizing techniques of industrial and agro-industrial wastes loaded AMMC, as well as their mechanical, corrosion, and physical characteristics, are described in this article. This research discusses the possibilities for innovative filler particles that are low-cost, easy to access and have physical and mechanical characteristics compared to traditional particles. The mechanical, physical, thermal, and corrosion characteristics of the composites improved as an outcome of such enhancements.

Keywords Aluminium · Composite · Waste · Eggshell, Rice husk ash

Introduction

The need for composites (hybrid materials)/green composites is rapidly increasing. One of the main reasons for this is that such composites have good mechanical and chemical characteristics. The inclusion of reinforcing agents/materials to the primary or base material significantly improves its properties. Another motive for switching from traditional to hybrid materials is to reduce pollution by recycling the trash from various sources and using it as reinforcements. Low-density, low-cost materials with strong mechanical characteristics have a wide range of applications in the marine, aircraft, and automobile industries, hence their development is very critical. Scientists were driven to develop hybrid materials by reusing industrial wastes due to a lack of raw resources and an increase in dangerous pollutants in the atmosphere. The industries producing these particles emit a huge amount of greenhouse gases such as N_2O_3, CH_4 and CO_2 [1]. These types of waste usage have grown in popularity in recent years, and this form of beneficial utilization is known as green manufacturing. Nowadays, instead of employing traditional raw materials, researchers and experts all over the world are focused on the development of such green manufacturing methods. Green manufacturing is defined as the use of waste materials to reduce detrimental impacts and create hybrid and innovative materials or products that do not affect the environment. Aluminium is used in a variety of sectors, including cans, foils, cooking utensils, window frames, beer kegs, automobiles, and aeroplane parts, due to its lightweight and high mechanical qualities. Because of the changing (improved) characteristics of Al after the inclusion of reinforcements, aluminium-based metal matrix composites (AMC) are also in high demand. The use of reinforcements sets the basic material (Al) different from other higher-order (expensive) metals in terms of characteristics. Heat sinks, microwaves, microchips, CPUs, aircraft wings, and other components made of AMC are in high demand in the electronics industry [1–4]. To build AMCs, most prior studies have employed

✉ Shashi Prakash Dwivedi
spdglb@gmail.com

1 Department of Mechanical Engineering, IET GLA University, Mathura 281406, India

2 G. L. Bajaj Institute of Technology & Management, Greater Noida, Gautam Buddha Nagar, Uttar Pradesh 201310, India

Table 1 The experimental values of reinforcements

S. No	Reinforcing agent	Experimental density (g/cm^3)	References
1	Silicon carbide (SiC)	~ 3.21	[5]
2	Aluminium oxide (Al_2O_3)	~ 3.98	[6]
3	Silicon nitride (Si_3N_4)	~ 3.17	[7]
4	Titanium carbide (TiC)	~ 4.93	[8]
5	Eggshell ash (ESA)	~ 2.50	[9, 10]
6	Rice husk ash (RHA)	~ 0.231	[11]

Table 2 Utilization of waste material as reinforcement in the development of composite material

Ref. No	Authors	Year	Reinforcing agent used	Developed materials	Conclusions
[17]	Hiremath et al.	2018	Eggshell	Glass fibre reinforced plastic	The various weight percentage of reinforcement has been used to enhance the mechanical properties
[18]	Bose et al.	2019	Carbonized eggshell, SiC, Cow dung ash, B4C, snail shell ash	Al-matrix composite	7.5 and 10 weight percentage was used to prepare the composite. Enhance the tribomechanical properties
[19]	Kumar et al.	2020	Eggshell	AA7075 metal matrix composite	To improve the mechanical properties of the friction stir process and study process parameters that affect the composite
[20]	Islam et al.	2020	SiC/Eggshell	Al-based composite	Optimize FSP parameters of the Al6061 composite was done on the composite by Box Behnken Design
[21]	Jannet et al.	2021	eggshell	AA2024 composite	FESEM analysis has been used for the distribution of reinforcement particles in the composite. XRD, micrographs, mechanical properties were investigated
[22]	Li et al.	2016	Eggshell	L-lactide composite	Analyze the physical properties
[23]	Heidarzadeh et al.	2021	Eggshell	Al-metal matrix composite	Enhance the mechanical properties of composite and SEM was investigated to the distribution of reinforcement particles in the composite
[24]	Cree and Rutter	2015	Eggshell	Limestone	Application of bio-inspired limestone derived ES
[25]	Mistry et al	2019	ES/Si3N4	Al-based composite	To analyze the mechanical properties and tribo-behaviour of composite. XRD and EDX were also investigated
[26]	Moona et al.	2020	ES/SiC/Al_2O_3	Al7075-T6 composite	To prepared the wear-resistant composite by using different wt.% of the reinforcement
[27]	Saravanan et al.	2014	RHA	A356.2 Composite	Enhance the mechanical properties at various weight percentages of reinforcement
[28]	Usman et al.	2014	Bagasse ash/RHA	Al-based Composite	AA Composite was prepared at 7 wt.% Si-RHA/Baggasse ash through the stir casting method. Analyzed the mechanical properties
[29]	Alaneme et al.	2014	RHA/SiC	Al-based composite	The weight ratio of reinforcement (1:3) was used in this composite. Analyze the corrosion and wear behaviour of composite
[30]	Vinod et al.	2018	RHA/Fly ash	A356	Effect of organic and inorganic reinforcement on the mechanical properties. Tribological properties were also analyzed
[31]	Verma and Vettivel	2018	RHA/B4C	AA7075 hybrid metal matrix composite	Composite was kept high tensile strength and hardness at 5 wt.% for both reinforcements
[32]	Hossain et al.	2017	RHA	Al-based composite	The optimum percentage of RHA was used in this composite. simulated the composite by finite element method

Table 2 continued

Ref. No	Authors	Year	Reinforcing agent used	Developed materials	Conclusions
[33]	Shoba et al.	2015	RHA/SiC	Al-based composite	Optimize the machining parameter for minimum surface roughness. ANOVA was used to define the results
[34]	Prasad and Shoba	2016	RHA/SiC	Al-based composite	To analysis the damping behaviour by the dynamic mechanical analyzer (DMA) at various wt.%
[35]	Dinaharan et al.	2017	RHA	AA6061 composite	scanning electron microscopy (SEM) and electron back-scattered diagram (EBSD) was used homogeneous dispersion of RHA. Analyzed the tensile property during FSP
[36]	Arora and Sharma	2018	RHA/SiC	AA6351 mono-composites	AA6351 mono-composite was prepared with (2 wt.% and 8 wt.%) of both reinforcements. Analysis mechanical properties
[37]	Anwer et al.	2016	PLA carbon nano fibre	Al-composite	The damping behaviour of the composite was measured at various wt.% of reinforcement. Morphological and mechanical properties were also analyzed
[38]	Yadav et al.	2021	Eggshell/RHA	AA3105 composite	Composite was prepared through the stir casting process. Enhance the mechanical properties such as tensile strength and hardness
[39]	Labella et al.	2014	Fly ash	Vinyl ester composite	Mechanical properties of polymer composite were also analyzed. Energy absorption under compression increased with strain rate for fly ash composite
[40]	Zare et al.	2019	SiC	Al7075	Improving thermal properties at various weight percentages. Physical properties were also analyzed
[41]	Niu et al.	2021	Inorganic particle (Si_3N_4,AlN,Al_2O_3,Cu_2O)	PEEK composites	Analyzed the mechanical and thermal properties of PEEK Composite by Modified phosphate
[42]	Cheng et al.	2009	Chicken feather fibre	PLA green composite	Analysis of the mechanical and thermal properties by SEM images
[43]	Murthy et al.	2017	Fly ash/TiO_2	AA7075 composite	Mechanical properties and thermal conductivity were obtained by hot forging. Thermal conductivity was slightly decreased of the composite
[44]	Almomani et al	2020	ES/Graphite	Al-based composite	Graphite was kept the self-lubricating properties. Tin and Mg were used to improve the density. Microhardness, wear and mechanical properties were measured of the composite
[45]	Kumar et al.	2020	ES/Alumina	Al-based composite	Composite was prepared very fine particle. Mechanical properties of the composite were investigated after heat treatment
[46]	Bahrami et al.	2017	RHA/SiC	Al-based composite	Monolayer and Bilayer of Al/SiC/RHA Composite have analyzed the mechanical, thermal and electrical behaviour

Table 3 Composition of AA3105 alloy (wt.%)

Element	Cu	Fe	Si	Cr	Ni	Ti	Zn	Mg	Mn
Wt.%	3.9–5	0.5	0.5–0.9	0.1	0.1	0.2	0.25	0.2–0.8	0.4–1.2

traditional reinforcing agents such as SiC, Al_2O_3, Si_3N_4, and TiC. The downside of utilizing such reinforcements is that they are extremely expensive and have densities greater than Al, thus they are not suitable for developing a low-density composite. Table 1 shows the experimental values of reinforcing agent density. Agro waste items containing carbides and ceramic oxides, such as eggshell ash (ESA), groundnut shell (GSA), and rice husk ash (RHA), are sufficient to improve the mechanical and physical qualities of the base material.

They also have low densities, hence they might be used to make metal matrix composites (MMCs) with low densities. The second obvious benefit of using such wastes is that pollution might be reduced, as these types of agricultural products emit a lot of hazardous pollutants. Because it is estimated that by 2030, roughly 70% of individuals will

Table 4 Mechanical properties of AA3105 alloy [39]

S. No	Properties	Value
1	Tensile Strength (MPa)	144.95
2	Toughness (Joule)	12
3	Hardness (BHN)	35
4	Melting Point (°C)	650
5	Ductility (%)	15
6	Density (g/cm^3)	2.8

be suffering from a lung-related ailment, pollution control will be critical [5–8]. The two principal pollution-causing agents are ESA and RHA, and the best approach to solve the problem is to put the waste to constructive use. If utilized as reinforcements, ESA and RHA could improve the underlying material's mechanical and physical qualities (Al). ESA is a waste product of the food industry, and it must be properly disposed of or it may cause major environmental problems. Because of its chemical composition and accessibility, various researchers have attempted to employ ESA for a variety of purposes. Egg shell's unique features make it a popular bio-filler reinforcing agent,

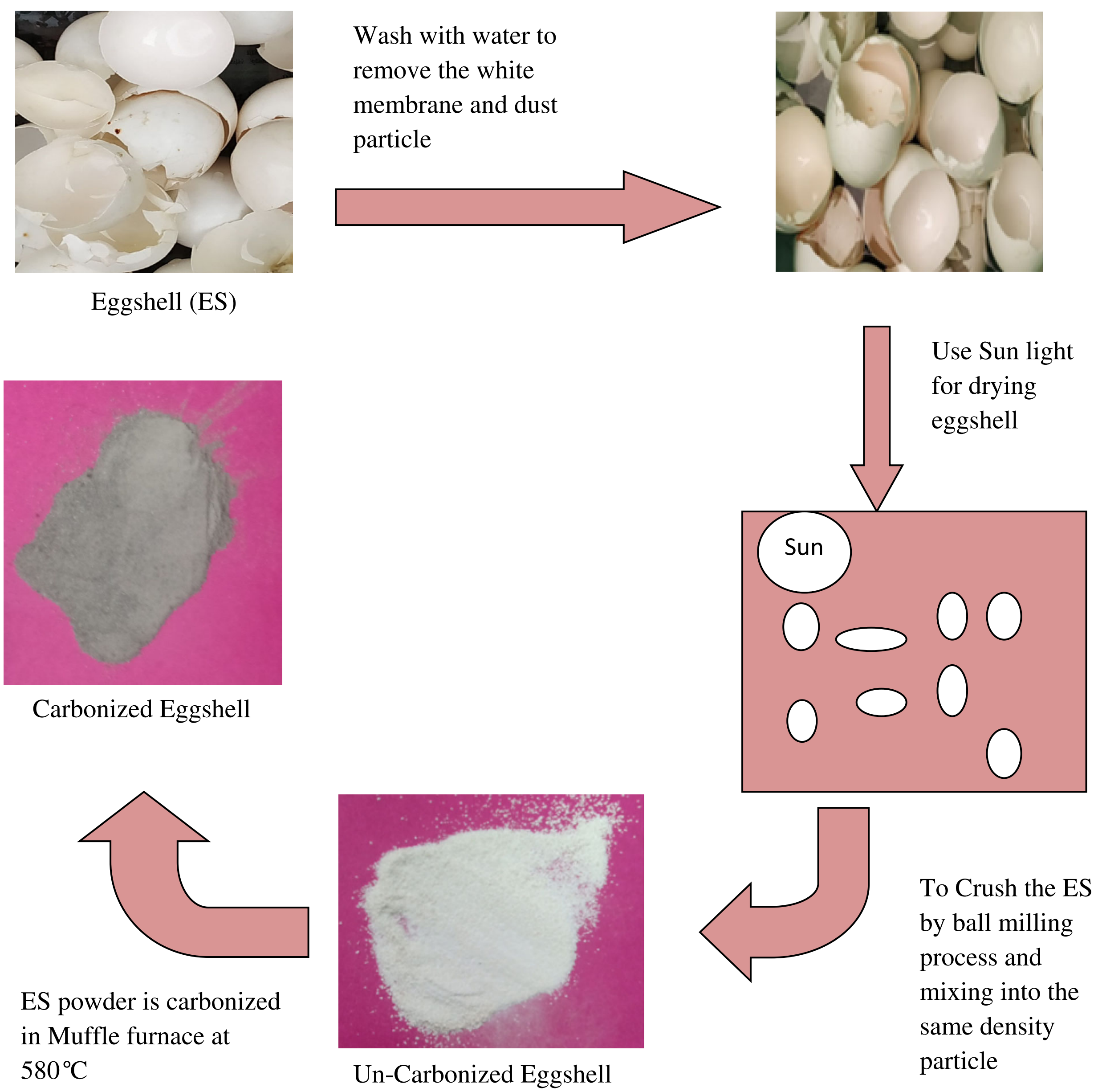

Fig. 1 Formation of carbonized eggshell powder from waste eggshell collected from the food industry

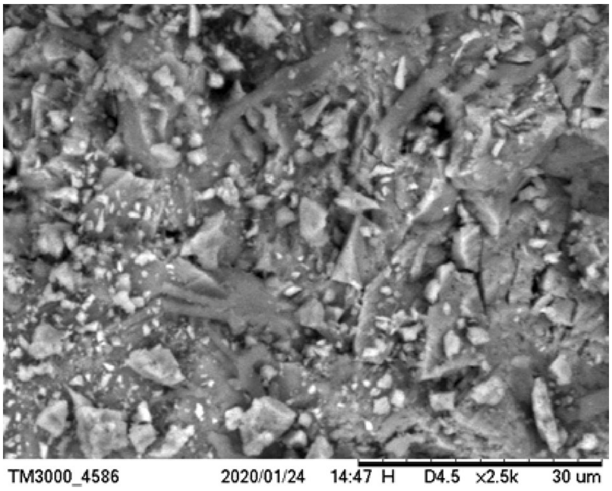

Fig. 2 SEM image of Eggshell powder

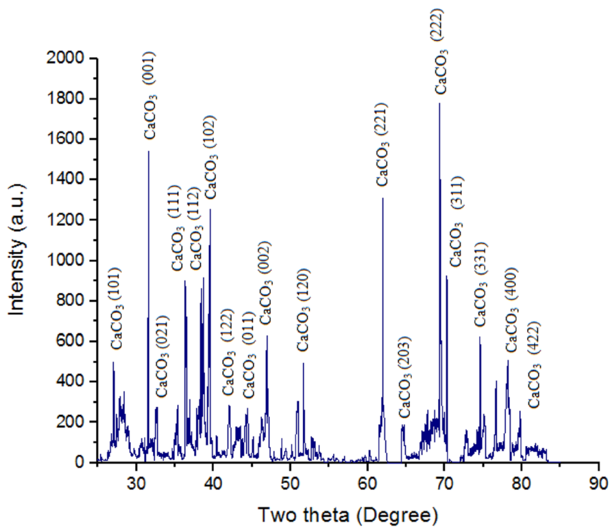

Fig. 3 Powder XRD of Carbonized Eggshell Powder

improving the chemical and mechanical and physical properties of the base material (Al). Another advantage of using Eggshell (ES) to reinforce base material is its bulk availability, lightweight, cost-effectiveness, and environmental friendliness. Aluminium reinforcement with ES and investigation of its modified properties, such as mechanical, chemical, and thermal, is a relatively new field of study. Different casting processes, such as mechanical and electromagnetic stir casting, are used to synthesize such compounds [9, 10]. AMMC has better characteristics relative to the base material because of its even distribution and good contact of reinforcing particles in the metal matrix. Employed various ratios and particle sizes of ES as a bio-filler in propylene-based composites [12–16], claiming that as the value of Young's modulus increases, so does the amount of ES [11]. The use of various reinforcing particles in the production of materials is shown in Table 2.

Materials and Methods

Matrix Material

The matrix phase used in the current study was AA3105 aluminium alloy. As a result of its great mechanical strength, this alloy is used in the fabrication of aircraft structures (fuselages and wings). Since AA3105 can withstand extreme temperatures (melting point ~ 635–654 °C), it is also employed in the production of high-temperature parts such as engines, shafts, brake rotors, and other vehicle parts that require high-strength yet lightweight materials [19]. The elemental composition in wt.% of AA3105, as well as its mechanical properties, is discussed in Tables 3 and 4 respectively.

Eggshell as Primary Reinforcement Material

As primary reinforcing particles, waste eggshell has been used in the fabrication of an aluminium-based composite material. Ceramic particles comprise the majority of ES, with $CaCO_3$ accounting for 94%, $MgCO_3$ for 1%, $Ca_3(PO_4)_2$ for 1%, and miscellaneous organic matter accounting for the remaining 4% [10]. Eggshells were acquired from local supermarkets, washed well, and then sun-dried for around 6 h to eliminate any moisture content as well as the covering ES layer. The powdered form of ES was obtained by ball milling this dry ESs. These powdered ES were then carbonized for up to 4 h at a temperature of approximately 550 °C to remove the carbonaceous particles from the ES powder. Carbonized eggshell particles were reported to have an average particle size of 25 μm. The formation of carbonized eggshell powder from waste eggshell recovered from foodstuff is depicted in Fig. 1. Scanning Electron Microscopy (SEM) images of carbonized ES powder has been shown in Fig. 2. The carbonized eggshell was subjected to X-ray diffraction (XRD) analysis to determine a clear picture of reinforcement, i.e., Eggshell. The resulting XRD pattern of carbonized ES is depicted in detail in Fig. 3. The XRD pattern of ES clearly shows that CaCO3 has the largest proportion, following by Mg.

RHA as Secondary Reinforcement Material

Waste rice husk ash (RHA) was chosen as the secondary reinforcing material for the development of AMMC. Rice husk was obtained from a local rice factory in India, rinsed with water to eliminate dust and other pollutants, and then

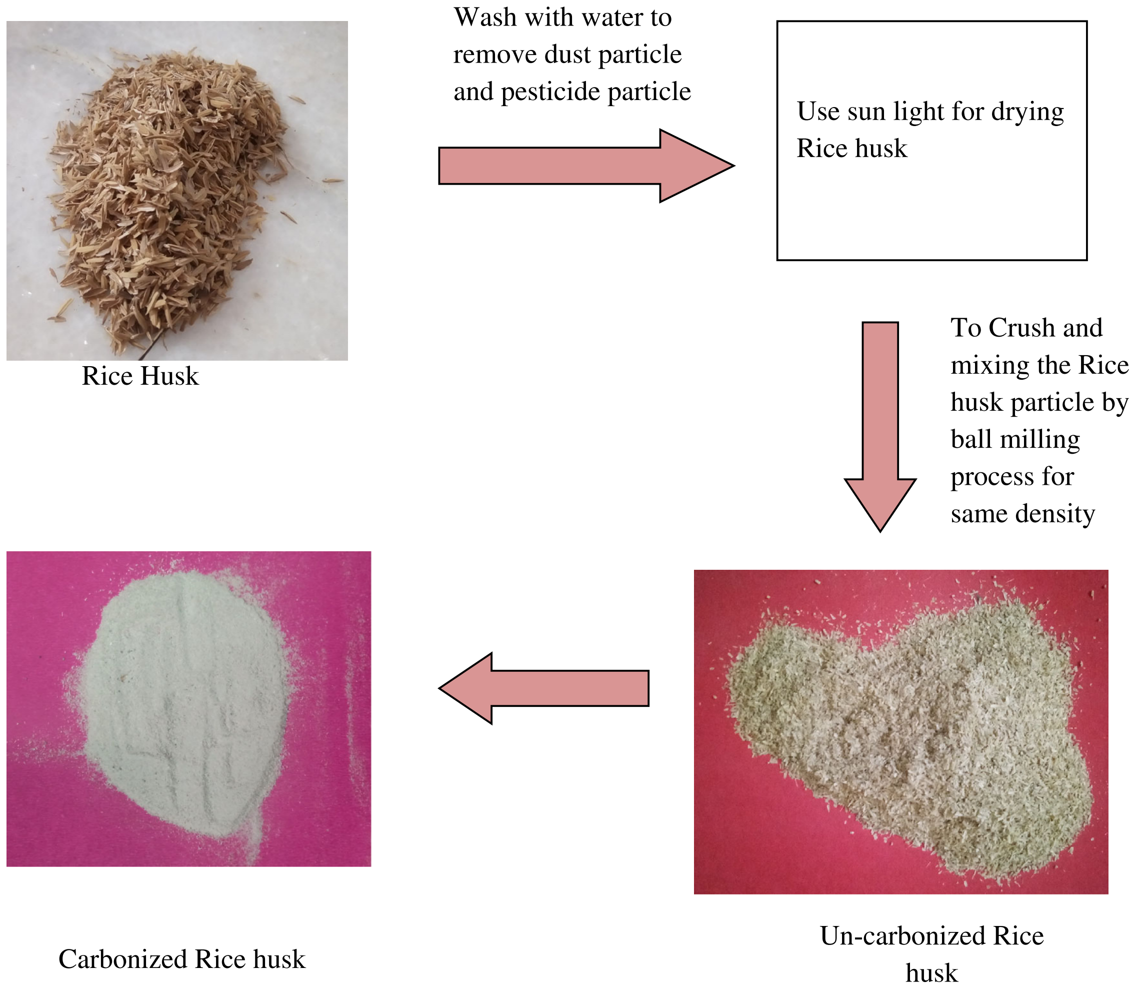

Fig. 4 Formation of RHA from waste rice husk collected from rice industry

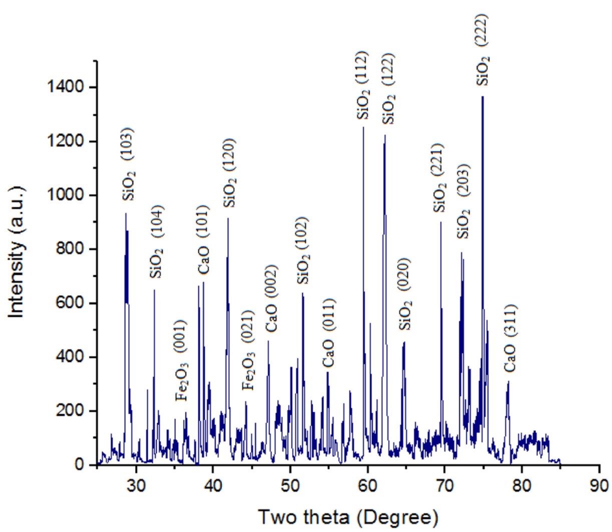

Fig. 5 Powder XRD of RHA powder

air-dried at atmospheric temperature (25 °C) for 24 h. To remove any moisture and organic content, this cleansed RH was heated at 300 °C for 2–3 h. As the organic component began to char, the husk colour went from yellowish to mild black during drying. Then it's heated for roughly 12 h at 700 °C to remove the carbonaceous material's influence. After heating it again, the black tint turned greyish white. Finally, rice husk ash has been generated and is ready to be employed as a metal matrix reinforcing material. Figure 4 depicts the creation of rice husk ash from raw rice husk gathered from a local rice company. Figure 5 shows the XRD of powder rice husk ash; it is clear that SiO_2 is the most abundant ingredient in RHA powder, followed by CaO and Fe_2O_3.

Ball-Milling Process of Reinforcement Particles

Figure 6 depicts the procedure of ball-milling reinforcing particles to create single-entity reinforcements. While the

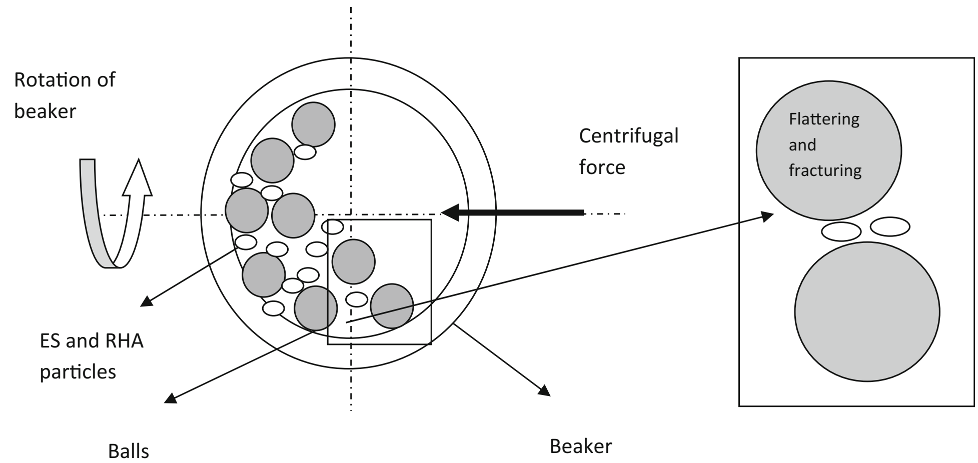

Fig. 6 Line diagram of the ball-milling process

Table 5 Parameters of the different ball- mills used to prepare the AMMC

Parameters	Attritors	Vibratory ball mills	Planetary ball mills	Roller mills
Ball weight powder ratio	< 0.0039	0.006–0.29	0–1.668	0–0.18
Shock frequency (Hz)	> 850	15–250	5.8–120	0–2.7
Ball velocity (m/s)	4.8–5.6	≤ 4.3	0.27–12.25	< 9
Kinetic energy (10^{-3} J/hit)	< 20	180	0.8–870	0–190

stirring process is in progress, building a composite material is a difficult operation due to the disparity in densities of numerous reinforcing. The key issue was adequate reinforcing particle placement in the metal matrix, as some tend to float while others settle into the matrix. Table 5 shows the different parameters of ball mills used to prepare the AMMC. The make and model of the ball-milling machine are RETSCH and Planetary Ball Mill PM 100 respectively. As a result, the problem of mismatched densities might be eliminated by using the ball milling technique. Ball-milling of carbonized eggshell powder and RHA was used in this investigation to create a single entity powder. The ball-milling process has taken up to 75 h to complete.

Development of Composite Material

Figure 7 depicts a line diagram of the stir casting method used to develop composite materials. As a matrix material, AA 3105 was used. Before mixing in the matrix material, carbonized eggshell powder and rice husk ash (RHA) were preheated at 300 °C and 200 °C, respectively. The single entity of ball-milled carbonized eggshell particles and RHA was warmed at 250 °C. In a muffle furnace, AA3105 was melted. As soon as the temperature of metal matrix temperature exceeds 690 °C, reinforcing particles were introduced. Squeeze and pressure were applied to the UTM machine in the mushy phase to remove pores and irregular reinforcing surface structure. Table 6 shows the composition of the produced composite material with reinforcing weight percent. Five composite materials with different compositions (Table 6) were made, and the physical and mechanical behaviour of these samples has been investigated. The developed composite material is shown in Fig. 8.

Materials Testing

A tensile test of the composite material was performed on the computerized universal testing machine. The parameters of a computerized universal testing machine for tensile testing of composite samples are mentioned in Table 7. Hardness testing of the composite samples was carried out on a Vickers hardness testing machine. A corrosion test of the samples was carried out in a salt spray chamber. Technical Specification of salt spray chamber for corrosion test is shown in Table 8. Thermal expansion of the composite material was performed in the muffle furnace. The technical specification of the muffle furnace is shown in Table 9.

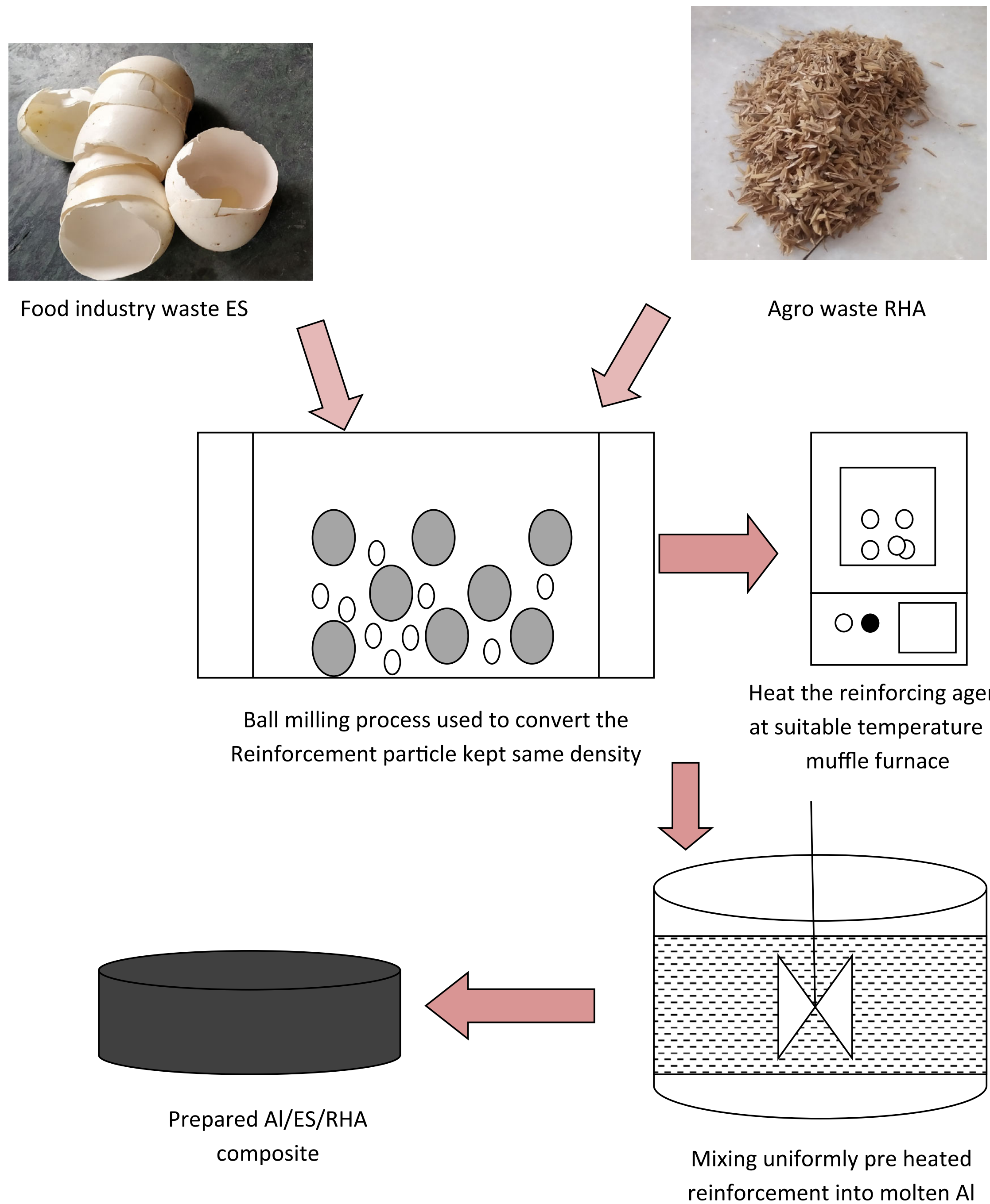

Fig. 7 Process to develop a hybrid composite material

Table 6 Sample number and their compositions

Sample no	ESA	RHA	Al
1	2.5	7.5	Rem
2	3.75	6.25	Rem
3	5	5	Rem
4	6.25	3.75	Rem
5	7.5	2.5	Rem

Results and Discussion

Microstructural Investigation

Figure 9 shows SEM images of an Al3105-based Metal Matrix Composite with various reinforcing weight percents of ES and RHA. The significant intermolecular force between the reinforcing particles and the base/matrix material is seen in this study (Al-3105). The robust

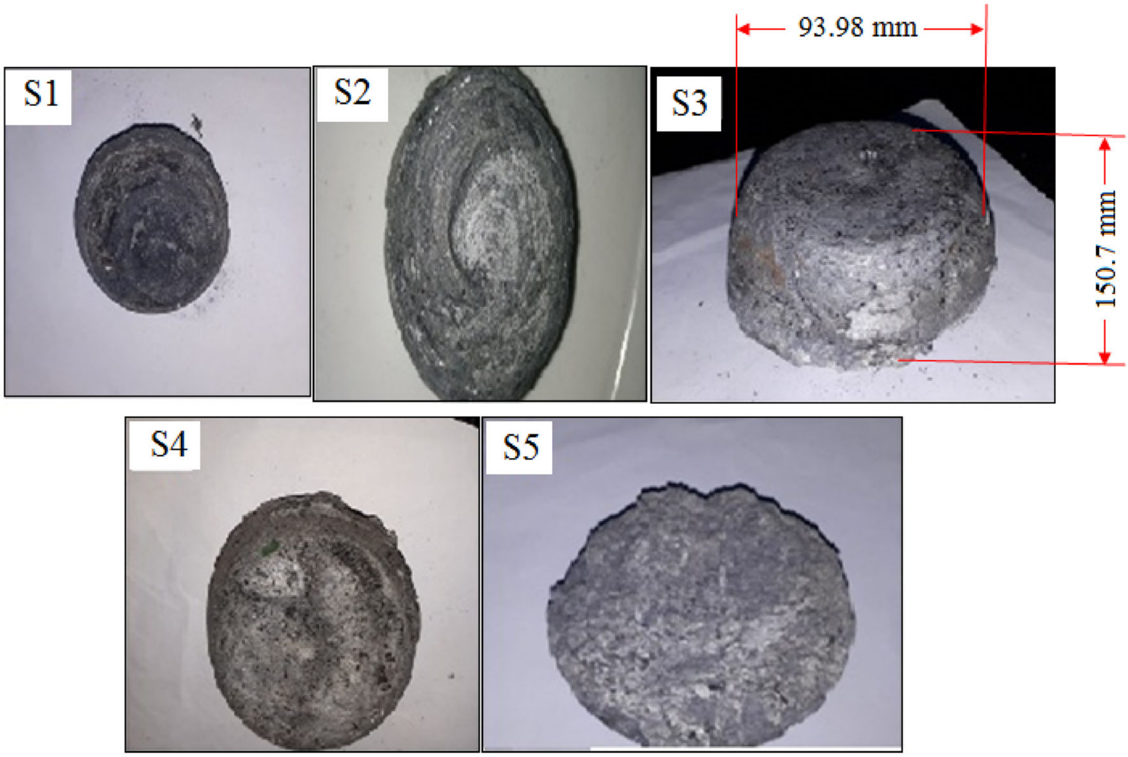

Fig. 8 Developed composite samples (S1–S5)

Table 7 Computerized universal testing machine parameters [39]

S. No	Parameters	Values set as
1	Gauge length	25–50 mm
2	Maximum extension	5 mm
3	Specimen diameter	0.5–30 mm
4	Strain rate	10-4–10-1 s-1

connection between the reinforcement particles and the matrix material indicates that the tensile strength has improved. The presence of a strong intermolecular force or good bonding between the reinforcing agent particles and the matrix alloy is a clear sign of high wettability. Furthermore, the existence of voids and porosity, as well as the claustration of reinforcing particles, indicates that the created hybrid composite would lose ductility at increasing reinforcement weight percentages. In most cases, strengthening indicates that the reinforcement particles and the base metal are well-bonded. In order to achieve the desired (higher) mechanical properties, uniformly dispersed reinforcing particles in the matrix are essential [42]. The homogeneous distribution and dispersion of the reinforcing particles in the metal matrix are greatly improved by the stir casting process [43]. The microstructure analysis demonstrates that the reinforcement particles are dispersed evenly or uniformly inside the matrix, which is consistent with earlier findings [6, 9, 10]. Casting in an electromagnetic field has a significant impact on reinforcing particle distribution and dispersion [44]. The microstructure study indicates that the matrix has a uniform distribution of reinforcement. The findings are in line with those of other researchers [6, 9, 10]. There will be a decrease in ductility as the content (wt.%) of reinforcing particles increases beyond a particular point. The presence of brittle and hard ceramic particles identified in the reinforcement caused the maximum drop in ductility to be 65.7% at 20 wt.% of reinforcement (ESA and RHA reinforcing particles). These images indicate homogeneous dispersion of RHA and ESA particles with little or no cavities or defects, as well as interfacial resolution between metal matrix and reinforcements i.e., ESA and RHA particles.

Mechanical Behaviour of Composite

Figure 10a depicts the relationship between the tensile strength of synthesized composite materials and varied weight percentages of reinforcements i.e., ESA and RHA particles. The tensile strength of the material rose as there is a rise in wt.% of reinforcements. When force, is applied reinforcement particles create barriers to deformations.

Table 8 Technical Specification of salt spray chamber for corrosion test

S. No	Title	Details
1	Make and model	Melix systems & solutions(ASTM b117)
2	Inner and outer material	1.2 mm thick SS 316 or 1.2 mm Thick SS 304
3	Insulations	50 mm insulation with High-density low K factor bonded glass-wool
		Insulation to avoid the heat. On the exterior of the unit and non-Hygroscopic nature
4	Temperature Sensors	RTD PT-100
5	Temperature Range	Chamber temp. ambient to 35 °C ± 1 °C and Saturation tower temp. up to 70 °C
6	Humidity	Non controlled humidity up to 99% RH
7	Chamber Heater	1000 W of Titanium heater at the bottom of the chamber
8	Saturation Heater	1000 W of Emersion Heater used to saturate the air from oil, grease, and dust
9	Air Pre Heater	Air will be heated up to 35 °C by preheating system
10	Temperature Uniformity	± 1%
11	Temperature Resolution	± 0.1 °C
12	Mist Collection As per standards	1–2 ML/80CM2/1 h (Average)
13	Spray Nozzle	Setup suitable with Glass Nozzle and Acrylic self-made venturi with adjustable air pressure and gauge up to 2 bar
14	Salt solution making tank	40 L of PVC tank to make the ready solution of salt

Basavarajappa et al. [47] reiterated similar observations for fly ash granules. The improved tensile strength of the composites can be linked to the fillers ESA and RHA, which has a stronger strength and offers better tolerance. When the weight percentage of reinforcements is greater than 7.5%, the tensile strength of the specimens decreased it could be owing to the reinforcement's low wettability with the metal matrix. Figure 11 shows the stress–strain diagram of different compositions. Maximum tensile strength was found to be 184.67 Mpa for composition Al/5% ESA/5% RHA composite with a percent elongation of 6.12%.

Figure 10b depicts the relationship between wt.% of reinforcements and the hardness of produced MMCs. The hardness of the composite was found to rise gradually as the weight ratio of RHA and ESA particles increased. It emerges as the matrix's surface area expands, resulting in smaller grain size distribution. The existence of this hard surface area tends to increase the plastic deformation resistance, resulting in increased hardness. Ramachandra and Radhakrishna [48] reached the same conclusion with SiC particulates reinforcing agents.

Figure 10c depicts the influence of ESA and RHA reinforcement on composite percentage extension. The ductility of the composite was observed to reduce as the weight percentage of reinforcements increased. This is caused by the hardening of the reinforcement particles or the clumping of the particles. Sudarshan et al. and Surappa [49] observed identical results for different weight percents of fly ash reinforcements.

Table 9 Technical specification of muffle furnace

S. No	Description	Value
1	Temperature	1400 °C
2	Operating Temperature	1200 °C
3	Heating element	SiC-rod
4	Chamber (12″ × 12″ × 6″)	Ceramic zirconium board
5	Temperature controller	PID control with SCR power control
6	Insulation	Ceramic fibre blanket

The effect of the addition of reinforcement particles i.e., ESA and RHA to the base material Al3105 has been discussed in Fig. 10d. The toughness of the final developed composite was reduced as there is an increase in the wt.% of reinforcements. On further addition of reinforcing agents, the toughness was increased to some extent due to good/uniform interfacial bonding development between the base material and reinforcements ES and RHA.

Corrosion and Thermal Behavior of Composite

A corrosion test of the composite was carried out in a salt spray chamber (Table 9). The weight of each sample before the corrosion test was kept uniform. Five different samples

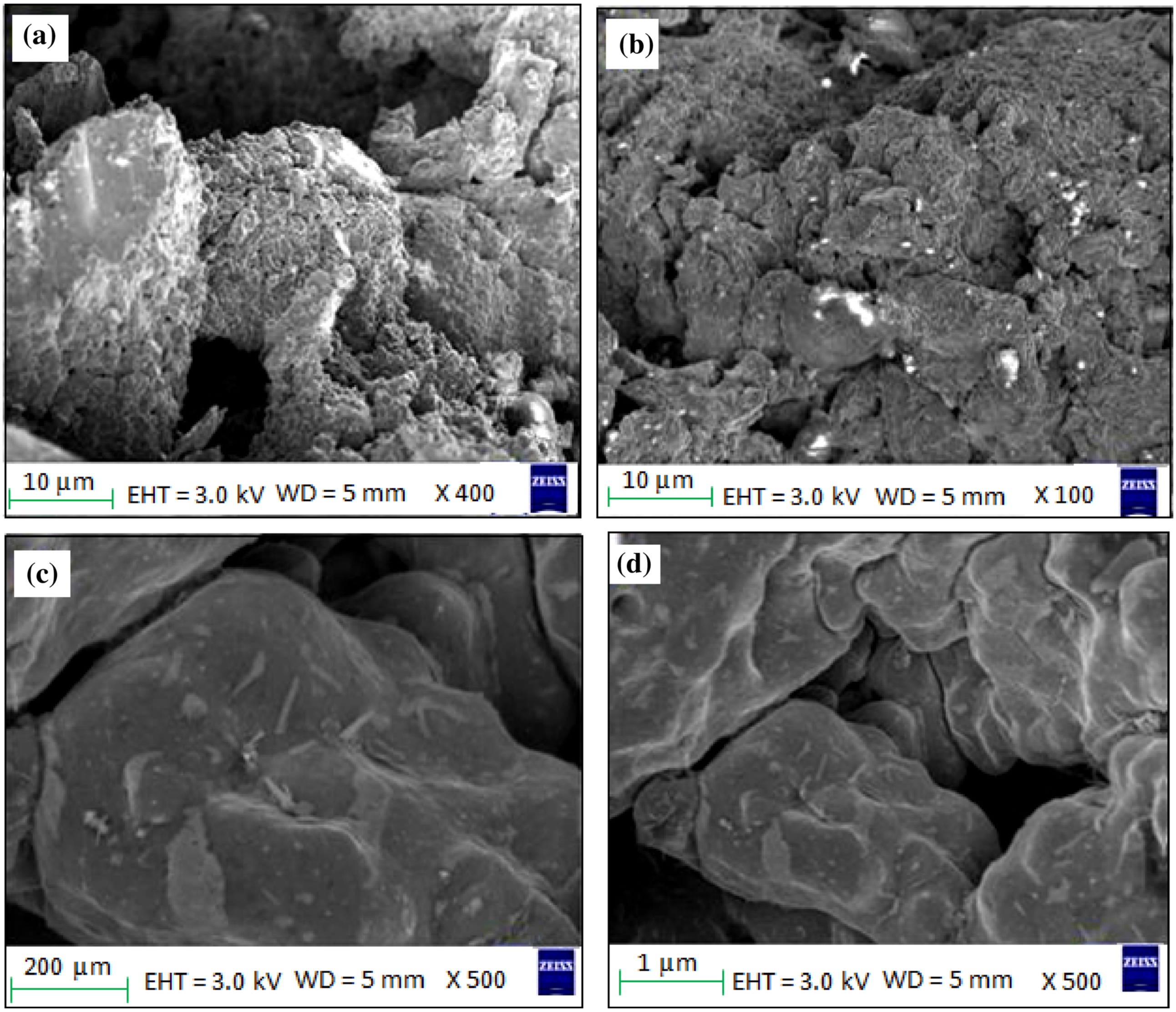

Fig. 9 SEM image of Al/5% ES/5% RHA

of the composite having different wt.% of the reinforcements and their corresponding loss in wt. was examined. It was observed that as the wt.% of the reinforcements gets increased the composite becomes more resistant to corrosion. Figure 12a indicates the variation of weight loss of different samples having different wt.% of the reinforcements. The dimension of each sample before the thermal expansion test was 2500 mm^3. A thermal expansion test was carried out in a muffle furnace for 72 h at the temperature of 450 °C. Figure 12b indicates the change in volume due to the change in temperature, it was found that the addition of reinforcements enhances the thermal stability of the composite material. For the fifth sample where the reinforcements i.e., ESA and RHA were added in max wt.% the thermal expansion is minimum.

XRD Analysis of Composite Material

The main goal of the XRD analysis is to figure out how many distinct phases are there in the MMC. The XRD plots of the ball-milled AA3105/5% CESA/5% RHA composite material are shown in Fig. 13. For mechanically stirred casted samples, these XRD were plotted between relative intensity (y-axis) and 2-theta diffraction angle (degree) (MSCS). The fluctuation of relative intensity with 2 theta angle of diffraction for Al3105/5% ESA/5% RHA is depicted in an XRD plot. The peak points corresponding to the various elements contained in the composite are shown in Fig. 13. The XRD plot clearly shows that the greatest intensity peaks are Aluminum (base metal), followed by $CaCO_3$, SiO_2, and CaO.

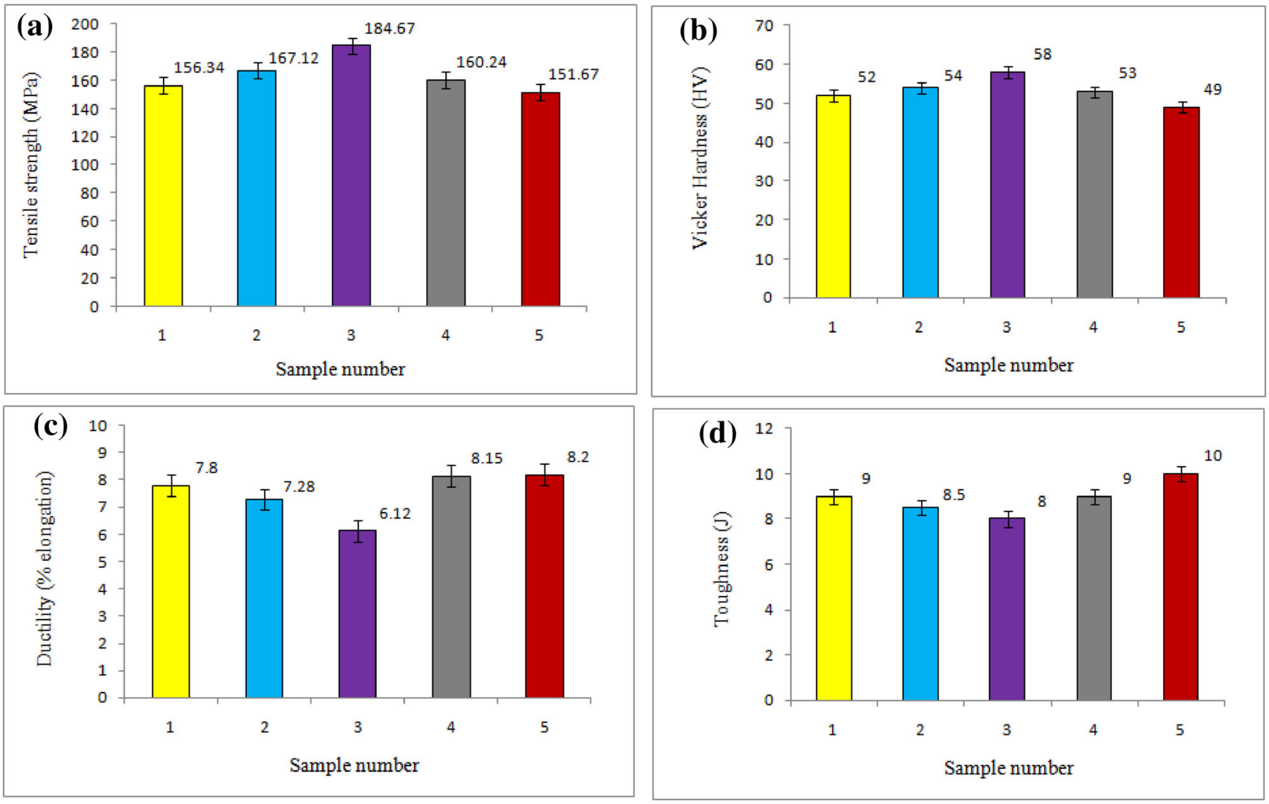

Fig. 10 Mechanical properties of composite; **a** Tensile Strength, **b** Vickers Hardness of Composites, **c** Ductility, **d** Toughness

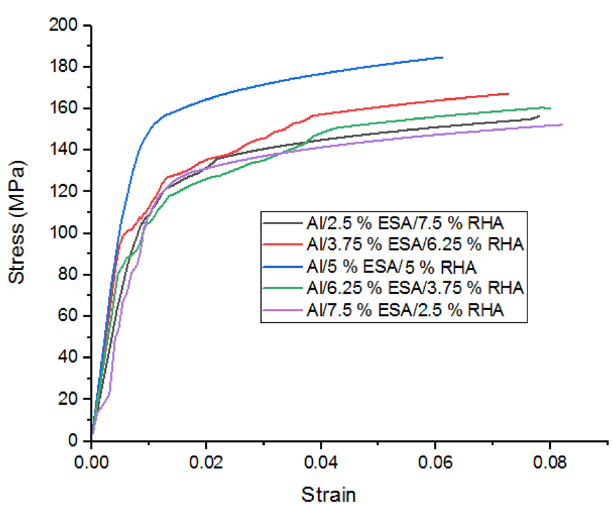

Fig. 11 Stress–strain diagram of different compositions

Conclusions

ESA and RHA can be utilized in the development of Aluminum-based composite materials. The correct wettability between the matrix material and reinforcement particles was observed in the microstructure of the AA3105/5% ES/5% RHA. An interfacial interaction reaction layer created between the matrix material and reinforcing material may result in adequate wettability. The highest value of tensile strength was found to be 184.67 MPa at 5 wt.% of ESA and 5 wt.% of RHA while highest hardness value was also found to be 58 HV for the third prepared sample i.e., having wt.% of each reinforcement 5%. As the wt.% of each of the reinforcements increases the toughness in J as well as ductility decreases and came out to be 10 J and 8.2% respectively this is due to the development of stronger interfacial bonding between the base metal Al3105 and reinforcements ES and RHA. However, the presence of hard phases in composites such as $CaCO_3$, SiO_2, and CaO respectively was responsible for enhancing the mechanical properties such as hardness and tensile strength of the composite. Good corrosion resistance is also evident from this study along with this the thermal stability of the developed composite increased to a significant extent.

Funding There is no funding support for this study.

Declarations

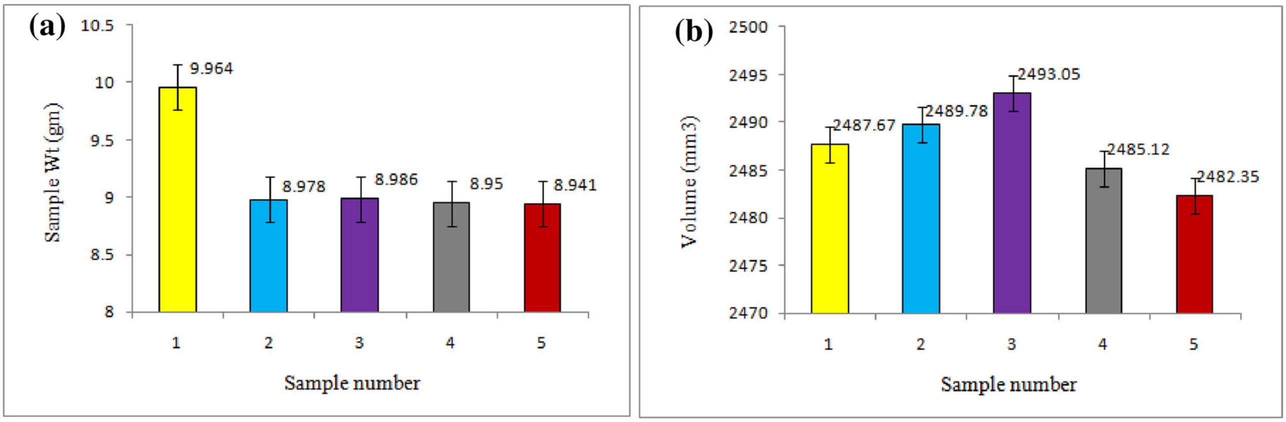

Fig. 12 Behaviour of composite; **a** Corrosion weight loss, **b** Thermal expansion behaviour

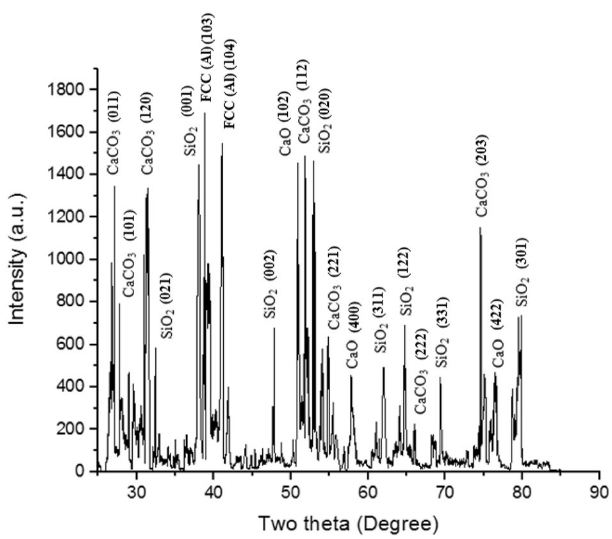

Fig. 13 XRD behaviour of Al + 5% ES + 5% RHA composite

Conflict of interest There is no conflict of interest from the authors.

References

1. S.P. Dwivedi, V.R. Mishra, Physico-chemical, mechanical and thermal behaviour of agro-waste RHA-reinforced green emerging composite material. Arab. J. Sci. Eng. **44**, 8129–8142 (2019)
2. X. Chen, C. Li, J. Wang, J. Li, X. Luan, Y. Li, R. Xu, B. Wang, Investigation on solar photocatalytic activity of TiO2 loaded composite: TiO2/eggshell, TiO2/clamshell and TiO2/CaCO3. Mater. Lett. **64**(13), 1437–1440 (2010)
3. E. Mosaddegh, A. Hassankhani, Application and characterization of eggshell as a new biodegradable and heterogeneous catalyst in green synthesis of 7, 8-dihydro-4H-chromen-5 (6H)-ones. Catal. Commun. **33**, 70–75 (2013)
4. P. Toro, R. Quijada, M. Yazdani-Pedram, J.L. Arias, Eggshell, a new bio-filler for polypropylene composites. Mater. Lett. **61**(22), 4347–4350 (2007)
5. A.J. Ruys, *Metal-Reinforced Ceramics* (Woodhead Publishing, Cambridge, 2020)
6. P.-F. Paradis et al., Non-contact thermophysical property measurements of liquid and undercooled alumina. Jpn. J. Appl. Phys. **43**(4), 1496–1500 (2004)
7. W.M. Haynes (ed.), *CRC Handbook of Chemistry and Physics*, 92nd edn. (CRC Press, Boca Raton, 2011), p. 4.88. ISBN 1439855110
8. J.F. Shackelford, W. Alexander, *CRC Materials Science and Engineering Handbook* (CRC Press, Boca Raton, 2000)
9. P. Patnaik, *Handbook of Inorganic Chemicals* (McGraw-Hill, New York, 2003). ISBN 0-07-049439-8
10. K. Periasamy, G.C. Mohankumar, Sea coral-derived cuttlebone reinforced epoxy composites: Characterization and tensile properties evaluation with mathematical models. J. Compos. Mater. **50**, 807–823 (2016)
11. J. Kamau, A. Ahmed, F. Hyndman, P. Hirst, J. Kangwa, Influence of rice husk ash density on the workability and strength of structural concrete. Eur. J. Eng. Technol. Res. **2**(3), 36–43 (2017)
12. E. Mosaddegh, A. Hassankhani, Preparation, characterization, and catalytic activity of Ca2CuO3/CaCu2O3/CaO nanocomposite as a novel and bio-derived mixed metal oxide catalyst in the green synthesis of 2H-indazolo [2, 1-b] phthalazine-triones. Catal. Commun. **71**, 65–69 (2015)
13. S.B. Hassan, V.S. Aigbodion, Effects of eggshell on the microstructures and properties of Al–Cu–Mg/eggshell particulate composites. J. King Saud Univ. Eng. Scie. **27**(1), 49–56 (2015)
14. S. Lunge, D. Thakre, S. Kamble, N. Labhsetwar, S. Rayalu, Alumina supported carbon composite material with exceptionally high defluoridation property from eggshell waste. J. Hazard. Mater. **237**, 161–169 (2012)
15. S. Mohd Rizal Salleh, A. Kamely, T.A. Taufik, Adv. Mater. Res. **264–265**, 871–879 (2011)
16. M.C. Yew, N.R. Sulong, M.K. Yew, M.A. Amalina, M.R. Johan, The formulation and study of the thermal stability and mechanical properties of an acrylic coating using chicken eggshell as a novel bio-filler. Prog. Org. Coat. **76**(11), 1549–1555 (2013)
17. P. Hiremath, M. Shettar, M.G. Shankar, N.S. Mohan, Investigation on effect of egg shell powder on mechanical properties of GFRP composites. Mater. Today Proc. **5**(1), 3014–3018 (2018)

18. S. Bose, A. Pandey, A. Mondal, P. Mondal, A novel approach in developing aluminum hybrid green metal matrix composite material using waste eggshells, cow dung ash, snail shell ash and boron carbide as reinforcements, in *Advances in Industrial and Production Engineering* (Springer, Singapore, 2019), pp. 551–562
19. S. Kumar, A.K. Srivastava, R.K. Singh, Fabrication of AA7075 hybrid green metal matrix composites by friction stir processing, in *Annales de Chimie-Science des Matériaux*, vol. 44, no. 4 (2020), pp. 295–300
20. A. Islam, S.P. Dwivedi, V.K. Dwivedi, Effect of friction stir process parameters on tensile strength of eggshell and SiC-reinforced aluminium-based composite. World J. Eng. **18**(1), 157–166 (2021). https://doi.org/10.1108/WJE-08-2020-0387
21. S. Jannet, R. Raja, S.R. Ruban, S. Khosla, U. Sasikumar, N.B. Sai, P.M. Teja, Effect of egg shell powder on the mechanical and microstructure properties of AA 2024 metal matrix composite. Mater. Today Proce. **44**, 135–140 (2021)
22. A. Heidarzadeh, R. Mohammadzadeh, D. Brabazon, Green materials and production of metallic composite materials. *JOM* **45**(1), 19b24
23. Y. Li, S. Xin, Y. Bian, K. Xu, C. Han, L. Dong, The physical properties of poly (L-lactide) and functionalized eggshell powder composites. Int. J. Biol. Macromol. **85**, 63–73 (2016)
24. D. Cree, A. Rutter, Sustainable bio-inspired limestone eggshell powder for potential industrialized applications. ACS Sustain. Chem. Eng. **3**(5), 941–949 (2015)
25. J.M. Mistry, P.P. Gohil, Experimental investigations on wear and friction behaviour of Si3N4p reinforced heat-treated aluminium matrix composites produced using electromagnetic stir casting process. Compos. B Eng. **161**, 190–204 (2019)
26. G. Moona, V. Rastogi, R.S. Walia, R. Sharma, Microstructure and wear study of Al 7075-T6/Eggshell/SiC/Al_2O_3 hybrid composites, in *Recent Advances in Mechanical Engineering* (Springer, Singapore, 2020), pp. 471–481
27. S.D. Saravanan, M. Senthilkumar, Mechanical behavior of aluminum (AlSi10Mg)-RHA composite. Int. J. Eng. Technol. **5**(6), 4834–4840 (2014)
28. A.M. Usman, A. Raji, M.A. Hassan, N.H. Waziri, A comparative study on the properties of Al-7% Si-Rice husk ash and Al-7% Si-Bagasse ash composites produced by stir casting. Int. J. Eng. Sci. **3**(8), 1–7 (2014)
29. K.K. Alaneme, T.M. Adewale, P.A. Olubambi, Corrosion and wear behaviour of Al–Mg–Si alloy matrix hybrid composites reinforced with rice husk ash and silicon carbide. J. Market. Res. **3**(1), 9–16 (2014)
30. B. Vinod, S. Ramanathan, M. Anandajothi, Effect of organic and inorganic reinforcement on tribological behaviour of aluminium A356 matrix hybrid composite. J. Bio Tribo-Corrosion **4**(3), 1–13 (2018)
31. N. Verma, S.C. Vettivel, Characterization and experimental analysis of boron carbide and rice husk ash reinforced AA7075 aluminium alloy hybrid composite. J. Alloy. Compd. **741**, 981–998 (2018)
32. M.R. Hossain, M.H. Ali, M. Al Amin, M.G. Kibria, M.S. Ferdous, Fabrication and performance test of aluminium alloy-rice husk ash hybrid metal matrix composite as industrial and construction material. Int. J. Eng. Mater. Manuf. **2**(4), 94–102 (2017)
33. C. Shoba, N. Ramanaiah, D.N. Rao, Optimizing the machining parameters for minimum surface roughness in turning Al/6% SiC/6% RHA hybrid composites. Proc. Mater. Sci. **10**, 220–229 (2015)
34. D.S. Prasad, C. Shoba, Experimental evaluation onto the damping behavior of Al/SiC/RHA hybrid composites. J. Market. Res. **5**(2), 123–130 (2016)
35. I. Dinaharan, K. Kalaiselvan, N. Murugan, Influence of rice husk ash particles on microstructure and tensile behavior of AA6061 aluminum matrix composites produced using friction stir processing. Compos. Commun. **3**, 42–46 (2017)
36. G. Arora, S. Sharma, A comparative study of AA6351 mono-composites reinforced with synthetic and agro waste reinforcement. Int. J. Precis. Eng. Manuf. **19**(4), 631–638 (2018)
37. M.A. Anwer, H.E. Naguib, Study on the morphological, dynamic mechanical and thermal properties of PLA carbon nanofibre composites. Compos. B Eng. **91**, 631–639 (2016)
38. M. Labella, S.E. Zeltmann, V.C. Shunmugasamy, N. Gupta, P.K. Rohatgi, Mechanical and thermal properties of fly ash/vinyl ester syntactic foams. Fuel **121**, 240–249 (2014)
39. R. Yadav, S.P. Dwivedi, V.K. Dwivedi, Synthesis and mechanical behavior of ball-milled agro-waste RHA and eggshell reinforced composite material. Mater. Perform. Charact. **10**(1), 237–254 (2021). https://doi.org/10.1520/MPC20190247
40. R. Zare, H. Sharifi, M.R. Saeri, M. Tayebi, Investigating the effect of SiC particles on the physical and thermal properties of Al6061/SiCp composite. J. Alloy. Compd. **801**, 520–528 (2019)
41. Y. Niu, S. Zheng, P. Song, X. Zhang, C. Wang, Mechanical and thermal properties of PEEK composites by incorporating inorganic particles modified phosphates. Compos. Part B Eng. **212**, 1087 (2021)
42. S. Cheng, K.T. Lau, T. Liu, Y. Zhao, P.M. Lam, Y. Yin, Mechanical and thermal properties of chicken feather fiber/PLA green composites. Compos. B Eng. **40**(7), 650–654 (2009)
43. K.S. Murthy, D.P. Girish, R. Keshavamurthy, T. Varol, P.G. Koppad, Mechanical and thermal properties of AA7075/TiO2/Fly ash hybrid composites obtained by hot forging. Prog. Nat. Sci. Mater. Int. **27**(4), 474–481 (2017)
44. M.A. Almomani, M.T. Hayajneh, Mu'ayyad, M. , Investigation of mechanical and tribological properties of hybrid green eggshells and graphite-reinforced aluminum composites. J. Braz. Soc. Mech. Sci. Eng. **42**(1), 1–13 (2020)
45. S. Kumar, S. Dwivedi, V.K. Dwivedi, Synthesis and characterization of ball-milled eggshell and Al_2O_3 reinforced hybrid green composite material. J. Metals Mater. Miner. **30**(2) (2020)
46. A. Bahrami, N. Soltani, S. Soltani, M.I. Pech-Canul, L.A. Gonzalez, C.A. Gutierrez, A. Möller, J. Tapp, A. Gurlo, Mechanical, thermal and electrical properties of monolayer and bilayer graded Al/SiC/rice husk ash (RHA) composite. J. Alloy. Compd. **699**, 308–322 (2017)
47. S. Basvarajappa, G. Chandramohan, A. Mahadevan, M. Thangavelu, R. Subramanian, P. Gopalakrishnan, Influence of sliding speed on the dry sliding wear behavior and the subsurface deformation on hybrid metal matrix. Wear **262**, 1007–1012 (2007)
48. M. Ramachandra, K. Radhakrishna, Effect of reinforcement of flyash on sliding wear, slurry erosive wear and corrosive behavior of aluminium matrix composite. Wear **262**(11), 1450–1462 (2007)
49. M.K. Surappa, Synthesis of fly ash particle reinforced A356 Al composites and their characterization. Mater. Sci. Eng. A **480**(1), 117–124 (2008)