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ORIGINAL CONTRIBUTION

Synthesis, Physical and Mechanical Behavior of Agro-Waste RHA and Eggshell-Reinforced Composite Material

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Abstract Eggshell (ES) and rice husk ash (RHA) were used in this study to develop an aluminum-based composite material. Physical and chemical parameters of the composite material, such as density, porosity, specific strength, and corrosion rate, have been examined by adding ES and RHA to the base material. The tensile strength and hardness of aluminum alloys have been improved by using waste materials, i.e., ESA and RHA. In addition to this porosity and corrosion rates have also been enhanced. The microstructural investigation has been also carried out to observe the wettability of reinforcement with base metal, i.e., Al alloy (AA-3105). The specific strength of base material AA3105 was 51.78 N-m/kg; however, after adding the reinforcements, i.e., AA3105/5% ES/5% RHA, the specific strength was found to be 67.004 N-m/kg. Results showed that specific strength improved by about 29.40% after the addition of 5% ES and 5% RHA in the AA3105. The theoretical density of the AA3105/5% ES/5% RHA was also found 3.07% lower than base aluminum alloy. Porosity percent and corrosion rate for same proportion (AA3105/5% ES/5% RHA) were found to be 0.13% and 0.44 mm/year, respectively. X-ray diffraction (XRD) of AA3105/5% ES/5% RHA composite showed the presence of Al, $CaCO_3$, SiO_2, and CaO, respectively, the presence of hard phases such as $CaCO_3$, SiO_2, and CaO are responsible for improving mechanical properties of base material, i.e., Al3105.

Keywords MMC · XRD · SEM · Specific strength · Porosity analysis

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Introduction

The demand of composites (hybrid materials)/green composites is raising at a very high rate; the primary reason for its high demand is that composites are having excellent mechanical and chemical properties. The addition of reinforcements to the base material enhances its properties to a great extent. Another reason to switch from traditional materials to mixed-breed (hybridized) ones is to cut down on pollution by reusing wastes from different sources and using them as reinforcing agents. There are a lot of different industries that need low-cost, low-density materials with good mechanical properties, like ships and aircraft. This means that new materials need to be made. Scientists were inspired to make hybrid materials out of industrial waste because there were more harmful pollutants in the air. There has been a rise in the use of these types of wastes over the last few years, and this type of use is called green manufacturing. Today, researchers and scientists all over the world are working on ways to make things that don't use traditional raw materials. To make things that are good for the environment, users can use waste materials to cut down on the harmful effects and make new and hybrid materials or products that don't harm the environment. Aluminum, due to its lightweight and good mechanical properties, finds its application in several industries like cans, foils, kitchen utensils, door/window frames. For a wide range of applications, metal matrix composites (MMCs) are long-lasting materials that incorporate demanding qualities into conventional materials [1].

Aluminum-based metal matrix composite (AMC) is also in great demand because of the altered (enhanced) properties of Al after the addition of reinforcements. The addition of reinforcements makes the base material (Al) far apart in terms of its properties from other higher-order (expensive) metals. AMC is in great demand in the electronics industries and they are used for making the heat sinks, microwaves, microchips, processors, wings of aircraft, landing gears, etc [1–4]. Many of the past studies have used traditional reinforcing agents such as SiC, Al2O3, Si3N4, and TiC to make AMCs. SiC, Al2O3, Si3N4, and TiC are more expensive that have densities higher than Al, so they are not smart enough to make a low-density composite. In this case, agro waste goods like eggshell ash, groundnut shell, and rice husk ash have carbides and ceramic oxides, which are enough to make the base material stronger and more durable. As a bonus, they have low densities, so they could be used to make a metal matrix composite (MMC) that isn't very dense, too. Because these wastes are made from plants, the pollution could be reduced because these plants produce a lot of toxic fumes. It is thought that by 2030, approximately 70% of people will have some kind of lung disease. Environmental regulation is the thing that needs to be done now [5–8]. ESA (eggshell ash) and RHA (rice husk ash) are the two major pollution-causing agents, and the best way to get over this problem is to utilize the wastes in some productive work. ESA and RHA if used as reinforcements could enhance the mechanical and physical properties of the base material (Al). ESA is a waste generated by food industries and its proper disposal is quite necessary, otherwise, it may give rise to serious environmental problems. Several researchers have attempted to use ESA for several applications the reason lies in its chemical composition and its accessibility. As eggshell consists of calcium carbonate and other hard phased material as found by its XRD, makes eggshells are an important reinforcing agent to enhance the mechanical as well as chemical properties of the base material. The other reason for reinforcing base material with ES is its bulk availability, lightweight, economical, and environment friendly. Reinforcement of Aluminum with ES and investigative analysis on its changed attributes such as mechanical, chemical, and thermal is a quite explorative field for research. As a result, MMCs can be tested and regulated in a wide range of conditions, making them ideal for a variety of applications [9]. The synthesis of such kinds of compounds is mainly done by different casting techniques like mechanical and electromagnetic stir casting [6, 10]. MMC has better properties if the reinforcing particles in the metal matrix are spread out evenly and have good contact with each other. Toro et al. [3] claimed that there have been a lot of different ways to use ES as a bio-filler in composites made with propylene, the value of Young's modulus increases as the ES content goes up. Alaneme and Sanusi [11] in 2015 have developed an Al-based hybrid composite and concluded that the mechanical and wear behavior of hybrid composite were enhanced at 10 wt% Al2O3/RHA and 0.5 wt% graphite. Dwivedi et al. [12] used RHA/B4C as a reinforcing agent to develop an AA6082 hybrid metal matrix composite. AA composite was fabricated with help of RHA/B4C (2.5 wt% to 10 wt%) and analyzed the porosity, density, thermal expansion. Usman et al. [13] used RHA as a reinforcing agent to prepare aluminum alloy composites. They claimed that the density decreased with increase reinforcement wt% and tensile strength and hardness were increased with 10 wt% reinforcement. Vinod et al. [14] used RHA/Fly ash to develop an A356 alloy composite, in that investigation the physical and mechanical properties were analyzed at different wt% of reinforcement. Shaikh et al. [15], various amounts of RHA and 10% SiC were added to an Al-based composite to make it different. Then, the composite was made and the mechanical and tribological properties were studied. It was made by Verma and Vettel [16], they made an AA7075 hybrid metal matrix composite. Subrahmanyam et al. [17], RHA, and Fly ash were taken (5 wt% to 15 wt%) to develop the composite, analyze the surface morphology and mechanical properties. Reddy et al. studied the use of stabilizers such as SiC and TiC in a hybrid MMC. There are three different combinations of SiC and TiC (SP1: 7.5 wt%, SP2: 5 wt%, and SP3: 2.5 wt%) that have been created and tested on the properties of the machine [18]. Arora and Sharma [19], analysis of mechanical properties, AA6351 was made with 2 wt% and 8 wt % of both reinforcements, which are RHA and SiC. Bahrami et al. [20] made the monolayer and bilayer of the Al/SiC/RHA composite and looked at how it worked in terms of mechanical, thermal, and electrical properties. Dwivedi and Mishra [21] AA6063 has been used as base material and analyzed the physio-chemical, thermal behavior of the composite. Also, the cost estimation of the RHA has uniformly replaced the ceramic particle. Singh et al. [22] used Al2O3/RHA as reinforcements developed functionally graded material (FGM) composite, FGM composite was given better performance at lower RPM and triangular shape. Prasad and Shoba [23] analyze the damping behavior of the Al-based composite. Dinaharan [24] had conducted the study of composite microstructure with various techniques (SEM, Optical microscopy, electron backscattered diagram). Durowoju et al. [25] Gr-Al composite was prepared with 20 wt% Si/SiC/ES. Hassan and Aigbodion [6] were added 2–12 wt% ES. The microstructure was studied by the SEM and EDS and analyzed the mechanical and physical properties of the composite. Dwivedi et al. [26] fabricated the composite with 4.5 wt% reinforcement and added 1.5% Cr to enhance the mechanical properties and improve the thermal expansion and ductility. Islam et al. [27], Al6061 composite was prepared by the stir casting process, and also optimize FSP parameters by Box–Behnken design. Parande et al. [28] developed Mg-Zn alloy and concluded that the better quality of the composite, by using fine grain size particle of ES. Almomani et al. [29] showed graphite is self-lubricating. Tin and Mg have been used to make them denser. There were tests on microhardness, wear, and mechanical characteristics. Li et al. [30] analyze the physical properties of L-lactide composite by using ES as reinforcement. Moona et al. [31] had analyzed the mechanical properties of Al-based composite with the help of various wt% of ES reinforcement. Agunsoy et al. [32] prepared the wear-resistant Al7075-T6 composite by using different wt% of the reinforcement (ES/SiC/Al2O3). Urtekin et al. [33] used ES to prepare an aluminum-based hybrid green metal matrix claimed the improvement in the thermal and residue stress of composite with using ES. Bose et al. [34] used ES/B4C/Snail shell ash/cow dung ash to prepare an aluminum-basedhybrid green metal matrix and analyzed the mechanical and tribological properties with different wt% of the reinforcement. Hosseini et al. [35] prepared sodium alginate natural composite and claimed that absorption capacity was decreased with the increase in the temperature of ES. Bose et al. [36] compare the mechanical properties between Al-based composite and Al-SiC composite with two wastages, i.e., Snail shell ash/ES.

From the archival literature, it has been observed that very few researchers utilized eggshell (ES) and rice husk ash (RHA) simultaneously in the development of aluminum-based composite material. In the present study, an attempt has been made to utilize ES and RHA after the ball-milling in the synthesis of Al-based composite material. XRD is a technique generally used for phase determination of various materials; it may also give data on unit cell dimensions. Microstructure, density, porosity, specific strength, and X-ray diffraction (XRD) have been observed to identify the ES and RHA addition in the aluminum alloy.

Materials and Methods

Matrix Material

Currently, aluminum (AA3105) is being used as a matrix/base material in the current research. This alloy is used in the manufacture of aeroplane structures because of its great mechanical strength (fuselages and wings). The excellent temperature resistance of AA3105 makes it a good choice for parts such as engines, shafts, brake rotors, and other car parts that require high-tensile strength yet lightweight materials, such as those found in automobile engines [37]. Table 1 discusses the chemical composition of AA3105, while the mechanical properties are given in Table 2.

Primary Reinforcement Material

Eggshell (ES) has been used as the major reinforcement in the fabrication of this aluminum-based composite material. Another organic matter (4%) is the remaining component of ES. The ceramic particles are the most abundant component of ES, followed by CaCO3 (94%), MgCO3 (1%), Ca3(PO4)2 (1%), Ca3(PO4)2 (1 percent), and Mg(PO4)2 (1%), with the remainder being another organic matter (4%) [38]. ES were collected from local shops and then thoroughly cleansed before being exposed to the sun for approximately 6 h to remove any moisture content and also to remove the ES coating that had been applied. The powdered form of ES was obtained after the dry ES was ball milled to a fine powder. It was necessary to carbonize the powdered ES under carbonization conditions for up to 4 h at a temperature of approximately 550 °C in order to eliminate the carbonaceous particles from the powdered ES. The average particle size of carbonized ES was found to be 25 µm. Figure 1 illustrates how waste ES from the food processing industry is converted into carbonized ES powder. XRD of carbonized ES was done to have an exact idea of the composition of reinforcement. Figure 2 gives a clear picture of the obtained XRD pattern of carbonized ES it can be well said from the XRD pattern of ES that $CaCO_3$ is having the highest percentage followed by Mg.

Secondary Reinforcement Material

In this work, waste rice husk ash (RHA) was used as a secondary reinforcement material instead of cement. Rice husk has been obtained from a local rice industry in India, and after being cleansed with water to remove dust and other impurities, it has been allowed to dry at room temperature (25 °C) for one day before use. This thoroughly cleaned RH was heated at 3000C for 2–3 h to remove all remaining moisture and organic matter from it. As the organic stuff

Table 2 Mechanical properties of AA3105 alloy [37]

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

Table 1 Composition of AA3105 alloy (wt%) [37]

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

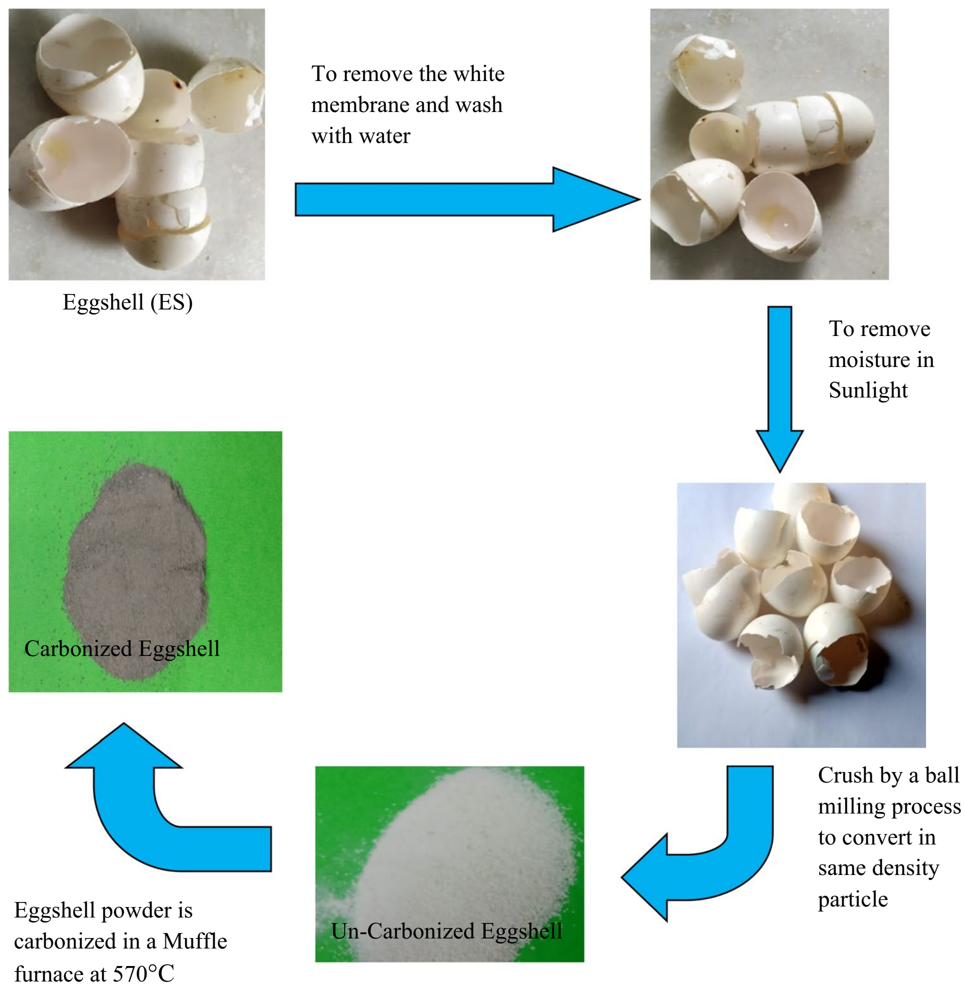

Fig. 1 Preparation of carbonized eggshell powder from waste eggshell

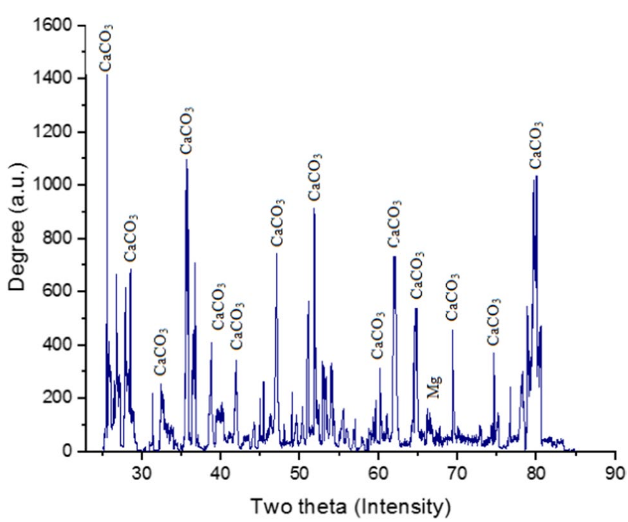

Fig. 2 Powder XRD of carbonized eggshell powder

began to char, the color of the husk changed from yellowish to a faint black while it was being dried. Then it is allowed to be heated at 700 °C for nearly 12 h to eliminate the effect of carbonaceous material. Once again after heating it its black color changed to grayish-white. Finally, the rice husk ash has been made; it can now be used to strengthen the metal matrix. Figure 3 shows the rice husk ash that was made from raw rice husk that was collected from some local rice industries. Figure 4 shows XRD of RHA there are a lot of SiO2, CaO, and Fe_2O_3 in the powdered rice husk ash.

Ball-Milling Process of Reinforcement Particles

Illustration of single-entity reinforcements produced by ball milling of reinforcing particles in Fig. 5 Developing a composite material is a difficult undertaking due to the differences in densities of different reinforcements, which makes it even more difficult while the stirring process is taking place. The primary issue that occurred was the right placement of reinforcing particles in the metal matrix, since some of the particles tended to float while others were sinking

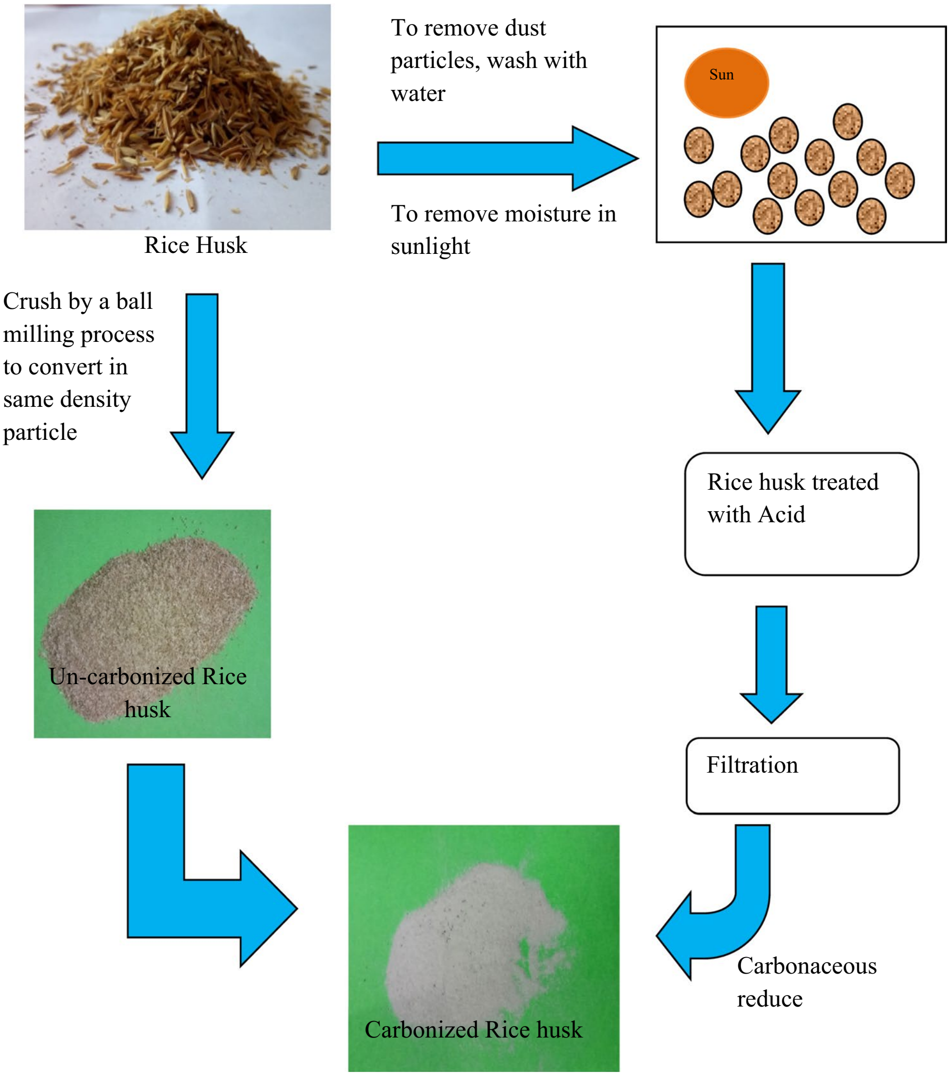

Fig. 3 Preparation of RHA from waste rice husk obtained from rice industry

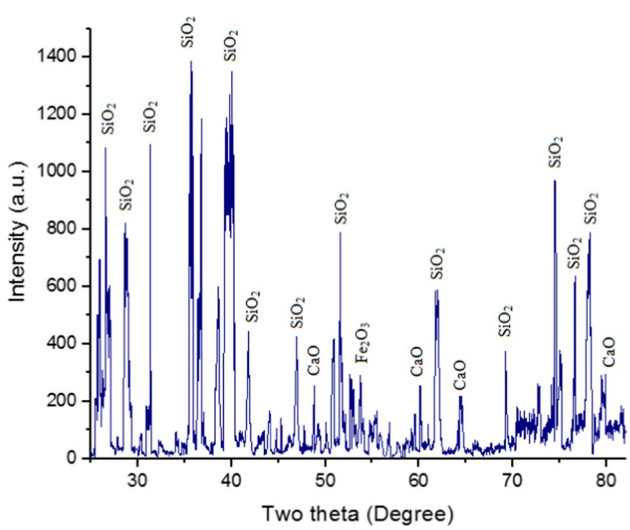

Fig. 4 Powder XRD of RHA powder

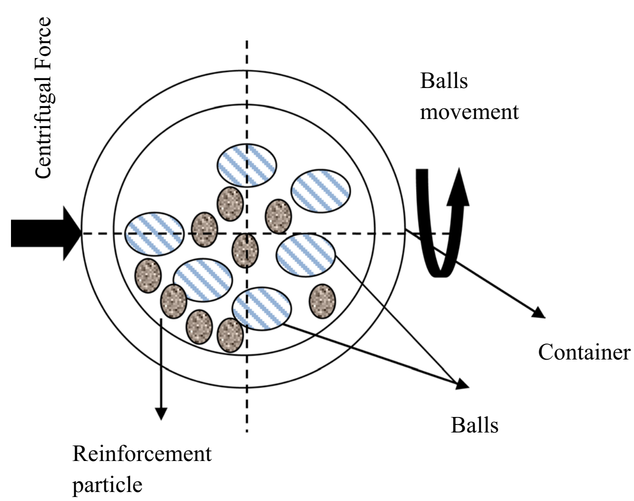

Fig. 5 The method of ball-milling reinforcing particles to create single-entity reinforcements

into the metal matrix. This problem of mismatched densities might be avoided entirely if the ball-milling technique was used instead of grinding. The carbonized eggshell powder and RHA were combined in a ball mill to form a single powder; the ball-milling procedure could take up to 75 h to complete. Figure 5 depicts the ball-milling process of reinforcing particles, which is used to turn them into single-entity reinforcement particles.

Development of Composite Material

Figure 6 shows the line diagram of the composite material development process by the stir casting process. AA 3105 was used as a matrix material. Carbonized eggshell powder and rice husk ash (RHA) were preheated at 300 °C and 200 °C, respectively, before mixing in the matrix material. While ball-milled carbonized eggshell particles and RHA in the single-entity were preheated at 250 °C, AA3105 was melted in a muffle furnace. Figure 7 Shows the Actual test set up used for preparing the composite material. As soon as the temperature of the metal matrix reached 690 °C particles of reinforcement (ESA and RHA) were added. Squeeze, the pressure was applied on the UTM machine in the mushy zone to eliminate the porosity and uneven distribution of reinforcement particles. Table 3 represents the weight percentage of the reinforcement added to the base material; this weight percentage has been decided from previous literatures of the same field [29].

Porosity Analysis

Composite materials have a lot to do with their porosity and the characteristics of their pores, like their size, interconnection, distribution, and more. A substance's porosity (P), is between the volume of substance and total volume. Figure 8 represents the schematic setup for the experimental density measurement Archimedes principle. It is defined by

$$P = \left(1 - \frac{\rho_{\text{Experimental}}}{\rho_{\text{Theoratical}}}\right) \times 100\%$$

Corrosion Rate

The composite was subjected to a 120-h corrosion test in the presence of 3.5 wt% NaCl of all the compositions tested. Equation 1 shows the corrosion rate formula in mm/year for

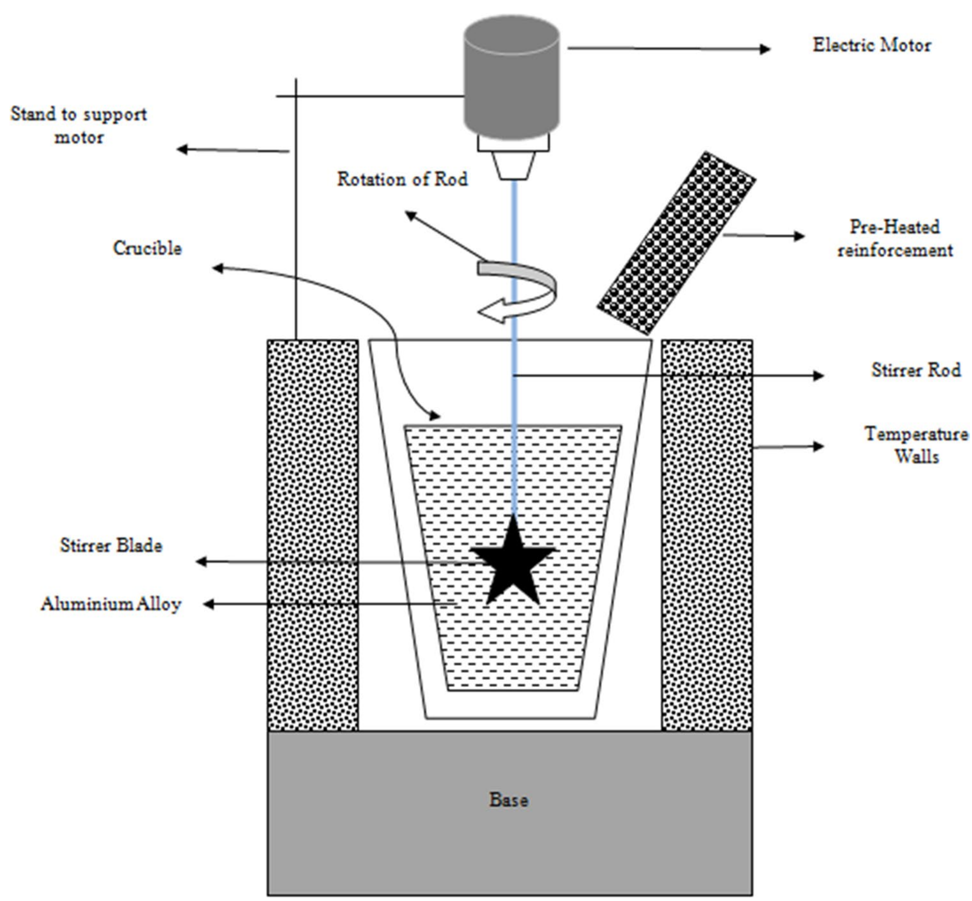

Fig. 6 Schematic diagram of the composite material development process

Fig. 7 Actual test set up used for preparing the composite material

Table 3 Composition of composite

Sample number	Al (wt%)	CESA (wt. %)	RHA (wt. %)
1	97.5	1.25	1.25
2	95	2.5	2.5
3	92.5	3.75	3.75
4	88	5	5
5	87.5	6.25	6.25

the ball-milled CESA and RHA reinforced aluminum-based composite material.

$$\mathrm{CR} = \frac{(\text{weight loss} \times k)}{(\text{density} \times \text{exposed area} \times \text{exposed time})} \quad (1)$$

Here; Weight loss = g.
Density = g/cm.^{3}
Exposed area = 9 cm.^{2}
Exposed time = 120 h.
$k = 8.75 \times 10^4$ (as per the ASTM G1-03 standard).

Results and Discussion

Microstructure Analysis

A scanning electron microscope (SEM) employs a focused beam of electrons to scan a sample's surface to obtain images of the material under examination. Numerous pulses are generated by electron interactions with atoms or ions, which provide details on the sample's surface morphology as well as the constitution. SEM images of the ball-milled AA3105/5% CESA/5% RHA composite material at different magnification is shown in Fig. 9. According to this investigation, there is a strong intermolecular force that exists between the particles of reinforcement and the base or matrix material (Al-3105). This strong connection between the reinforcement particles and the

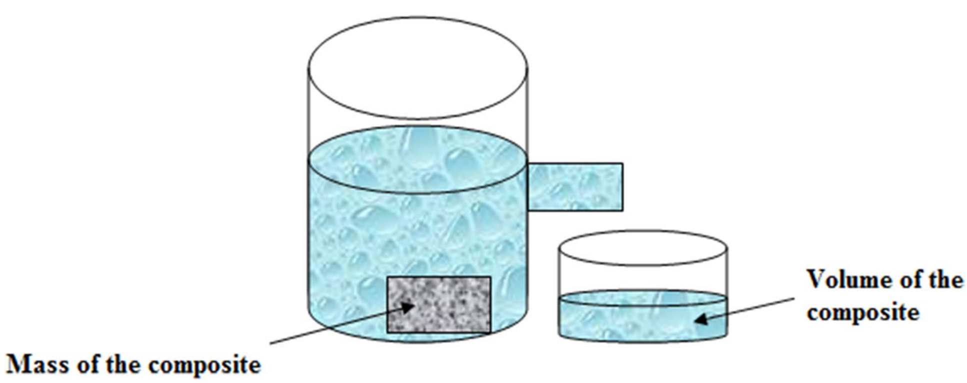

Fig. 8 Experimental density measurement of composite by Archimedes principle

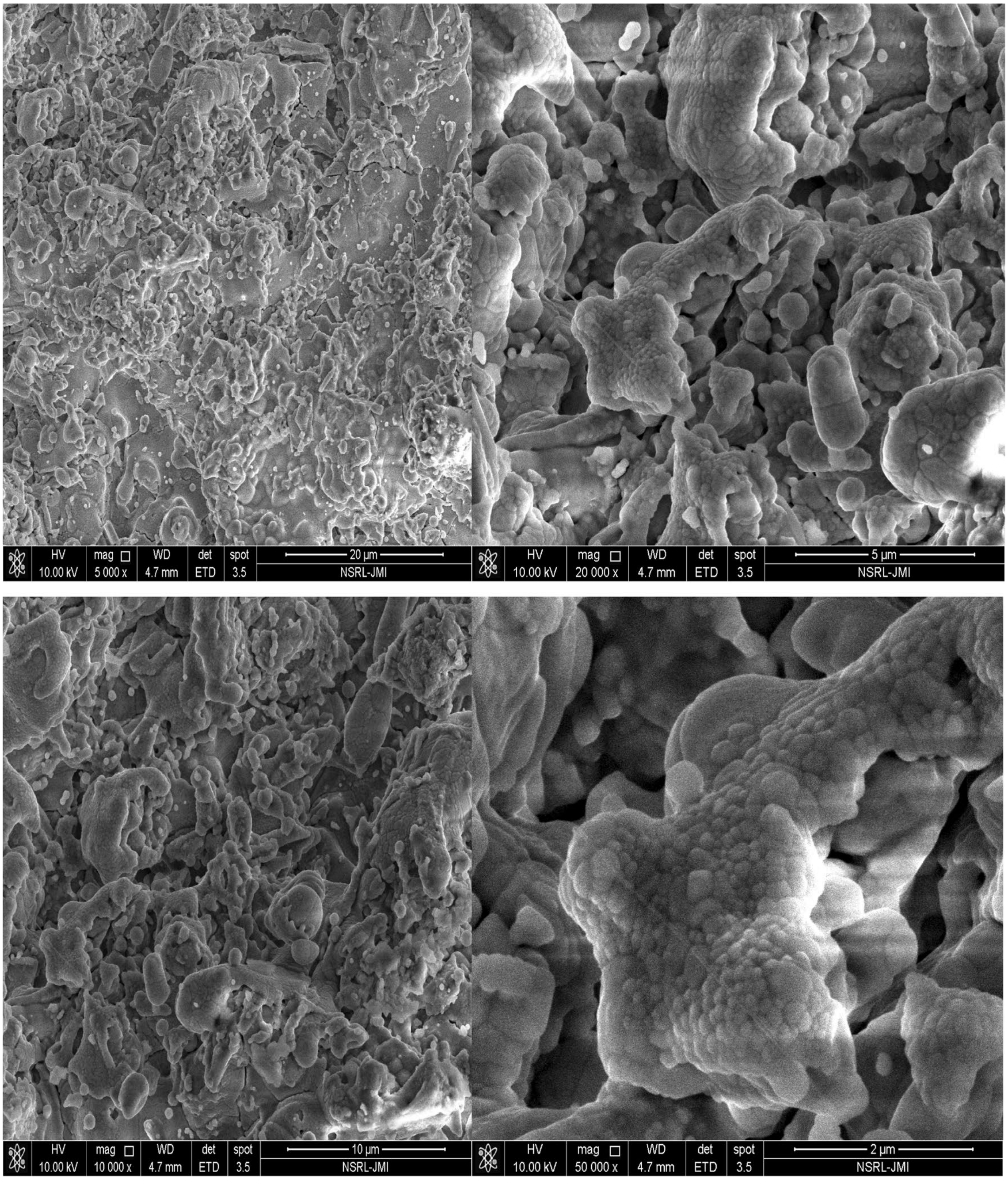

Fig. 9 SEM image of ball-milled AA3105/ 5% CESA/5% RHA composite material

matrix material plainly demonstrates that there has been some improvement in the tensile strength of the material. An increase in intermolecular force or improved adhesion between the molecules of the reinforcing material and the molecules of the matrix metal is a strong indication that the material has good wettability. If a hybrid composite has greater voids and porosity, it will have less ductility than a hybrid composite constructed with a lower weight-percentage of reinforcement. Most of the time, strengthening is a clear indicator of good bonding between the reinforcement particles and the underlying base metal. To achieve the desired (higher) mechanical characteristics, it is critical that the reinforcing particles be distributed uniformly throughout the matrix structure. It has been shown that the stir casting method has a significant favorable impact on the uniform distribution and dispersion of reinforcing particles in the metal matrix (Fig. 1). [39]. The microstructure analysis reveals that the reinforcement particles are evenly or uniformly distributed within the matrix and they are in line with the claims of previous researchers [6, 10]. An electromagnetic field can have a big impact on how reinforcement particles are distributed and spread out when casted [40], the microstructure investigation demonstrates that the reinforcement is evenly spread out in the matrix. As there is an increment in the content (wt%) of reinforcement particulates beyond a certain limit there will be a decrement in the ductility. The maximum reduction of ductility was observed to be 65.7% at 20 wt% of reinforcement, the possible reason behind this is the presence of brittle and hard nature of ceramic particles found in the reinforcement (ESA and RHA reinforcing particles).

Theoretical and Experimental Density

The density of the newly produced aluminum alloy-based composite (Al3105) reinforced with ESA and RHA has been computed according to the Archimedes' principle, while the rule of mixture approach has been used to determine the theoretical value of density for the composite, as previously stated. Using the recorded weights, the experimentally estimated values have been obtained, and these values have been compared with their theoretical rule for the densities of the mixture, which is almost exactly in agreement with the experimentally evaluated values. Figure 10 clearly shows the density comparison as found out by Archimedes principle (experimental values) and rule of mixture method (theoretical values). From the graphical analysis (Fig. 9), it is quite evident that there is a gradual decrement in the density as the reinforcement particles (ESA and RHA) are added to the metal matrix. Thus, it could be well said that the Al 3105 alloy density is decreased as the wt% of reinforcement increases. A similar type of density trend has been revealed by several researchers [6, 10].

Porosity Analysis

Porosity in casting metal matrix composites (MMC) has long been recognized as a flaw that affects strength development specifically in particle-reinforced composites. It is very much clear from the past studies that the major reasons for the generation of porosity includes the entrance of air bubbles in the molten form of a material matrix, deposition of water vapors on the surface of particles, trapping of gases during the blending stage, contraction while crystallization is being carried out, etc. Numerous researchers have claimed that the parameters of casting are among the major components that influence the creation of porosity, cast MMC is said to have the best characteristics when the content of porosity is minimum. A pressure vessel is used to seal the sample and then reduce the amount of pressure by a certain amount, and the rise in volume of gas contained inside is measured. As a result, if the bulk volume is known, porosity may be calculated by measuring the grain volume.

Carbon fiber-reinforced polymer composites, for example, have a long history of being plagued with porosity. To describe the cavities formed by trapped air or volatile gas during the curing process, the word "porosity" is often used to describe it. The volume of gas that is physically bonded (physisorption) to the solid surface at different pressure levels is measured as part of the porosity analysis method. As a result of the trapped air from resin mixing (such as bubbles), voids may also be formed in composite materials. Depending on the manner of processing, the trapped air might be found in resin films or liquid resins. The mechanical characteristics of the Metal matrix, like tensile strength, Young's modulus, Poisson ratio, and damping capability, would tend to decrease as porosity concentration rises. The breakdown phase is begun by the voids created; the existence of porosity reduced the mechanical characteristics of cast MMC. Figure 11 gives the graphical representation of the porosity percentage for

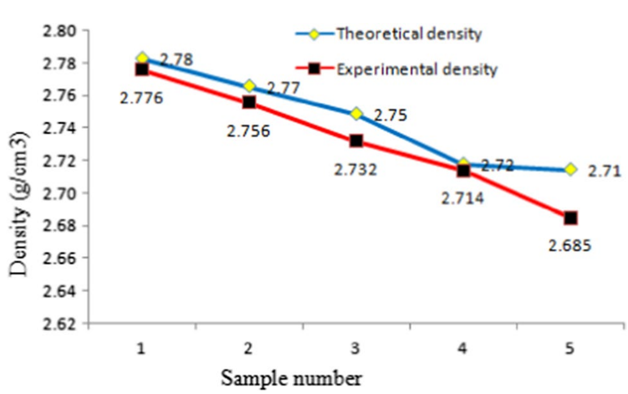

Fig. 10 Theoretical and experimental density of composite

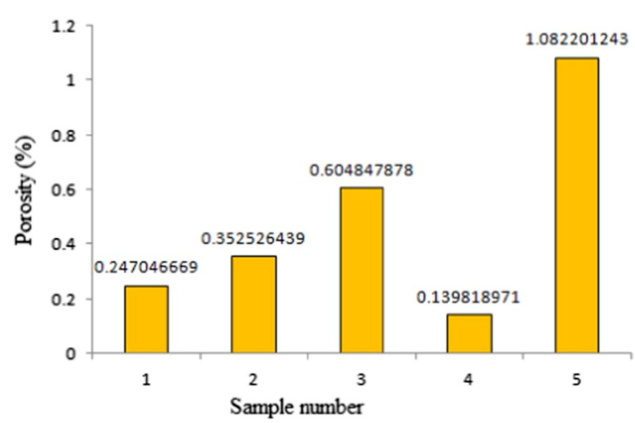

Fig. 11 Percent porosity of the composite

a different prepared sample of MMC (Al/ESA/RHA) in different wt% of the reinforcements. It was observed that as the wt% of reinforcement particulates increases porosity also tends to increase thereby decreasing the strength. Five different samples of Al-based metal matrix composite MMC, i.e., Al/ESA/RHA (1.25/1.25, 2.5/2.5, 3.75/3.75, 5/5, 6.25/6.25) have been taken under consideration out of these samples the highest porosity percentage (1.082%) was observed for that sample which is having highest wt% of reinforcement the reason is improper mixing thereby creating the voids which result in decreasing the tensile strength of the composite. The lowest value of porosity (highest strength) was observed for the fourth sample having 5 wt. % of each reinforcement. Furthermore, the porosity of mechanically casted MMC is higher as compared to the porosity of such samples which have been cast electromagnetically. Densities of the reinforcement particles (ESA and RHA) were lower than matrix material (Al 3105). It was observed that when the quantities of reinforcement particles were 2.5% (1.25% ESA and 1.25% RHA), then reinforcement particles were easily mixed. However, some quantities of reinforcement particles were found to be at the upper surface of the solidified composite due to lower densities of the reinforcement particles as compared to aluminum alloy. When the weight percent of the reinforcement particles were increased up to the weight percent of 7.5% (3.75% ESA and 3.75% RHA), then agglomeration of the reinforcement particles was enhanced. Resulting, the percent porosity of the solidified composite was also increased. However, it was observed that percent porosity for the composition Al/5% ESA/5% RHA was found to be lower than other combinations of reinforcement particles. Lower porosity may be observed for the composition Al/5% ESA/5% RHA composite material due to the formation of proper wettability developed between the matrix material and reinforcement material. It has been noted in the previous research work that the weight percent of nano-reinforcement particles was kept lower. However, it has been also observed [37–41] that when the micron size reinforcement particles quantities were kept in lower quantity, the probability of the formation of porosity is increased. This study results showed that percent porosity was higher for the compositions Al/1.25% ESA/1.25% RHA composite, Al/2.5% ESA/2.5% RHA composite, and Al/3.75% ESA/3.75% RHA composite as compared to the composition Al/5% ESA/5% RHA composite. However, beyond the 10% of reinforcement particles (5% ESA and 5% RHA) addition in the aluminum alloy, porosity increased significantly as shown in Fig. 10. Percent porosity significantly increased for the composition Al/6.25% ESA/6.25% RHA composite due to the much agglomeration of the reinforcement particles within the composite material after solidification.

Table 4 Comparative study of tensile Strength, experimental density, specific strength

Sample. No	Tensile strength	Experimental density	Specific strength
1	157.55	2.776	56.75432
2	166.65	2.756	60.46807
3	173.45	2.732	63.48829
4	181.85	2.714	67.00442
5	171.75	2.685	63.96648

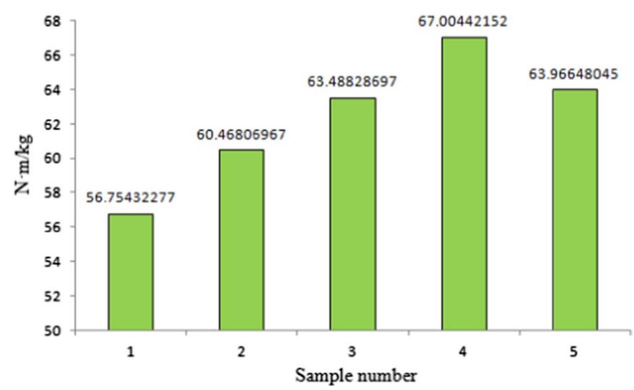

Fig. 12 Specific strength of composite

Specific Strength Behavior

Specific strength is calculated by dividing the experimental strength by the experimental density of the material. It's also used a lot to compare different kinds of things. Researchers are always on the lookout for a material that has a higher specific strength than one that is less dense. There were a lot of projects in the United States that used materials that had a lot of specific strength when they first started. If you want to talk about how strong something is, you can call it the strength-to-weight ratio, or strength/weight ratio. Uniform distribution of the reinforcement particles is very important if you want to get a high value for specific strength. The more voids or porosity there is, the lower the specific strength will be [42]. Table 4 shows the values of tensile strength, experimental density, and specific strength of the composite material. Figure 12 demonstrates the specific strength value for the differently prepared samples. It was found that as the reinforcement % increases specific strength also tends to increase, the highest value of specific strength was observed to be 67.004 N-m/kg (4th sample) at 5wt% of each reinforcement (ESA/RHA). After further increasing the wt% of the reinforcement specific strength goes on decreasing this is due to non-uniform distribution of reinforcements.

Corrosion Rate of Composite Material

The corrosion rate of 1.25%, 2.5%, 3.75%, 5%, and 6.25% of ESA and RHA (each) reinforced aluminum-based composite was carried out at room temperature through 3.5% NaCl solution and immersion examination in 1% of HCl water solution [41]. For example, salt spray testing is a key technique for determining how resistant a component or material is to corrosion when subjected to prolonged exposure to salt spray. An enclosed salt fog tank must be used for salt spray testing in order to get accurate results [29]. Out of the five different prepared samples having different wt% of reinforcements, it was observed that the highest value of corrosion rate was observed to be 0.657 mm/year for the 5th sample which is having highest wt% (6.25 of each reinforcement (ES and RHA)), while the lowest corrosion rate (0.349 mm/year) was observed for 1st sample containing lowest wt. % of each reinforcement (2.5%). The corrosion rate for sample number 4 (composition Al/5% ESA/5% RHA composite) was found to be 0.447 mm/year. The corrosion rate of sample number 4 is lower than other selected compositions in the present study. However, the Corrosion rate of sample number 4 is slightly higher than the composition Al/1.25% ESA/1.25% RHA composite. It can be said from the above trend that as the value of reinforcement increases the corrosion rate (mm/y) also increases. Figure 13 shows the graphical (bar chart) representation of the variation of corrosion rate of composite material.

XRD of Composite Material

The main purpose of XRD analysis is to know the number of different phases present in the MMC. Figure 12 corresponds to the XRD plots of ball-milled AA3105/5% CESA/5% RHA composite material. The XRD pattern has been plotted between the relative intensity (y-axis) and diffraction angle of 2-theta (degree) for mechanically stirred casted samples (MSCS). XRD plot shows changes in relative intensity with variation in angles of diffraction (2-theta) for Al3105/5% ESA/5% RHA. Figure 14 shows the peak points corresponding to the different constituents present in the composite. It is quite evident from the XRD plot that the peaks of highest intensity are of Aluminum (base metal) followed by $CaCO_3$, SiO_2, and CaO respectively, there is only a single peak of MgO indicating its minimal presence in the sample.

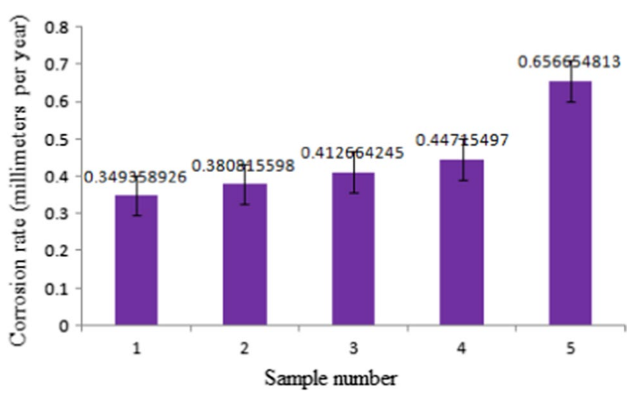

Fig. 13 Corrosion rate of composite

Conclusions

In the present investigation, MMC has been synthesized by using ES and RHA as reinforcements. ES and RHA have been ball milled to make the densities of each and every particle uniform, finally, these elements have been carbonized to remove the presence of any carbonaceous material. Intermolecular forces among reinforcing particles and the base/matrix material are noticeable during microscopic examinations (Al-3105). The main points that can be concluded from this study are as follows:

- The density of Al 3105 alloy decreases with an increasing weight percentage of reinforcement. Porosity rose considerably following solidification of the Al/6.25% ESA/6.25% RHA composite due to agglomeration of the reinforcement particles inside it.
- At 5 wt% of each reinforcement (ESA/RHA), the greatest value of specific strength was recorded (4th sample) at 67.004 N-m/kg. The specific strength decreases when the weight percent of the reinforcement is increased.
- As the amount of reinforcement rises, the rate of corrosion (in millimeters per year) increases as well. Aluminum (base metal) has the greatest intensity peaks, fol-

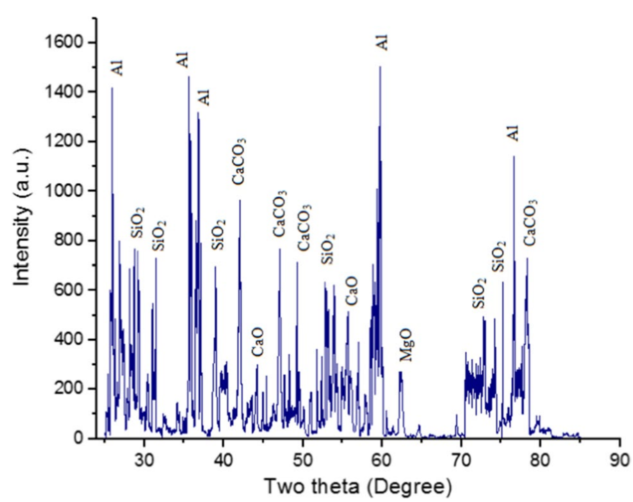

Fig. 14 Composite material XRD of ball-milled AA3105/5% CESA/5% RHA

lowed by CaCO3, SiO_2, and CaO, in that order. There is just a single peak of MgO, suggesting that it is present in very small amounts in the sample. Specific strength improved by about 29.40% after the addition of 5% ES and 5% RHA in the AA3105. However, density was reduced by about 3.07% after adding the same reinforcement percent (5% each ES and RHA) in Al alloy.

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Declarations

Conflict of interest The authors have not disclosed any competing interests.

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