Silicon (2019) 11:817–829
https://doi.org/10.1007/s12633-018-9881-5

ORIGINAL PAPER

Fabrication and Characterization of Organic and In-Organic Reinforced A356 Aluminium Matrix Hybrid Composite by Improved Double-Stir Casting

B. Vinod[1] · S. Ramanathan[1] · V. Ananthi[2] · N. Selvakumar[3]

Received: 28 November 2017 / Accepted: 23 April 2018 / Published online: 5 May 2018

Abstract

Composites are light in weight when compared to woods and metals. It consists of two or more distinct phases such as matrix phase and a dispersed phase. Metal matrix composites are expensive and limitations in achieving stiffness and toughness for materials to overcome these limitations, hybrid metal matrix composites (HMMC's) are fabricated and designed. In recent years hybrid metal matrix composites (HMMC's) are plays a vital role especially in material science in the field of aerospace, marine, transportation, military and structural applications. Aluminium (Al) based metal matrix hybrid composites are used extensively in the field of automotive industries due to its low density and high strength-to-weight ratio. In the present study, aluminium A356 alloy with different weight fractions (0, 5, 7.5, 10 and 12.5%) of RHA and Fly ash reinforced hybrid composites are fabricated by using double stir casting technique. Determination the effect of the addition of organic (RHA) and in-organic (Fly Ash) reinforcement with aluminium A356 alloy on the physical and mechanical properties such as hardness, density and porosity were studied. FE-SEM, XRD, and EDS were analysed for A356 alloy/RHA-Fly Ash hybrid composite. The size distribution of the matrix alloy and reinforcement particles was measured using particle size. A significant improvement in the mechanical property was observed when adding the reinforcement with as-cast aluminium matrix alloy.

Keywords Hybrid composites · Double stir-casting · Agro wastes · Mechanical properties · Particle size analyzer · Microstructure

1 Introduction

Metal matrix composites began in 1950's consists of two phases such as matrix phase and reinforce/dispersive phase. Problems related to the application of metal matrix composites include costly fabrication techniques and specific application problems such as foreign object damage and erosion in engine fan components [1]. Hybrid materials are consists of two compounds one of them are inorganic and another one is organic in nature. Hybrid composites are the fourth generation composites that have potential in some cases it substitutes single reinforcement composites due to the improved properties and possibility of reducing the production cost of hybrid composites [2]. In recent years, Aluminium Metal Matrix Hybrid Composites (AHMMC's) are gaining widespread popularity in several technological sectors owing to their excellent corrosion and wear resistance, higher fatigue life, good high-temperature oxidation resistance in addition to being light in weight when compared with conventional alloys. At present aluminium are attractive for various applications in aerospace and automotive filed because of their high strength-to-weight characteristics [3]. Due to the increase in population, a plenty of wastage materials are generated from milling, agricultural fields, and industrial activities by the technology development. It is enlightening to note that agro wastes materials such as coconut shell, rice husk, bamboo, fly ash, bagasse, etc., are used as reinforcement.

✉ B. Vinod
vinod.c2009@gmail.com

1 Department of Manufacturing Engineering, Annamalai University, Annamalainagar 608002, India

2 Physics Section, FEAT, Annamalai University, Tamilnadu, India

3 Director, Nano Centre, Mepco Schlenk Engineering College, Sivakasi, Tamil Nadu, India

The major quantities of wastage generated from sources turn in to ashes. Since the usage of Fly ash and Rice husk ash are not still widely spread. While adding to metal matrix, these reinforcements show promising results to obtain low thermal expansion, low density, high strength of material and hardness [4]. One the most reasonable for production of hybrid metal matrix composite is liquid metallurgy technique [5]. The cost of preparing composites material using different techniques are labelled in Table 1 [6]. Comparing various techniques double stir-casting method is selected for the fabrication of hybrid composites due to an occurrence of less damage to reinforcement, maximum yield and also low cost in preparation of materials. In this process, reinforcement particles are incorporated into the aluminium matrix and producing good wettability. Hence, this processing method will reduce the common problem of porosity and ductility which are observed in composite materials. It minimises the final cost of the product.

In the present study, Aluminium A356 alloy with different weight fractions of RHA and Fly ash reinforced hybrid composites are fabricated by using double stir casting technique. The physical and mechanical properties are studied for the resulted hybrid composites. XRD, EDS and microstructure were analysed for A356 alloy /RHA & Fly Ash hybrid composite. The size distribution of the matrix alloy and reinforcement particles was measured using particle size.

2 Materials and Methods

Aluminium A356 alloy with different weight fractions (0, 5, 7.5, 10 and 12.5%) of RHA and Fly ash reinforced hybrid composites are fabricated by using double stir casting technique. The aluminium as-cast A356 was used as the matrix material with a mean particle size of 36.04µm are utilised in present work. Rice husk ash and Fly ash powders are used as the reinforcements having a mean particle size of 23µm with 99% purity and 15µm with 99.3% purity, respectively. The size distribution for each particle is a significant physical property for defining behaviour and nature of the material. Table 2 indicates details about RHA & Fly ash reinforcement particles. In the present study, four types of hybrid composites were prepared as represented in (Table 6).

Table 2 Details of Reinforcement

Reinforcement	Grain Size (µm)	Density (g/cm^3)
Rice Husk Ash	20-25 µm	1.60 g/cm^3
Fly ash	15-20 µm	1.95 g/cm3

2.1 Matrix Material

The base material A356 alloy is a precipitation hardening aluminium alloy with 7%Si, 0.3%Mg is used as matrix. The alloying elements (Si and Mg) lead to high strength and hardness. It is significant applications in auto industry, aircraft and marines [7]. A356 aluminium alloy supplied by Sargam Metals Private Limited, Manapakam, Chennai, is used in the present investigation. The element content of A356 alloy provided by the company is listed in Table 3.

2.2 Reinforcement Material

The addition of reinforcement will improve the various properties of the matrix material. The agro waste materials such as Rice husk ash and Fly ash particles are taken as reinforcement to fabricate the hybrid composites. Now a day's these particles reinforced aluminium hybrid composites are gaining importance due to low cost, good mechanical characteristics, high strength of matrix, lower the corrosion and wear resistance over the un-reinforcement alloy.

2.3 Preparation of Rice Husk Into Ash

From the Rice mill, rice husk is a by-product. It is the major waste product in the agriculture industry and most

Table 1 A comparative evaluation of the different techniques used for Hybrid metal matrix fabrication

Method	Range of shape and size	Metal yield	Damage to reinforcement	Cost
Powder metallurgy	Wide range	High	Fracture will takes place	Expensive
Spray casting	Limited shape	Medium	Cracks are formed	Expensive
Squeeze casting	Limited by per-form shape	Low	Severe damage	Moderately expensive
Liquid metallurgy (Stir casting technique)	Wide range of shapes	Very high; greater than 90%	No damage	Least expensive

Table 3 Chemical composition of as-cast aluminium A356 alloy

Constituent	Si	Mg	Fe	Cu	Mn	Zn	Others (Each)	Others (Total)
Wt. (%)	6.50-7.50	0.25-0.45	0.20	0.20	0.13	0.10	0.12	Balance

in-expensive with low density [8]. In this present study, rice husk was procured from Saroja rice mill, Tamilnadu and was thoroughly washed with water to remove the dust and dried at room temperature for one day. Washed rice husk was then pre-heated by using Muffle Furnace at 200 °C temperature for 60 minutes to remove the moisture and organic matter. During this operation, the colour of the husk changed from yellowish to black because of charring of organic matter as shown in Fig. 1a. The ash obtained from the process was conditioned in a tubular furnace at a temperature of 650 °C for 180 min to reduce the volatile and carbonaceous constituents of the ash. After this process, the loss of ignition in RHA occurs and the colour changed from black to greyish white as shown in Fig. 1b [9]. The chemical composition of Rice husk ash is presented in Table 4.

2.4 Fly Ash

Fly ash was obtained from Neyveli Lignite Corporation Limited, Cuddalore District, Tamilnadu as shown in Fig. 2. Fly ash is fine particulate waste material produced by pulverized coal-based in a thermal power station. It includes a significant amount of silica both amorphous and crystalline lime available at low costs. The particle size of reinforcement (fly ash) is also one of the major factors influencing the mechanical and tribological behaviour of hybrid composites. While, adding the fly ash particles to aluminium metal matrix which tend to improvement in hardness, tensile strength and wear resistance. However, low density and low cost are other attractive benefits for adding Fly ash [10]. Fly ash is widely used in supplement of Portland cement in concrete production. The chemical composition of fly ash is presented in Table 5.

2.5 Fabrication of Aluminium Hybrid Composites

The aluminium hybrid metal matrix composite (AHMMC) can be manufactured by various manufacturing techniques such as stir casting, sintering, pressure die infiltration, forging, chemical vapor deposition etc. In order to provide good wettability between matrix and reinforcement particles, stir casting is the most common method used in the manufacturing field [11]. The fabrication was prepared using a double stir-casting technique in accordance with Alaneme et al. [12]. The proper mixture of hard particulate not only reduces interfacial energy but also prevents chemical interaction between the dispersed phase and the matrix in a crucible furnace. Aluminium A356 alloy as matrix, Rice husk ash (RHA) and Fly Ash as reinforcement consists of different weight ratios (0, 5, 7.5, 10 and 12.5 wt.%) are utilised for the preparation of hybrid composite materials. Initially, the reinforcement particles are pre-heated individually at a temperature of 250 °C to reduce dampness and improve wettability with the molten aluminium A356 alloy. The argon-gas is charged into a crucible furnace and aluminium alloy is heated above the liquidus temperature (i.e. >650 °C) is embedded and alloy melts completely. The liquid aluminium alloy was then cooled in the furnace to a semi-solid state at 600 °C temperature illustrate. The pre-heated reinforcement particles are added at this temperature and stirring of the slurry was performed for 10 min manually. The second process was performed by using mechanical stirrer at a speed of 400 rpm for 15 min and the composite slurry was superheated at 720 °C temperature helps to improve the distribution of reinforcement particles in the aluminium based composite. Therefore finally, the molten metal was

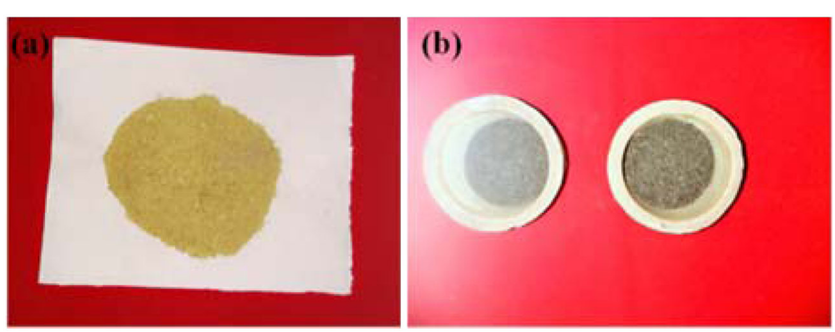

Fig. 1 Rice husk ash powder

Table 4 Chemical composition of Rice husk ash

Constituent	SiO2	Al2O3	C	CaO	MgO	Fe2O3	LOI
Wt. (%)	90.23	3.54	1.58	1.23	0.53	0.21	2.29

Table 5 Chemical composition of Fly ash

Constituent	SiO2	Al2O3	Na2O	K2O	Fe2O3	LOI	others
Wt. (%)	58.90	25.50	0.3	0.20	4.93	4.10	6.07

transmitted into the die to make a specimen in desired shape and size inserted with metallic chills to increase the solidification rate in hybrid composite material as shown in Fig. 3.

2.6 Measurement of Physical And Mechanical Properties On Aluminium Hybrid Composites

The theoretical and experimental density was measured by rule of mixture and Archimedes' principle respectively as represented in (Table 6). It was observed that, by using double stir casting technique, high amount of reinforcement particles are responsible for decreasing porosity level and minimal casting defects in hybrid composites. The physical and mechanical properties such as hardness, density, porosity and XRD, EDS analysis are studied. The micro hardness of the double-sir casting specimens was determined by using Vickers's hardness testing apparatus (HMV-2T, Shimadzu) with an operating load of 100g and a dwell time of 15s using a Vickers micro hardness testing machine (INSTRON) is shown in Fig. 4a. The micro hardness tested specimens are shown in Fig. 4b.

2.7 Initial Microstructure Of Alloy And Hybrid Composites

The Fig. 5 shows typical SEM micrographs of aluminium A356 alloy, fly ash and rice husk ash particles. The specimens were prepared using standard carbide papers, and to expose the microstructural features polished specimens were etched with Keller etching solution used to achieve fine microstructure. The microstructure of unreinforced

Fig. 2 Fly ash powder

as-cast aluminium A356 alloy is shown in Fig. 5a, Rice husk ash (RHA) is appeared by means of fiber-reinforcement consists of flakes as shown in Fig. 5b while, particles of fly ash are typically in the form of solid spheres known as precipitator fly ash as shown in Fig. 5c.

3 Results and Discussions

Determination of the effect of the addition of organic (RHA) and inorganic (Fly Ash) reinforcement with aluminium A356 alloy was studied. FE-SEM, XRD and EDS were analysed for A356 alloy /RHA & Fly Ash hybrid composite. The size distribution of the matrix alloy and reinforcement particles was measured using particle size analyser.

3.1 Study of Physical and Mechanical Properties

(a) Bulk density

Bulk density is the ratio of the mass of material to its bulk volume; pores are reduced with increasing bulk volume. Table 6 clearly displays the bulk density of the theoretical and experimental densities of aluminium alloy and A356/ RHA-Fly ash hybrid composite was found to be varied. It is gradually decreased with increasing the concentration of RHA and Fly ash particles beyond 10% reinforcement. The value of bulk density for A356 Al alloy (2.63g/cm^3), A356/10% (RHA-Fly ash) and A356/7.5% (RHA-Fly ash) is 2.66 g/cm^3 and 2.69 g/cm^3 respectively. Increasing in bulk density is attributed due to the effect of particles packing. A356 alloy containing 5%, 7.5%, 10%, 12.5% (RHA-Fly ash) hybrid composites exhibited higher bulk density than that pure A356 alloy are represented in Table 6. It is important to express the density in the form of bulk density (not relative density) because these materials will be investigated as load-bearing ceramic materials to replace other lower density materials such as Aluminium. This may be attributed due to the effect of particle size [13]. The smaller sized particles dispersed among larger ones can increase the powder reactivity that reduces the space occupied by pores between the particles.

(b) Porosity

The percentage of porosity and its size distribution in cast hybrid metal matrix composites (HMMC's) plays a major role in controlling the mechanical

Fig. 3 Experimental set up of Stir Casting Process

properties. The experimental density (Bulk density) for alloy and hybrid composites was determined by Archimedes' principle [14] according to the ASTM B962-13. Porosity (P) was calculated for all the hybrid compositions by using the below equation.

$$P = \frac{w_{\text{sat}} - w_{\text{d}}}{w_{\text{sat}} - w_{\text{sus}}} \times 100\%$$

Where, W_{sat} - saturated weight, W_d - dry weight, W_{sus}- Suspended immersed weight

It is necessary that porosity kept a minimum level when the desired high performance of machining would be achieved. The porosity of the A356 alloy and RHA-Fly ash reinforced with A356 alloy hybrid composite as a mixture of ceramic particles decreases in the range of 5%, 7.5% is shown in Table 6. The recorded results are evidenced that the 10% (RHA/Fly ash) reinforced hybrid composite (1.87%) has considerably reduced open pores when compared to A356 alloy (2.42%). Increasing the concentration of RHA/Fly ash tends to decrease the porosity of A356/5%RHA-5%Fly ash (2.38%) and A356/7.5%RHA-7.5%Fly ash (2.24%). A contrary trend is observed in the bulk density data, the 10% (RHA-Fly ash) has a very low porosity among the other three concentrations. The result suggests that 10% concentration of RHA-Fly ash is effective, due to the removal of pores and it enhances the mechanical properties of the hybrid composites. In case of further increasing the concentration of 12.5% (RHA/Fly ash) tends to increase the porosity (2.49%), due to an effect of low wettability and high agglomeration at the high reinforcement content. Pore nucleation at the matrix interface is also the reasons for higher porosity for 12.5% (RHA-Fly ash). Reduction of porosity in the 10% (RHA-Fly ash) due to hard particles is well wetted by the matrix and uniform distribution of particle in the matrix of the hybrid composite. Therefore, the A356/10%RHA-10%Fly ash can be considered as a potential reinforcement for hybrid composite preparation. More pores are filled by RHA/Fly ash and the number of open pore decreases, at 10% (RHA-Fly ash). The porosity is the main factor that affects the micro hardness of the hybrid composites.

(c) Micro hardness Test

Micro hardness test was conducted on the polished specimens of A356 aluminium alloy and A356/ RHA

Table 6 Physical and Mechanical Properties Al A356 Alloy and A356/RHA-Fly ash hybrid Composites

Sl No.	Composition (wt %)	Theoretical Density (g/cm3)	Experimental Density (g/cm3)	Porosity (%)
1.	A356 Alloy	2.68	2.63	2.42
2.	A356/5% RHA-5% Fly ash	2.71	2.66	2.38
3.	A356/7.5% RHA-7.5% Fly ash	2.73	2.69	2.24
4.	A356/10% RHA-10% Fly ash	2.79	2.74	1.87
5.	A356/12.5% RHA-12.5% Fly ash	2.81	2.76	2.49

Fig. 4 **a** Experimental set up of Vickers hardness testing machine, **b** Fabricated micro hardness Prepared Samples

- Fly ash hybrid composite. The samples were ground, polished mechanically and etched chemically by using Kroll's reagent (a mixture of 7 ml HF, 3 ml HNO_3 and 50 ml H_2O). The tests were conducted at three different positions to keep away from the potential result of indenter on the hard reinforcement particle, the average of five readings are taken and reported. Figure 6 shows that hardness of hybrid composite increases with the content of reinforcements increasing up to A356/10%RHA-10% Fly ash hybrid composite individually, which could be attributed to the existence of RHA and Fly ash hard particles. It shows that hardness increases with increasing weight percentage of reinforcements up to 96 MPa respectively. Tests are carried out at different positions to avoid the potential result of indenter resting on the hard reinforcement particle [15]. The addition of organic and inorganic particles, the mechanical property of the A356/10%RHA-10% Fly ash hybrid composite observed high hardness due to the formation of more interfaces in the matrix. Therefore, higher strength and hardness is always associated with a lower porosity of the HMMCs.

(d) Tensile Test

Tensile tests were used to assess the mechanical behaviour of the matrix alloy. By following the ASTM

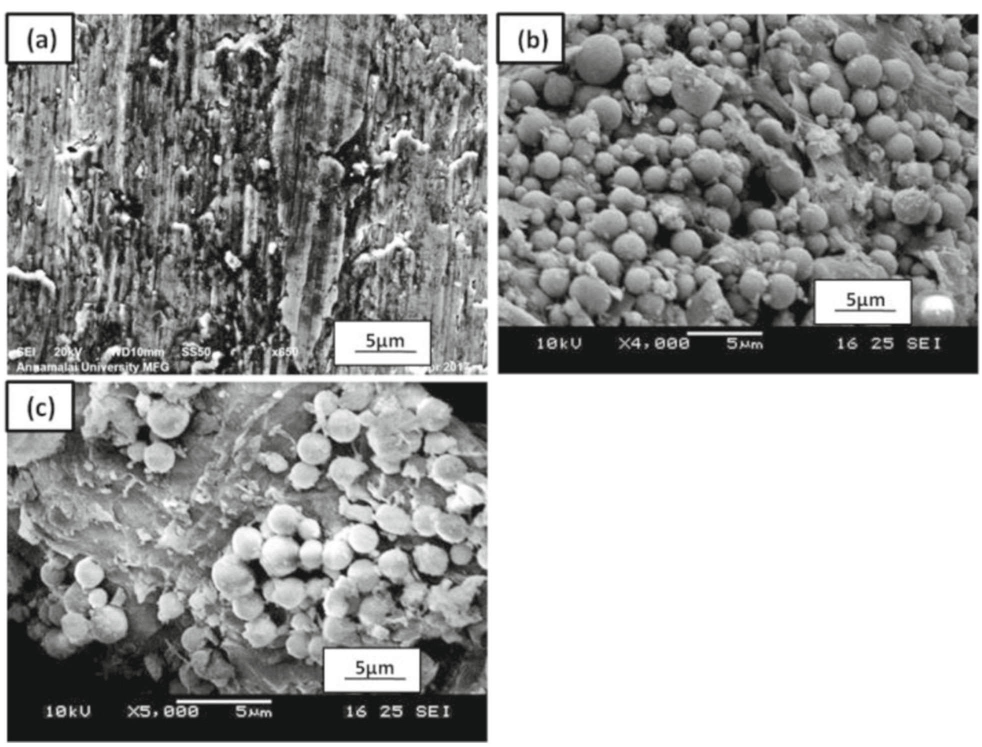

Fig. 5 SEM micrographs of **a** A356 alloy, **b** RHA particles and **c** Fly ash particles

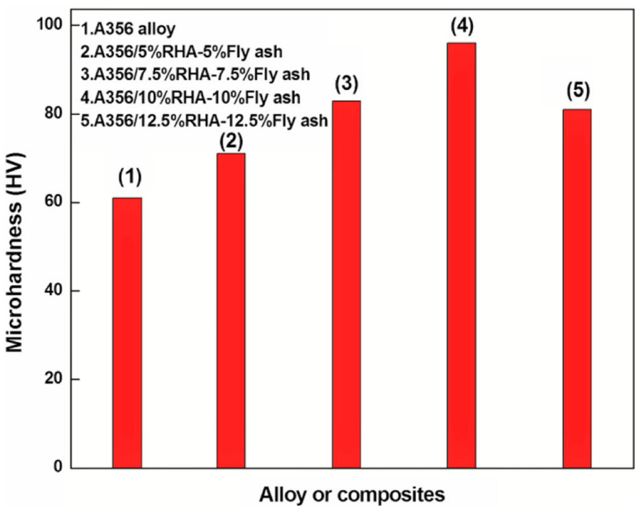

Fig. 6 Graphical representation of Micro hardness test

standard tensile specimens with diameter of 12mm and length of 120mm are prepared by Ultimate tensile strength(UTS), often shortened to tensile strength (TS) ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, when the specimens cross-section. The mechanical properties of tensile, impact and flexural for aluminium A356 alloy is represented in Table 7 The tensile test was conducted at a load of 400KN with a dwell time 10s using 'Instron universal testing machine' as per ASTM E8 standards.

(e) Impact test

To determine the toughness (or) impact strength of aluminium alloy in the presence of notch and specimen is struck by a "tup" attached to the swinging pendulum of specific design and weight. The specimen breaks at its notched cross-section upon impact, and the upward swing of the pendulum is used to determine the amount of energy absorbed (notch toughness) in the process. Energy absorption is directly related to the brittleness of the material. This destructive test involves fracturing a notched impact test specimen and measuring the amount of energy absorbed by the material during fracture. The impact test was conducted according the standard of ASTM E-23. The impact specimens with length 55mm, diameter 10mm and charpy V-notch 2mm depth with notch radius are prepared by using charpy impact testing machine. The test result could be seen on Table 7.

(f) Flexural Test

Flexure tests are generally used to determine the flexural modulus or flexural strength of a material. The material is laid horizontally over two points of contact (lower support span) and then a force is applied to the top of the material through either one or two points of contact (upper loading span) until the sample fails. The maximum recorded force is the flexural strength of that particular sample. Flexural test was conducted to determine the fracture strength by a four-point bending test using following equation.

$$K_{\mathrm{IC}} = \frac{6Ma^{\frac{1}{2}}}{db^2}y \quad (1)$$

Where, M - moment of the four points bending load, d and b - width and height of the bending samples bar, L1 and L2 the outer and inner spans, respectively and Y is the equation about (a/b) ratio. For the stable crack growth mode in the single edge notched beam four-point bending specimen, it was suggested that a/b = 1/2, L_1 = 40mm and L_2 = 20mm. The outer and inner spans were 40 and 20 mm, respectively. The nominal dimensions of the testing bars are taken as 3mm x4mm x50 mm as per ASTM D790- 17 standards. The result of aluminium alloy is plotted in Table 7.

3.2 Particle Size Distribution (PSD) of Organic and Inorganic Hybrid Composites

For the physical and chemical property of a material, PSD is an important tool where it affects the strength and load-bearing properties of composite materials. The size distribution of each particle is represented in the form of a histogram as shown in Fig. 7. The particle size of A356 aluminium alloy is observed as 36.04 µm and it is shown in Fig. 7a. Whereas, Fig. 7b shows the particle size of Rice husk ash is taken as 23 µm and the particle size of fly ash is taken as 15 µm as shown in Fig. 7c [16, 17]. However, it shows the size distribution of each material and tends to improve the properties of many industrial manufacture products. The major requirements for uniform distribution of particles in the melt are found to be good wettability.

Table 7 Mechanical properties for aluminium alloy

Sample	Tensile strength (MPa)	Yield stress (MPa)	% Elongation GL of 60mm	Impact properties (Joules)	Flexural properties (MPa)
A356 alloy	130 MPa	90 MPa	2.50 %	2.03 J/mm2	397 MPa

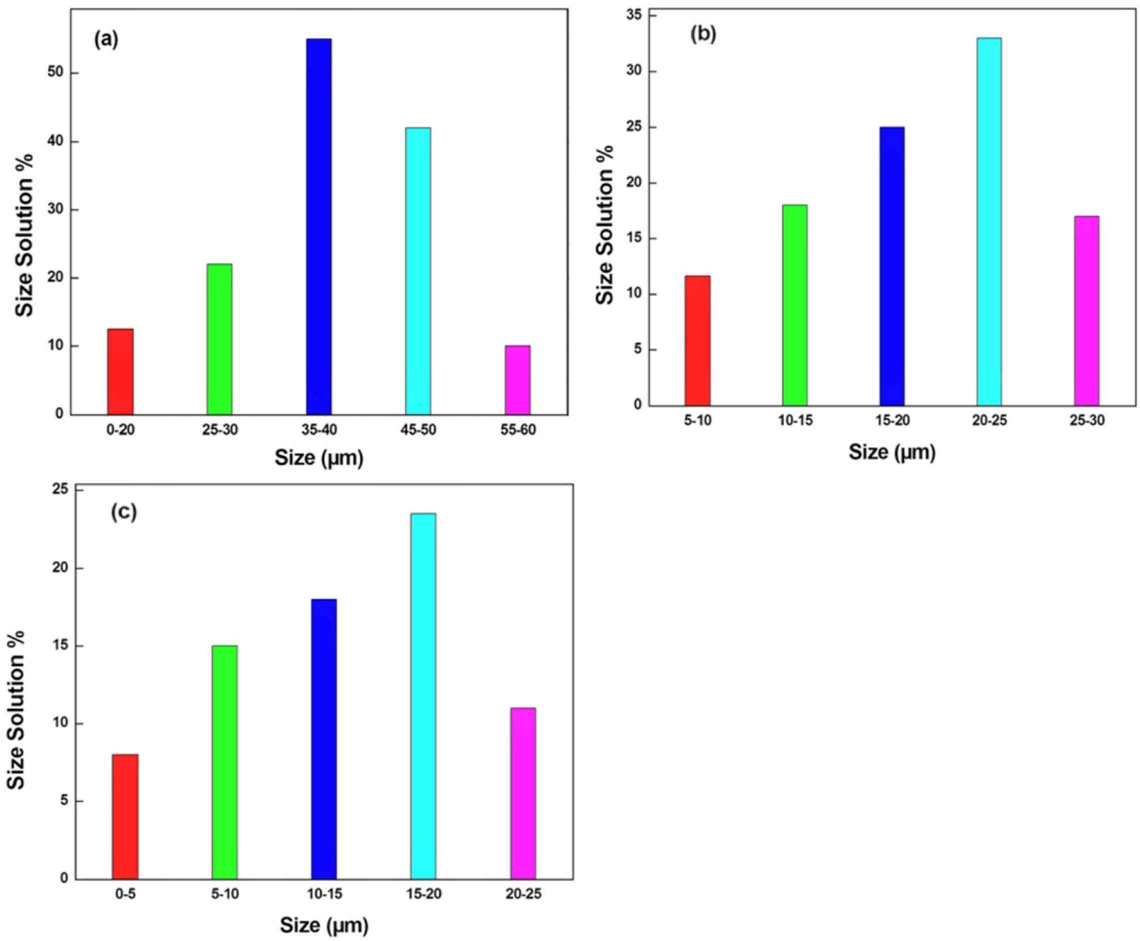

Fig. 7 Particle size distribution of **a** Aluminium A356 alloy, **b** Rice Husk Ash (RHA) and **c** Fly ash

3.3 Microstructure Analysis of Aluminium Hybrid Composites

The microstructure plays a major role in analysing the distribution of distinct phases in an aluminium matrix alloy. The samples were cleaned with acetone and dried in air before measurement. The microstructure was studied by using Field Emission Scanning Electron Microscope (FE-SEM). Figure 8a and e represents the microstructure of the aluminium A356 matrix alloy and A356/RHA and Fly ash hybrid composites. It shows that the phases are near uniformly distributed in the metal matrix. The micro structure revealed good retention of RHA and Fly ash particles in the matrix. Rice husk ash (RHA) has the appearance of fibre- reinforcement flakes and Fly ash was the morphology of hollow spheres, some of them with patent pores. RHA and Fly ash particles are successively incorporated with aluminium A356 alloy by using double-stir casting technique. Microstructure analysis reveals that uniform distribution between reinforcement particles and aluminium alloy. This type of reinforcement particles has a distinct effect on the properties of particulate hybrid composites. The main task is to get a uniform distribution of particles in the liquid melt and then to reduce the segregation of particles during pouring. From the Fig. 8(a), it is seen that aluminium A356 alloy is not uniformly distributed cracks and pores are observed due to low density and high porosity. It will reduce while adding proper reinforcement to the matrix [18]. The FE-SEM micrographs of the prepared A356/RHA-Fly ash hybrid Composites are presented in (Fig. 8b and e), it can be seen that increasing the weight fraction of reinforcement particles decreasing the porosity level and increasing the density which possess the quality of casting. It is evident from the Fig. 8b that the incorporation of RHA and Fly ash particles influence the solidification pattern of the semi-solid composite melt which resulted in the refinement of grains. The grain refinement occurs due to following two factors. First, the incorporation of Fly ash and RHA particles develop resistance to the growing Al grains during the solidification process. Second, reinforcement particles act as a grain nucleation site and the aluminium grains solidify on it. When the weight fraction of reinforcement particles increases, number of nucleation sites is created

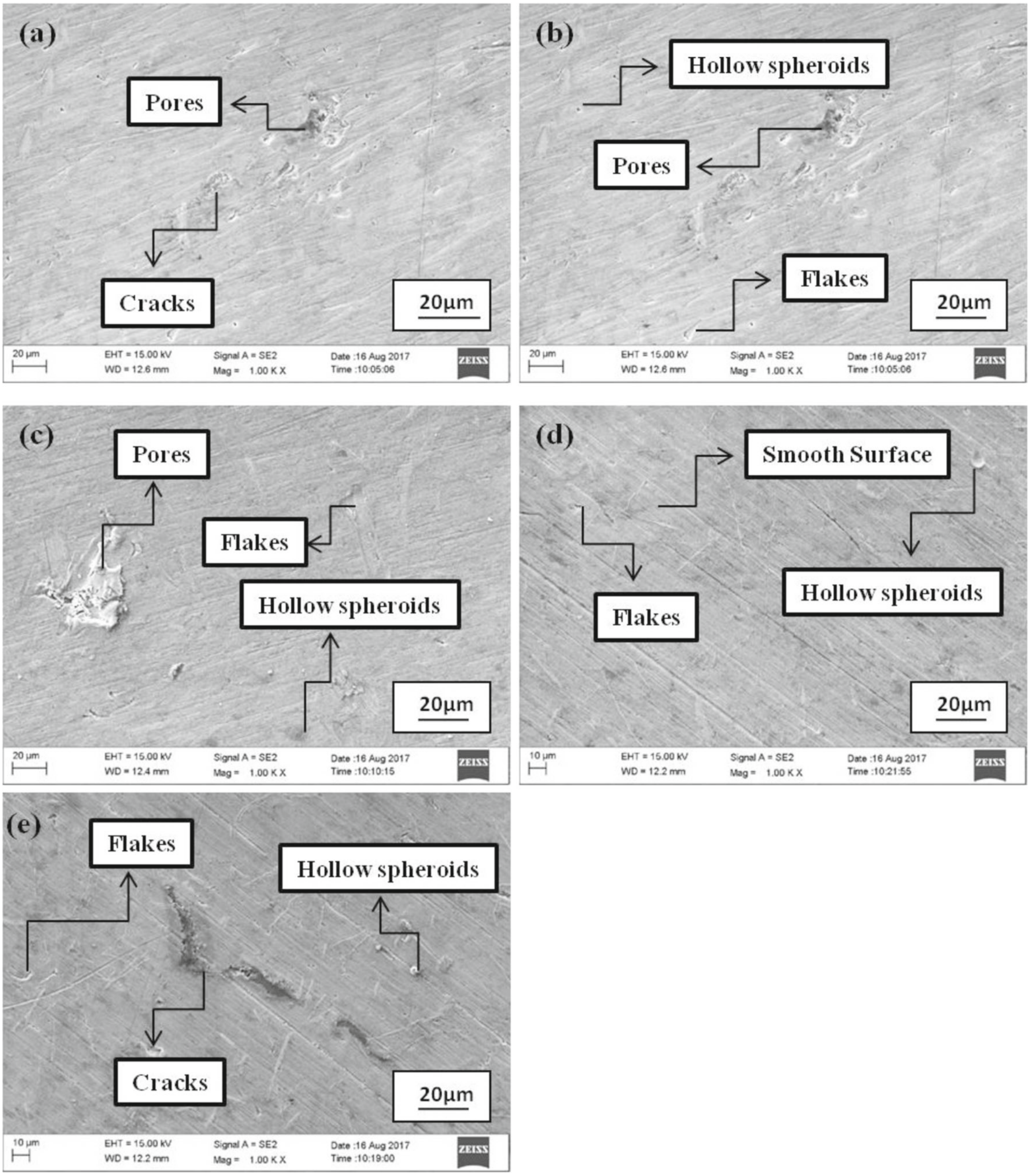

Fig. 8 FE-SEM micrographs of **a** A356 aluminium Alloy, **b** A356/5% RHA-5% Fly ash, **c** A356/7.5%RHA 7.5% Fly ash, **d** A356/10% RHA-10% Fly ash and **e** A356/12.5% RHA-12.5% Fly ash hybrid Composites

owing to constitutional under cooling zone in front of the particles. The net result is more grain refinement forming finer grains. It can be seen from Fig. 8c; most of the fly ash particles and RHA are located in intragranular regions. Intragranular distribution of ceramic particles is preferred over intergranular distribution in aluminium hybrid metal matrix composites (AMHC'S) to obtain higher hardness tends to increase the mechanical properties [19]. It is further evident from Fig. 8d, the reinforcement particles are distributed near homogeneously in the aluminium matrix. If reinforcement particles increases, amount of nucleation sites are formed more grain refinement which tends to smooth surface. This type of particulate dispersion is essential requirement to increase mechanical properties of the AHMCs. The bulk density variation between the aluminium matrix and reinforcement particles plays a significant role during solidification.

Further increasing weight fraction, A356/12%RHA-12% Fly ash hybrid composite at higher magnification, the figure reveals the finer details of the interface between the aluminium matrix and Fly ash and RHA particle; no reaction products surround the reinforcement particles. It is evident from Fig. 8e, there is no interfacial reaction between aluminium alloy and reinforcement particles. It is also identified that when an interfacial reaction takes place between aluminium and ceramic particles, reaction products always surrounds the particle and become weaken the mechanical strength. A pure interface is required to appreciate the load bearing capacity of the AHMC. It can be concluded that the primary aluminium size decreases as the addition of reinforcement particles increases. Further increasing of reinforcement 12.5% of RHA and Fly ash in aluminium A356 alloy it leads to the occurrence of non-homogeneous distribution, agglomeration of particles

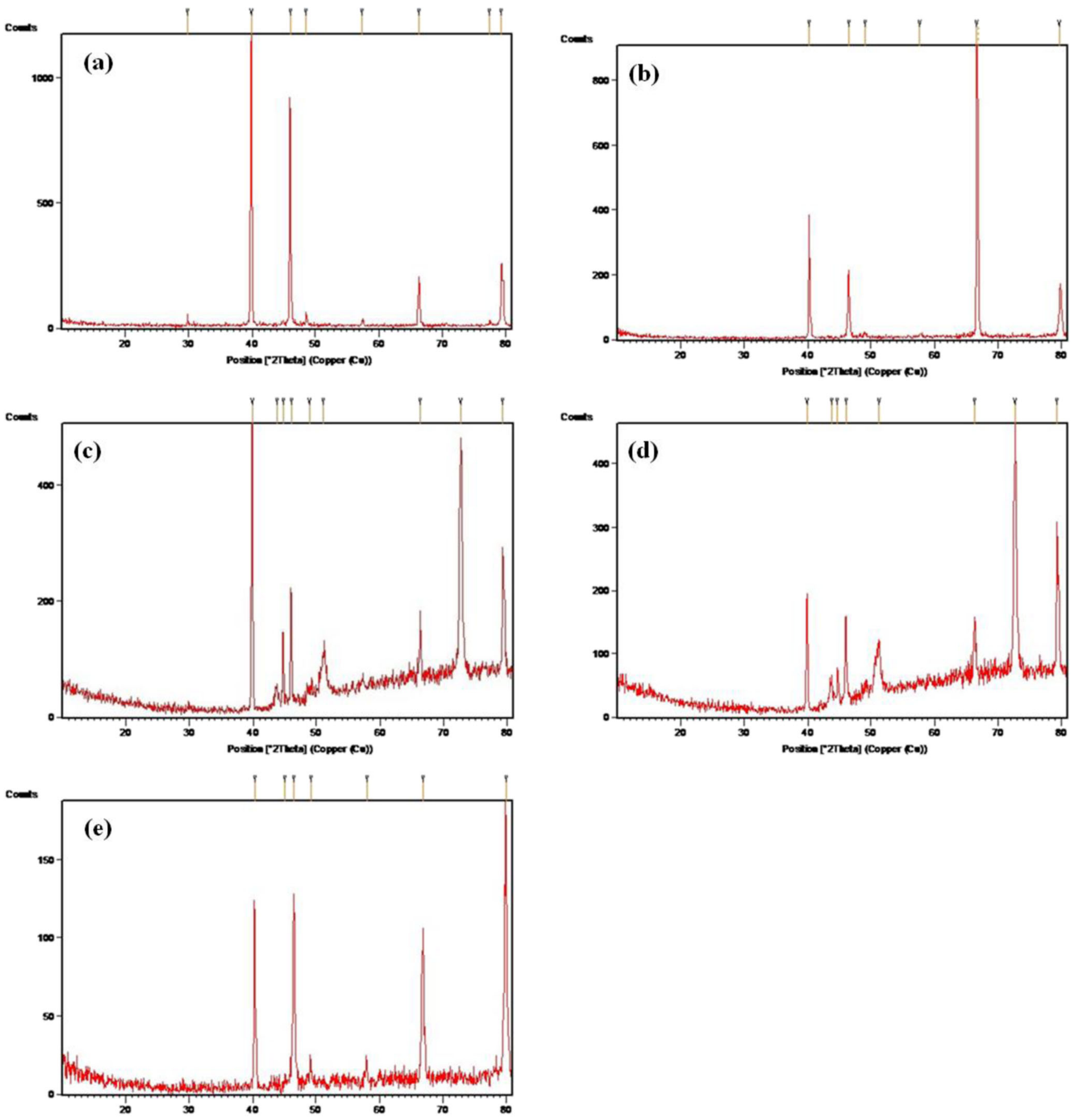

Fig. 9 X-Ray Diffraction Analysis of **a** Aluminium A356 Alloy, **b** A356/5% RHA-5% Fly ash, **c** A356/7.5% RHA-7.5% Fly ash, **d** A356/10% RHA-10% Fly ash and **e** A356/12.5% RHA-12.5% Fly ash hybrid Composites

and a certain degree of porosity increases; weak interfacial bond is identified between matrix alloy and reinforcements lead to an embrittlement of hybrid composites due to cluster formation. The outcome in hybrid composites is associated with a decrease in micro hardness. Therefore, it is clearly identified that A356/10%RHA-10%Fly ash hybrid composite is a good choice for automobile and industrial sector.

3.4 Analysis of X-Ray Diffractometer

The XRD analyses were carried on all materials by using the X-Ray Diffractometer to analyse structural properties and identify spatial arrangements of atoms in crystalline materials. Figure 9a and e shows the X-Ray diffraction pattern of A356 Alloy and A356/RHA- Fly ash hybrid composites. The XRD pattern has confirmed the presence of Major Al alloy in the sample. From Fig. 9a, the Al alloy consists of an Al phase as a major phase and it is observed for all the spectra nearly at $2\theta = 39°, 46°, 66°, 79°$. The observed values well coincide with the standard JCPDS card No: 89 - 4037 [20].

Figure 9b and c shows an XRD pattern of hybrid composite specimen and the Al phase observed at $2\theta = 40°, 46°, 66°, 79°$ is coexistent with a new peak at $2\theta = 20°, 46°, 49°$ formed in A356/5%RHA-5%Fly ash and A356/7.5%RHA-7.5%Fly ash specimens due to the SiO_2, Al_2O_3, Fe_2O_3 (JCPDS card no: 86-1629, 29-1128, 86-0550). It can be seen from XRD profile of 10% (RHA-Fly ash) hybrid composite that the intensity of the reflections is significantly high, indicating the higher crystalline is formed around a sample. The intensity of Al phase (peak) significantly decreased in A356/10%RHA-10%Fly ash specimens and subsequently, some new peaks with high intensity grew up at $2\theta = 20°, 30°, 46°, 49°$ due to the presence of high amount of SiO_2, Al_20_3, Fe_2O_3 as shown in Fig. 9d. This observation leads to a conclusion that the integrity of Rice husk ash and fly ash particles are thermodynamically stable at the applied casting temperature. In case of A356/12.5%RHA-12.5%Fly

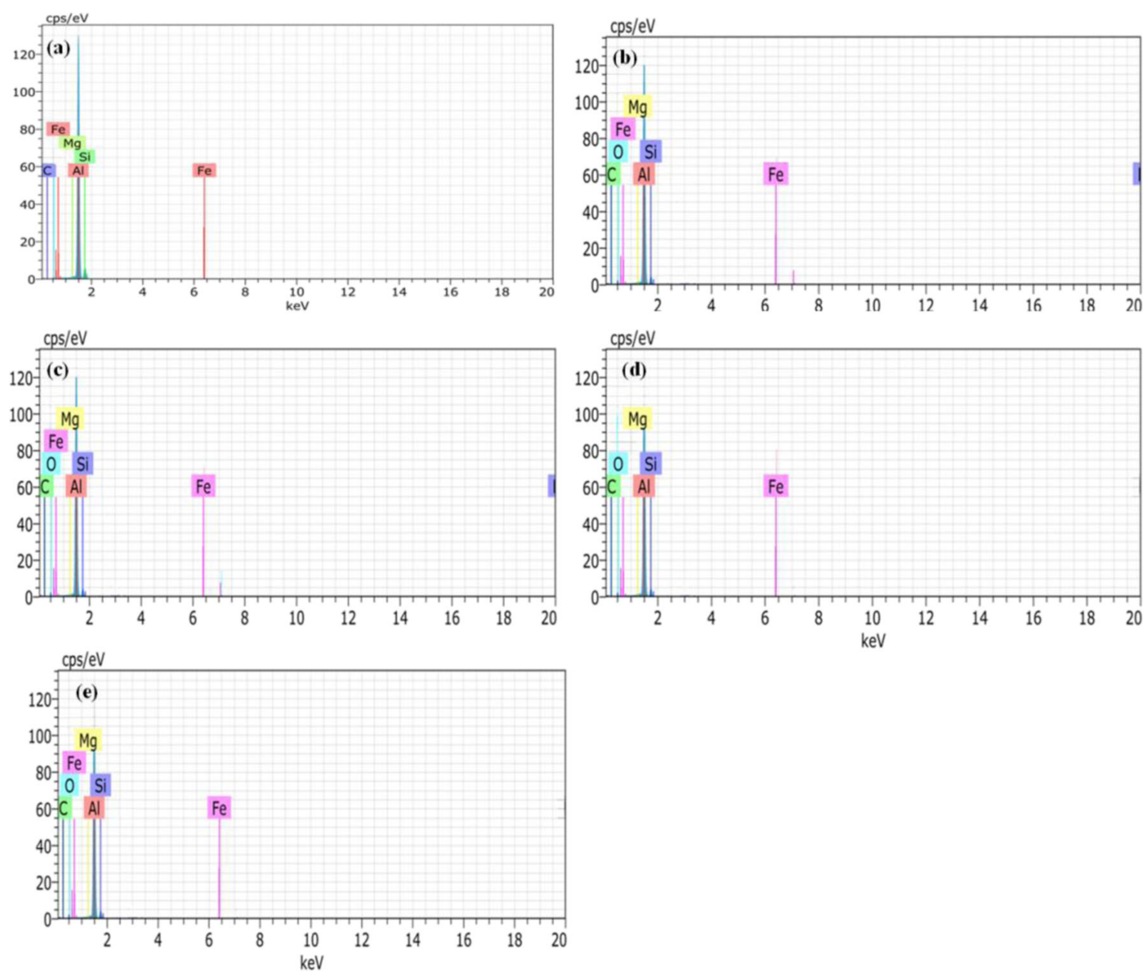

Fig. 10 EDS Analysis of **a** Aluminium A356 Alloy, **b** A356/5% RHA-5% Fly ash, **c** A356/7.5% RHA-7.5% Fly ash, **d** A356/10% RHA-10% Fly ash and **e** A356/12.5% RHA-12.5% Fly ash hybrid Composites

ash specimen, Al peaks slightly shifted and decreased the intensity. New peaks formed at $2\theta = 40°, 66°$ shows more intensity due to the formation of interfacial compound $MgAl_2O_4$ due to rice husk ash present in the specimen. More amount of Al_2O_3 are present and SiO_2 combine with Mg in the aluminium alloy leads to a formation of the brittle intermetallic compounds was utilized in the field of automobile sectors. The brittle interfacial reaction product formed ($MgAl_2O_4$) leads debonding would be expected to occur as a result of processing condition and act as critical flaws, which lower the strength of the A356/12.5%RHA-12.5%Fly ash specimen. From Fig. 9e, it is inferred that the diffraction peaks of any other elements except aluminium, Al_2O_3, Fe_2O_3, and SiO_2 are not detected. The results suggest that formation of new brittle phases with higher intensity plays a major role in the properties of the RHA and Fly ash with Al alloy matrix composites [21]. Therefore, XRD pattern showed that these crystalline phases are increasing weight fraction of reinforcement increases and hence, it is beneficial to improve the mechanical strength of resultant hybrid composites. The information about the quantitative phase analysis is identified by XRD analysis to determine the relative amounts of phases in a mixture by using reference relative peak intensities.

3.5 Elemental Analysis of Aluminium Hybrid Composites

Materials Science has become an essential part of both industrial and academic research. Since, as part of this study experience with EDS and XRD measurement techniques are required for the elemental analysis or chemical characterization of advanced materials. In Fig. 10, Y-axis shows the counts (number of x-rays received and processed by the detector) and the X-axis shows the energy level of the counts [22]. Figure 10a shows the EDS spectrum of aluminium A356 alloy with Al, Si and Mg peaks. Figure 10b and e shows the EDS spectrum of A356/RHA and Fly ash hybrid composites which indicates the presence of Al, C, Mg, Si, and O peaks. Carbon and oxygen are predominant in aluminium alloy sample whereas silicon is predominant in 10% hybrid composite due to high amount reinforcement (i.e. O and C peaks) in the material as shown in Fig. 10d; it leads to softening the material. From Fig. 10e, aluminium is predominant and reducing silica content in 12.5% sample this is due to poor wettability tends to increase of porosity level and reduces the strength of material [23]. Presence of carbon in the samples (i.e., Fig. 10b and e) indicates the participation of organic molecules from rice husk ash; silicon and aluminium indicate to form silica-aluminous phase from fly ash as well as amorphous silica from rice husk ash [24]. Thus, confirming the formation of inorganic and organic hybrid composites.

4 Conclusion

Aluminium A356 alloy with different weight fractions of (0, 5, 7.5, 10 and 12.5%) RHA and Fly ash reinforced hybrid composites are successfully fabricated by using double stir casting technique. Determination the effect of the addition of organic (RHA) and inorganic (Fly Ash) reinforcement with aluminium A356 alloy was studied. The purpose of reuse wastage materials into raw materials is especially beneficial not only for the environment but also automotive sectors that require large volumes of materials in the production of connecting rods and piston rings. FE-SEM and XRD, EDS and microstructure were analysed for A356 alloy /RHA & Fly Ash hybrid composite. The mechanical property of A356 alloy matrix was increased due to the addition of organic and inorganic particles, a formation of more interfaces in the matrix. Therefore, higher strength and hardness is always associated with a lower porosity of the HMMCs. The density of the hybrid composites increases while increasing the reinforcement particles with A356 alloy. A356/10%Fly ash&10%RHA hybrid composite offered higher hardness compared to other hybrid composites is due to uniform distribution of reinforcement particles in the melt and having good wettability. However, when the reinforcement contents of RHA and Fly ash increase to 12.5 wt%, it weakens the interface by the pre-existing force. The brittle-interfaced reaction product phases are formed, resulting in a non-beneficial effect on the strength above (or) below 10 wt% RHA and Fly ash. A significant improvement in the mechanical property was observed when adding the reinforcement with as-cast aluminium matrix alloy.

Acknowledgments The authors wish to thank Professor Dr. N.Selvakumar, Director, ‘Nano centre’, Mepco Schlenk Engineering College, Sivakasi, Tamil nadu, India rendered the support for the fabrication of Hybrid Composites. The authors also wish to acknowledge for the extended facilities by ‘Centralised Instrumentation Science Laboratory’, the Department of Physics, Annamalai University.

References

1. Rawal SP (2001) Metal-matrix composites for space applications. JOM J Miner Met Mater Soc 53:14–17
2. Singh J, Chauhan A (2016) Characterization of hybrid aluminum matrix composites for advanced applications–a review. J Mater Res Technol 5:159–169
3. Dwivedi SP, Sharma S, Mishra RK (2015) Microstructure and mechanical behavior of A356/SiC/Fly-ash hybrid composites produced by electromagnetic stir casting. J Braz Soc Mech Sci Eng 37:57–67
4. Subrahmanyam APSVR, Narsaraju G, Rao BS (2015) Effect of rice husk ash and fly ash reinforcements on microstructure and mechanical properties of aluminium alloy (AlSi10Mg) Matrix composites. Int J Adv Sci Techn 76:1–8

5. Bhushan RK, Kumar S, Das S (2013) Fabrication and characterization of 7075 Al alloy reinforced with SiC particulates. Int J Adv Manuf Technol 65:611–624
6. Hashim J, Looney L, Hashmi MSJ (1999) Metal matrix composites: production by the stir casting method. J Mater Process Technol 92:1–7
7. Shivkumar S, Wang L, Keller C (1994) Impact properties of A356-T6 alloys. J Mater Eng Perform 3:83–90
8. Chandrasekhar S, Pramada PN (2006) Rice husk ash as an adsorbent for methylene blue-effect of ashing temperature. Adsorption 12:27–43
9. Prasad DS, Krishna AR (2012) Tribological properties of A356.2/RHA composites. J Mater Sci Technol 28:367–372
10. Rohatgi PK (1994) Low-cost, fly-ash-containing aluminum-matrix composites. JOM J Miner Met Mater Soc 46:55–59
11. Dwivedi SP, Sharma S, Mishra RK (2015) Microstructure and mechanical behavior of A356/SiC/Fly-ash hybrid composites produced by electromagnetic stir casting. J Braz Soc Mech Sci Eng 37:57–67
12. Alaneme KK, Akintunde IB, Olubambi PA, Adewale TM (2013) Fabrication characteristics and mechanical behaviour of rice husk ash–Alumina reinforced Al-Mg-Si alloy matrix hybrid composites. J Mater Res Technol 2:60–67
13. Kulkarni SG, Menghani JV, Lal A (2016) Investigation of mechanical properties of fly ash and Al_2O_3 reinforced A356 alloy matrix hybrid composite manufactured by improved stir casting. IJEMS 23:27–36
14. Anandajothi M, Ramanathan S, Ananthi V, Narayanasamy P (2017) Fabrication and characterization of Ti6Al4V/TiB_2-TiC composites by powder metallurgy method. Rare Met 36:806–811
15. Vanarotti M, Shrishail P, Sridhar BR, Venkateswarlu K, Kori SA (2014) Study of mechanical properties & residual stresses on post wear samples of A356-SiC metal matrix composites. Procedia Mater Sci 5:873–882
16. Givi AN, Rashid SA, Aziz FNA, Salleh MAM (2010) Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete. Construct Build Mater 24:2145–2150
17. Bui DD, Hu J, Stroeven P (2005) Particle size effect on the strength of rice husk ash blended gap-graded Portland cement concrete. Cem Concr Compos 27:357–366
18. Hwang CL, Huynh TP (2015) Effect of alkali-activator and rice husk ash content on strength development of fly ash and residual rice husk ash-based geopolymers. Construct Build Mater 101: 1–9
19. Dinaharan I, Kalaiselvan K, Murugan N (2017) Influence of rice husk ash particles on microstructure and tensile behavior of AA6061 aluminum matrix composites produced using friction stir processing. Composites Commun 3:42–46
20. Sivakumar G, Ananthi V, Ramanathan S (2017) Production and mechanical properties of nano SiC particle reinforced Ti–6Al–4V matrix composite. Trans Nonferrous Metals Soc China 27:82–90
21. Amritphale SS, Mishra D, Mudgal M, Chouhan RK, Chandra N (2016) A novel green approach for making hybrid inorganic-organic geopolymeric cementitious material utilizing fly ash and rice husk. J Environ Chem Eng 4:3856–3865
22. Selvam JDR, Smart DR, Dinaharan I (2013) Microstructure and some mechanical properties of fly ash particulate reinforced AA6061 aluminum alloy composites prepared by compocasting. Mater Des 49:28–34
23. Liu Y, Zheng L, Li X, Xie S (2009) SEM/EDS and XRD characterization of raw and washed MSWI fly ash sintered at different temperatures. J Hazard Mater 162:161–173
24. Shoumkova A, Stoyanova V (2013) SEM–EDX and XRD characterization of zeolite NaA, synthesized from rice husk and aluminium scrap by different procedures for preparation of the initial hydrogel. J Porous Mater 20:249–255