A novel approach for utilization of agro-industrial waste materials as reinforcement with Al–7Si–0.3Mg matrix hybrid composite on tribological behaviour

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Abstract

Waste particles are the huge environmental problem facing today. This paper mainly focuses on utilization of waste particles and aspect of tribology by examining economic, environmental impact on wear loss and coefficient of friction. Aluminium with a different weight fraction of agro (RHA) and industrial (fly ash) waste particulates are fabricated by double stir-casting process. The dry sliding wear behaviour of Al alloy and aluminium hybrid composites for various applied load, sliding distance with sliding speed on wear rate and friction coefficient was conducted by pin-on-disk apparatus. The hypothesis of this study is decreasing the wear loss and coefficient of friction increasing the lifespan of material and also minimising the cost of material. Limited attempts are made on aluminium with waste particles to examine the effect of sliding wear rate. The A356/7.5%RHA–7.5% fly ash hybrid composite achieved higher wear resistance superior to the as-cast alloy.

Keywords Waste particles · Tribology behaviour · Environment · Ultrasonic probe · Hardness · Wear debris

1 Introduction

Composite materials are a mixture of two or more homogeneous phases at a macro scale is bonded together with a set of desirable properties, can be obtained. The sustainable industry growth and people's life improvement greatly depend on the usage of the alternative product in various fields. Composites are generally classified into four generations such as:

- (a) 1st generation (1940s)—deal with Glass fiber reinforced Composites.
- (b) 2nd generation (1960s)—deal with high Performance composites in an industrial area.
- (c) 3rd generation (1970s–1980s)—deal with smear layer and dentinal fluid.
- (d) 4th generation (1990s)—deal with Hybrid materials and Nano composites.

The fourth generation was gained a significant focus in this work until today. Hybrid composites primarily consist of organic and inorganic materials. At present aluminium hybrid metal matrix composites (AHMMC's) are achieving widespread popularity for producing higher hardness, increasing wear resistance and greater fatigue life in addition to lightweight material compared with conventional alloys [1]. Now-a-days more studies are focusing on the development of aluminium based hybrid composites is carried out to explore their possible applications in various engineering and automotive fields. AMMCs reinforced with agro-waste particles have possessed better wear characteristics owing to reduce wear rate increases mechanical strength and wear resistance to expand material life. Recycling of waste particles become an increasingly important aspect of sustainability. For fabrication compare with other techniques, liquid process gaining some advantages such as easier control of matrix

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structure, good wettability between matrix and reinforcement particles, low cost, better finishing can be produced in this method [2]. To achieve extra strength and durability, recently researchers are focused on a production of AHMMC's through stir casting process. The result shows an improvement in mechanical properties and uniform distribution between the reinforcement and matrix when the particles are introduced into casting slurry at minimum temperature for melting the alloy [3].

In replacement of components and machinery are the most significant industrial problem is wear. The pin-on-disc were performed using an instrument known as Tribometer, it travels in one direction for an unlimited time even at higher velocity pin from a centre of the disc helps material safely and steadily throughout wear test. The study on wear by means of hybrid composite materials is essential for the automobile sector. Moreover, wear loss increases as it reduces downtime, operating cost and fuel utilisation are benefits in structural components [4]. Wear mechanism of aluminium alloys can be improved by the addition of proper reinforcement in the matrix phase. The wear properties have been influenced by the addition of hard particles such as SiC, RHA, jute, fly ash, Coconut shell, etc. and are enhanced in the matrix phase of a composite material. The agro-wastage particles are taken as reinforcement with matrix alloy recognized lower wear rate than base alloy. This study indicates the addition of lightweight particles increases not only strength but also reduces wear loss simultaneously. While taking sliding distance as constant load and sliding speed is applied on a disc to investigate tribology. The wear resistance decreases with an increase of sliding speed, which is similar to that of other metallic materials. Elango et al. [5] reported that wear behaviours are dependent on sample materials. The counterface materials and its surface finish were included with sliding distance and applied load at various test conditions. In recent times, more focus is made on the usage of high strength Al-Si alloys for structural applications in aerospace and general engineering sectors. This demand is needed to conduct dry sliding wear behaviour on aluminium composite materials. To examine the wear behaviour, limited attempts made on 7XXX alloy reported by

Venkataraman and Sunderarajan [6]. Dry-sliding wear behaviour of Al A356 alloy with lightweight material exhibits high stiffness compared to other composites. However, these materials are good potential for utilizing structural sheets in aeroplanes and armours in the military field. From the literature no work has been done so far to study the effect of applied load, sliding speed and sliding velocity on Al A356 alloy with organic and inorganic as different weight fraction to observe wear rate.

It was first attempt usage of waste particles as reinforcement for global sustainable development in cost reduction, material savings and environmental protection. The tribological goal is to increase wear resistance and reduce wear loss and friction coefficient shows long operational lifespan of material, improving material quality and increasing durability of A356 alloy.

2 Materials and methods

2.1 Selection of material

Cast aluminium alloys are widely used to manufacture the composite materials depends upon need in industries. Among other aluminium alloys, A356 (Al-7Si-0.35Mg) contains high machinability and hardness used in the manufacturing of truck chassis parts and connecting rods. The chemical composition of an aluminium alloy as received from the company is represented in Table 1.

Study on hot deformation using light-weight materials is a significant role for manufacturing engineers and material scientists [7]. In present work, the particle size of waste particles such as RHA is taken as 23 μm and fly ash is taken as 15 μm attributed to high strength and lightweight to minimize the cost of production. The major industrial wastage is fly ash obtained from heating of coal at elevated temperature. The main reason usage of fly ash as reinforcement due to the presence of alumina and silicon oxide helps to increase material strength utilised not only in industries but also construction field. Present study fly ash is taken from Neyveli Lignite and chemical composition of as received fly ash is represented in Table 2.

Table 1 Chemical composition of aluminium A356 alloy

Constituent	Si	Mg	Cu	Fe	Mn	Zn	Others (each)	Others (total)
Wt. (%)	6.5–7.0	0.3	0.12	0.15	0.10	0.13	0.12	Balance

Table 2 Chemical composition of as received fly ash

Constituent	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	Fe ₂ O ₃	LOI	Others
Wt. (%)	58.90	25.50	0.3	0.20	4.93	4.10	6.07

2.2 Conversion of rice husk into ash

Among various mixtures of reinforcement like jute, rice husk, palm, plant stalks, hulls, leaves, etc., rice husk (RH) is containing low porosity level and high stiffness due to the presence of high amount silica content utilising a large amount of solid waste by-product in industries. However, to increase material strength major amount of rice husk is turned into ash in preparation of hybrid composites. By using vortex method now-a-days initially many industrial sectors are focused on the utilization of wastage particles in a useful manner by dispersing into aluminium melt. In this study, rice husk was obtained from Saroja rice mill, Tamilnadu and was thoroughly washed with water to remove the dust and dried at room temperature for 1 day. Washed rice husk was pre-heated at 200 °C temperature for 60 min in a muffle furnace to remove the moisture. During this operation, the colour of the husk changed from yellowish to black because of charring of organic matter. The ash obtained from a muffle furnace was transformed into a tubular furnace at a temperature of 650 °C for 180 min to reduce the volatile and carbonaceous constituents of the ash [8]. During this process colour of ash changed from black to greyish white tends to increase the strength of a material and chemical composition is presented in Table 3.

2.3 Fabrication of aluminium hybrid composite

The stir casting method is one of the better known approaches in fabrication of aluminium composites to maintain a uniform distribution between matrix and reinforcement. A double-stir casting technique is conducted for preparation of hybrid composite materials and details are represented as shown in Fig. 1. After successful preparation of hybrid composite, then the molten metal was transmitted into a mild steel finger die in the form of cylindrical rods with 20 mm diameter and 150 mm long to solidify. Samples are prepared to study tribological behaviour [9, 10].

2.4 Microscopy, X-ray diffraction (XRD) and EDS analysis

For microstructural studies, samples are cut and cold mounted with a diameter of 10 mm and length of 10 mm. The hybrid composite materials were ground, polished mechanically and etched chemically by using Kroll's reagent (a mixture of 7 ml HF, 3 ml HNO₃ and 50 ml H₂O). To identify the behaviour of a material optical microscope (OM) is

used to capture the cracks/pores appearance of the tested samples. The samples are cleaned with a Kroll's reagent and dried in air to examine the distinct structure of a material. The microstructural analyses are conducted using a scanning electron microscope (SEM Model JSM 5610 LV) and chemical composition of each element is identified by EDS spectrum. The elements in each component were identified by phase distribution was observed by XRD pattern.

2.5 Measurement of hardness, compression strength and bulk density

The Vickers micro hardness test is an essential part to measure the material strength and easier rather than other hardness tests. The experiment was conducted as per ASTM E 384 standards applying at a load of 100 g and a dwell time 15 s [11]. The tests are carried out at three different positions for each sample average readings are calculated and are shown in Table 4. The hot compression test was conducted as per ASTM E 9 standards at a load of 300 KN dwell time 20 s. The specimen with 15 mm diameter and 30 mm length are placed between two flat dies and the die surfaces are lubricated with a small quantity of zinc serrate powder to reduce the friction between the specimens during compression. Strength was calculated for all materials of similar geometry, after loading 50% of height is reduced. It is necessary that for keeping density as a minimum level high performance of machining would be achieved. The experimental density of all samples is conducted according to Archimedeian principle. Bulk density was calculated using the following equation [12].

$$\text{Bulk density (B)} = \frac{W_d}{W_{\text{sat}} - W_{\text{sus}}} \times \text{Density of water (g/cm}^3\text{)}$$

where W_{sat} —Saturated weight, W_{sus} —Suspended weight, W_d —Dry weight.

2.6 Wear tests

The pin-on-disk apparatus was used to conduct dry sliding wear tests at room temperature under varying applied load, sliding speed and sliding distance against EN 31 stainless steel disc with 100 diameter and 8 mm thickness. The disc was cleaned using abrasive paper (grit size 120) for surface roughness prior to each test. The pins loaded against sliding disc using dead weight samples are prepared by a cylindrical form of 30 mm length and 10 mm diameter as per

Table 3 Chemical composition of rice husk ash

Constituent	SiO ₂	Al ₂ O ₃	C	CaO	MgO	Fe ₂ O ₃	LOI
Wt. (%)	90.23	3.54	1.58	1.23	0.53	0.21	2.29

Fig. 1 Schematic representation fabrication of hybrid composites

Table 4 Investigated values of Micro hardness, Compression strength and Bulk density

Material	Micro hardness (HV)	Compression strength (K/ Nmm ²)	Bulk density (g/cm ³)
A356 alloy	61	462	2.63
A356/5%RHA–5% fly ash	77	476	2.66
A356/7.5%RHA–7.5% fly ash	82	483	2.69

ASTM-G99 test standards for wear study [13]. Three tests were conducted for each sample and average values are plotted are shown in Figs. 2 and 3. The applied load, sliding distance and sliding speed are recorded when specimens are seized to calculate wear loss and coefficient of friction. The wear tests are observed from weight loss measurement and wear mechanism determined with a various applied load (10–50 N), sliding speed (1–5 m/s) and sliding distance (300–1500 m), respectively. The wear tests are conducted with a set of six samples tested in each condition wear loss was measured and coefficient of friction was recorded from

digital display for each sample. The wear tests are conducted above sliding speed of 5 m/s at which material will be seized. It generates abnormal sound and vigorous vibration indicates an occurrence of seizure which in turn increases the frictional force (due to adhesion between two contact surfaces) was identified on EN 31 steel disc by the naked eye.

3 Results and discussion

The micro hardness and bulk density of hybrid composite are measured to examine the effect of reinforcement on matrix. Flow curves are investigated at a different temperature, sliding distance with sliding speed to identify material behaviour. The analysis of worn surfaces and worn debris were conducted by SEM and optical microscope to recognize wear tracks.

3.1 Effect of micro hardness, compression strength and bulk density

Micro hardness is an important property for engineers to measure a unique quality of a widely used in industrial

Fig. 2 Histogram of error in Wear loss **a** A356 alloy, **b** A356/5% RHA–5% fly ash hybrid composite and **c** A356/7.5% RHA–7.5% fly ash hybrid composite

sectors. Before testing all samples are polished and tests were conducted on three different positions on each sample since the average five readings are evaluated and presented in Table 4. Hardness was improved due to the increasing reinforcement particles. Hence, high hardness is achieved by the addition of A356/7.5%RHA–7.5% fly ash hybrid composite. The A356 alloy exhibits high porosity level and it is due to agglomeration. However, it reduces while increasing weight fraction of reinforcement particles and material strength increases up to 483 K/Nmm². The Bulk density of investigated materials is provided in Table 4. It is observed that the density of an alloy is lower than that of the hybrid composite. The value of bulk density for A356 Al alloy, A356/5% (RHA–Fly ash) and A356/7.5% (RHA–Fly ash) is 2.63 g/cm³, 2.66 g/cm³ and 2.69 g/cm³, respectively. Increased bulk density is attributed to the high amount of silica content present in RHA [14]. These values are used for calculating the wear rate of materials from the weight loss measurement.

3.2 Wear mechanism

The study of wear mechanism on hybrid composite materials plays a major role for material scientists and manufacturing engineers utilised for a particular application. Their response was analysed conducting wear test. The wear rate of hybrid composite materials is dissimilar from metallic materials because it consists of three different phases. In the present work, wear behaviour of aluminium alloy with hybrid composites is analyzed and presented in detail. For conducting wear mechanism, the Pin-on-disc apparatus is used to measure dry sliding wear rate and friction coefficient, a comparison was taken for dry sliding wear rates of A356 alloy reinforced with fly ash particle various weight ratios was presented by different investigators are listed in Table 5. A suitable counterface disc plays a vital role in carryout wear resistance while conducting different parameters. In the current study, sliding wear rate of A356 alloy on a pin-on-disc disc was $1.2 \times 10^{-3} \text{ mm}^3/\text{m}$, 5% of (fly ash—RHA) is $1.0 \times 10^{-3} \text{ mm}^3/\text{m}$ and 7.5% of (fly ash—RHA)

Fig. 3 Histogram of error in Coefficient of friction **a** A356 alloy, **b** A356/5% RHA–5% fly ash hybrid composite and **c** A356/7.5% RHA–7.5% fly ash hybrid composite

Table 5 Comparison of dry sliding wear rate for aluminium hybrid composites

Investigators	Test configuration	Test conditions	Material	Wear rate ($10^{-3} \text{ mm}^3/\text{m}$)
Rohatgi et al. [15]	Pin-on-disc	$v = 1 \text{ m/s}$	A356 Al	0.0012
		$L = 20 \text{ N}$	A356Al + 6% fly ash particles	0.0090
		$t = 3000 \text{ s}$	A356 Al	0.0084
			A356Al + 12% fly ash particles	0.0074
Suruppa [16]	Pin-on-disc	$v = 1 \text{ m/s}$	A356 Al	0.0012
		$L = 20 \text{ N}$	A356Al + 6% fly ash	0.0090
		$L = 50 \text{ N}$	A356 Al	0.0017
			A356Al + 12% fly ash	0.0015
Jianbin Zhu and Hong Yan [17]	Pin-on-disc	$v = 1 \text{ m/s}$	A356 Al	0.0012
		$L = 20 \text{ N}$	A356Al + 23.5vol% fly ash	0.0057
		$t = 900 \text{ s}$		
Present authors	Pin-on-disc	$v = 1 \text{ m/s}$	A356 Alloy	0.0012
		$L = 10 \text{ N}$		
		$v = 2 \text{ m/s}$	A356 Al	0.0015
		$L = 20 \text{ N}$	A356Al/5% (fly ash-RHA)	0.0010
		$v = 3 \text{ m/s}$	A356 Al	0.0018
		$L = 30 \text{ N}$	A356Al/7.5% (fly ash-RHA)	0.0012
		$v = 4 \text{ m/s}$	A356 Al	0.0019
		$L = 40 \text{ N}$	A356Al/5% (fly ash-RHA)	0.0011
		$v = 5 \text{ m/s}$	A356 Al	0.0021
		$L = 50 \text{ N}$	A356Al/7.5% (fly ash-RHA)	0.0013

is $0.8 \times 10^{-3} \text{ mm}^3/\text{m}$ has superior to that of previous study. It is concluded that waste particles are highly influenced on matrix achieved the lowest relative wear loss and coefficient of friction among other investigators in their respective test conditions as represented in Table 5.

3.3 Microstructural analysis on elemental materials

The particle size of fly ash and RHA are taken as 15 and 23 μm influences on mechanical properties of the material reduce particle clustering and make the distribution of particles more uniform. The initial microstructure of aluminium alloy is taken as 36.04 μm and is shown in Fig. 4a. Rice husk ash (RHA) is appeared as flakes and fly ash in the form of the spherical shape shown in Fig. 4b and c. Rice husk is an agricultural waste major amount of husk is transformed into ash generated in a controlled temperature. Utilisation of rice husk is reduced storage of land not only used for industries but also used in ceramics, metallurgy. The optical micrographs of Al A356 alloy with agro-industrial waste as reinforcement particles at a different wt% of (0, 5 and 7.5) as shown in Fig. 5. From Fig. 5a, the grain shape of aluminium is larger column; the alloy containing micro pores which are identified on material surface attributed to more porosity level. The Fig. 5b shows, pores and pits/cracks are smaller than that of aluminium alloy is reduced due to an addition of reinforcement particles. The micro pores/pits are filled with hard particles and are shown in Fig. 5c. Yellow colour indicates

the deformation of material decreases with increasing reinforcement particles.

3.4 Effect of organic and inorganic particles

The variation of wear loss on aluminium A356 alloy with an increase in organic (RHA) and inorganic (Fly ash) particles are shown in Fig. 6a. Compare to aluminium alloy it is observed that an increase in reinforcement particles tends to decrease in wear loss of all the materials. In hybrid composite materials, wear resistance are recognized higher due to the presence of high-density content which acts as a load-supporting element. The severe reduction in wear loss of hybrid composites can be attributed to the following reasons such as a uniform distribution of reinforcement particles in the melt are found to be good wettability which tends to increase its strength and improve the wear resistance in materials significantly [18]. The transfer of RHA and Fly ash content may spread over the disc surfaces under dry sliding conditions, leading to the lowering of material loss. The effect of reinforcement particles in an aluminium matrix on a friction coefficient is shown in Fig. 7a. It indicates that increased content of ash particles in Al matrix results in the decreased coefficient of friction. The coefficient of friction increases in A356/5% (RHA–Fly ash) hybrid composite due to pulled out reinforcement particles in matrix alloy and crammed between two surfaces. Moreover, the formation of smooth layers on a surface can be mainly attributed to the lower friction coefficient in a hybrid composite. Lower coefficient

Fig. 4 SEM micrographs of elemental materials **a** A356 alloy **b** RHA particles **c** fly ash particles

Fig. 5 Optical micro graphs of worn surface at a speed of 3 m/s and applied load of 20 N **a** A356 alloy, **b** A356/5% RHA–5% fly ash hybrid composite and **c** A356/7.5% RHA–7.5% fly ash hybrid composite

of friction is observed in A356/7.5wt.%RHA–7.5% fly ash hybrid composite compared with aluminium alloy.

3.5 Effect of applied load on wear loss

The variation of wear loss on A356 alloy, A356/5%RHA–5%Flyash, A356/7.5%RHA–7.5%Flyash hybrid composites in different applied loads (10–50 N) at a constant sliding speed of 3 m/s and for a fixed sliding distance of 1200 m is shown in Fig. 6. The addition of 5% RHA–5% fly ash with A356 alloy shows decrease in wear loss compare to aluminium A356 alloy due to an interfacial bond between matrix and reinforcement particles perform an important role in wear mechanism have been reported by Ravikiran and Surappa [19]. Figure 6b, it is observed that wear loss decreases in A356/7.5%RHA–7.5% fly ash compare to A356/5% RHA–5% fly ash due to decrease applied load and increases the weight percentage of hybrid composites. At minimum loads (below 40 N) wear loss was higher in unreinforced alloy and hybrid composites compared to weight rate method similar observations obtained by Surappa [20].

3.6 Effect of sliding distance on wear loss

The effect of aluminium A356 alloy on various sliding distance (300–500 m) at a constant sliding speed of 3 m/s along with a fixed applied load of 50 N is shown in Fig. 6c, it is clearly seen that higher wear loss due occurs to an

effect of plastic deformation on the surface causes delamination and cracks are occurring in a material. While, adding the weight fraction of 5% RHA–5% fly ash with A356 alloy at a different sliding distance, abrasion will occur at the beginning as pin comes in contact with a surface, leading to rubbing action between two surfaces it decreases as increasing weight percentage of reinforcement particles. However, it was observed that the matrix reinforced with fly ash and RHA particle of different weight fraction exhibit significantly lower wear resistance than that of an unreinforced alloy. The 7.5% RHA–7.5% fly ash with A356 alloy hybrid composite shows wear rates of hybrid composites decrease with increase in weight fraction of reinforcement particles. This can be attributed that, the hard particles act as a load-bearing constituent in case of hybrid composites and enhance the load carrying capacity, leading decrease in wear rate. Therefore, the decrease in sliding velocity tends to increase in wear rate for all composite materials.

3.7 Effect of sliding speed on wear loss

The effect of wear loss of A356 alloy and different weight fraction of hybrid composites on various sliding speed (1–5 m/s) at a constant applied load of 50 N and fixed sliding distance of 1200 m is shown in Fig. 6d. The A356 alloy exhibits severe oxidation at higher sliding speed due to high debris on the surface of a material. The A356 5%RHA–5% fly ash hybrid composite shows a decrease in wear loss and strength increases attributed addition of

Fig. 6 Variation of wear loss on aluminium A356 alloy and hybrid composite on **a** different weight percentage of RHA–Fly ash, **b** applied load, **c** sliding distance and **d** sliding speed

hard particles compare to A356 alloy. For all sliding speeds, three factors are noted majorly such as limiting the lifespan of material, material performance and lower material strength. Further increasing weight fraction (7.5%) tends to decrease in wear loss due to low vibration and noise results in increased efficiency. However, wear found increases when increasing sliding speed this is attributed to increasing of contact time, the surface area between EN 31 steel and composite pin. Hence, it was concluded that 7.5% (RHA–Fly ash) with A356 alloy performs lower wear loss compare to other hybrid composite.

3.8 Analysis of coefficient of friction (C.O.F)

The coefficient of friction is conducted to examine the performance of material and lifespan of structural components when sliding against each other [21]. The effect of hard particles with A356 aluminium alloy on a coefficient of friction is shown in Fig. 7b–d. It is observed that increasing reinforcement particles tends to reduce the friction

coefficient. The addition of A356/7.5RHA–7.5% fly ash content to the base matrix material is a significant change in coefficient of friction this is about 1.4 times lower than matrix alloy as shown in Fig. 7. It confirms that pulled out RHA and fly ash reinforcement particles in contact surface will decrease the coefficient of friction and act as a lubricant on the material surface.

3.9 Effect of applied load on C.O.F

At a constant sliding speed of 3 m/s and sliding distance of 1200 m, abrasive wear occurs at the beginning for A356/5%RHA–5% fly ash hybrid composite due to increasing applied load in friction. This will reduce proper reinforcement particles are added to matrix alloy, which improved hardness and reduced the area of contact. The hybrid composite material exhibits a lower frictional coefficient compared to the aluminium alloy for all loads. The coefficient of friction for A356/7.5RHA–7.5% fly ash hybrid composite is lower compared to aluminium alloy.

Fig. 7 Variation of co-efficient of friction on aluminium A356 alloy and hybrid composite on **a** different weight percentage of RHA-Fly ash, **b** applied load, **c** sliding distance and **d** sliding speed

This induces a strong oxide film between two surfaces leading a smooth layer which is relatively lower wear debris and leads to a decrease in coefficient of friction. Generally, friction force increases while increasing load; it is not proportional to the load increment method. This could be due to the high temperature generated on the surface of a material at higher loads. The effect of applied load on the friction coefficient of unreinforced alloy and hybrid composites was examined as represented in Fig. 7b.

3.10 Effect of sliding distance on C.O.F

The friction coefficient of A356/5%RHA-5% fly ash hybrid composite shows a decreasing trend with a various sliding distance (300–1500 m) at a constant applied load of 50 N and a sliding speed of 3 m/s as shown in Fig. 7c. At load constant, frictional heating tends to increase oxidation and softening effect was observed result in a frictional loss. In sliding distance for A356/7.5%RHA-7.5% fly ash hybrid composite decreases oxidation wear when two

sub-surfaces are brought into contact with relative motion coefficient of friction is lower compared to base alloy. It is also observed that sliding distance increases the coefficient of friction is also increases significantly.

3.11 Effect of sliding speed on C.O.F

The Coefficient of friction for A356/5%RHA-5%Flyash and A356/7.5%RHA-7.5%Flyash hybrid composites with different sliding speed (1–5 m/s) at a constant applied load of 50 N and a fixed sliding distance of 1200 m is shown in Fig. 7d. In aluminium alloy, the coefficient of friction is higher while increasing sliding speed; it reduces increasing hard particles. Further addition of 7.5% reinforcement particles with A356 alloy decreases the coefficient of friction compare to A356/5%RHA-5% fly ash hybrid composite due to the metal surface is normally covered with a layer of oxide will prevent metal-to-metal contact. Hence, it tends to avoid the formation of adhesion and reducing a tendency of adhesive wear particulates. The constant

sliding distance results in decreasing coefficient of friction and increases with increasing sliding speed for all materials well agreed by Suresha [22]. Hence, the coefficient of friction during abrasion wear test of aluminium alloy with fly ash composite has identified that lower coefficient of friction was observed due to hard particles is increased the material strength compared to base alloy.

3.12 Analysis of worn surfaces using SEM

Analysis of SEM on a worn surface is an important tool for accurate determination of wear behaviour during dry sliding. SEM analysis is conducted on the worn surfaces of

A356 matrix alloy and hybrid composite at room temperature as shown in (Figs. 8, 9, 10). Before conducting SEM analysis initially, specimens are cleaned in an ultrasonic bath with acetone which removes some wear debris on the material surface. The wear unreinforced alloy shows intense plastic flow at low loads of 10–40 N and cracks are appearing due to excess of heat generated when a load was increased to 50 N shown in Fig. 8a and b [23]. The worn surface of A356/5%RHA–5% fly ash hybrid composite (Fig. 9a and b) clearly exhibits a distinct layer and smooth surface also appear because of fly ash and RHA content. The pores and cracks were not observed in hybrid composite materials at a lower load of 20 N and observed only

Fig. 8 SEM morphologies of the worn surface of A356 alloy at the applied load of 30 N: **a** low-magnification micrograph and **b** high-magnification micrograph

Fig. 9 SEM morphologies of the worn surface of A356/5% RHA–5% fly ash at the applied load of 30 N: **a** low-magnification micrograph and **b** high-magnification micrograph

Fig. 10 SEM morphologies of the worn surface of A356/7.5% RHA–7.5% fly ash at the applied load of 30 N: **a** low-magnification micrograph and **b** high-magnification micrograph

at a higher load of 50 N. The worn surface of A356/7.5% RHA–7.5% fly ash hybrid composite exhibit oxide debris and smooth regions also observed as shown in Fig. 10a. The ploughing action of hard asperities is identified on a counter surface due to increasing load and sliding speed and leads to hardened worn debris [24]. The dark colour has appeared as flakes regions and white colour appear as hollow spheres regions can be seen on worn surface runs parallel to the sliding direction indicating that smooth grooves are occurred on the surface of a material and is shown in Fig. 10b. The intention of increasing the weight percentage of (RHA–Fly ash) particles in aluminium alloy is to study the influence of material characterises on wear rate. It is also observed that wear resistance increases with increasing hard particles. However, a hybrid composite of (Figs. 9 and 10) shows smooth grooves on the material surface.

3.13 Wear debris analysis

The wear debris formed during steady state to examine wear mechanism for each sample using typical SEM analysis. The particles are observed as large pores and tearing takes place in the base alloy as shown in Fig. 11a. This type of morphology indicates aluminium matrix has undergone significant plastic deformation and causes a fracture. The wear debris reduces due to an addition of waste particles scattered in the aluminium matrix can minimise the mean size of hard particles and also high impact

on a material as shown in Fig. 11b. From the Fig. 11c it is observed that 7.5% hybrid composite has larger strip debris than the base alloy due to an increase of activation energy can decrease oxidation rate. Therefore, reducing wear debris forming smooth surface is beneficial for bearings, in a spacecraft or satellite. X-ray diffraction of Al alloy (Fig. 12a) is exhibit district peaks and strong Al, Mg peaks are observed [25]. The A356/5% RHA–5% fly ash and A356/7.5% RHA–7.5% fly ash of hybrid composites sharp peaks of Al_2O_3 and Fe_2O_3 was increased (Fig. 12b and c). It indicates that these crystalline phases are increasing weight fraction of reinforcement particles increases and it is beneficial to improve the mechanical properties of resultant hybrid composites.

3.14 EDS analysis

The EDS analysis is carried out on the worn surface of all samples under dry sliding conditions. A typical EDX spectrum on the worn surface of A356 alloy at a load of 10 N and speed of 3 m/s are identified Al, Si and Mg instinct peaks as shown in Fig. 13a. The high intensity of Al peak and low intensity of the Si peak indicates plastic deformation in alloy during sliding. The worn surface of A356/5% (RHA–Fly ash) hybrid composite at a load of 20 N and sliding speed of 2 m/s is shown in Fig. 13b. While comparing with EDX profile, it is clearly seen that new peaks 'O' and 'C' are formed due to the addition of hard particles. Further increasing weight fraction of

Fig. 11 Typical SEM images of the wear debris at the applied load of 30 N: **a** A356 alloy, **b** A356/5% RHA–5% fly ash hybrid composite and **c** A356/7.5% RHA–7.5% fly ash hybrid composite

Fig. 12 XRD analysis of **a** A356 alloy, **b** A356/5% RHA–5% fly ash hybrid composite and **c** A356/7.5% RHA–7.5% fly ash hybrid composite

Fig. 13 EDS Spectrum of Worn surface at Sliding speed of 3 m/s. **a** A356 alloy, **b** A356/5% RHA–5% fly ash hybrid composite and **c** A356/7.5% RHA–7.5% fly ash hybrid composite

(7.5%) reinforcement particles which tends to increase O and C peaks at 20 N load and speed 3 m/s as shown in Fig. 13c. Hence, it is concluded that from the EDS spectrum no oxygen peaks are formed attributed the presence of argon gas was maintained stable throughout fabrication process [26]. Therefore, A356/7.5%RHA–7.5% fly ash hybrid composite is a good choice for industrial sectors.

4 Conclusion

In this study effect of the addition of organic and inorganic content on A356 alloy was investigated, in order to analyse the influence of deformation on wear resistance. It is quite challenging to sieve through these materials and come up with the most relevant ones to the task at hand. The analysis of worn surface, optical microscope, compression strength, micro hardness and bulk density emphasize their qualities. From these following new findings are drawn:

1. The waste materials are not only found abundantly but also can be used as a good additive for composite materials which turns industrial-waste into industrial-wealth. The utilization of waste particles into raw materials has a lot of attention in recent years due to its low cost and environmental safety that require large volumes of materials in the production of connecting rods and piston rings.
2. It has inferred that micro hardness and compression strength increases due to uniform distribution of reinforcement particles throughout the matrix.
3. Improving wear resistance of aluminium hybrid composites possess tribological benefits such as longer lifespan of material, energy savings through a reduction in wear loss and coefficient of friction.
4. The material on counterface against pin-on-disc apparatus is mainly influenced about 50% of reduction takes place in wear and coefficient of friction.
5. Wear debris is formed highly by increasing speed and applied load wear rate vary between high and low on A356 alloy, deformation induced during operation components are subjected to rapid failure.
6. The incorporation of A356/7.5RHA–7.5% fly ash hybrid composite increases wear resistance and decreases wear debris compared with matrix alloy and other hybrid composite.
7. The formation of smooth layers are observed on a worn surface of A356/7.5%RHA–7.5% fly ash is favourable controlling wear behaviour superior to that matrix alloy and incorporation of reinforcement particles is identified by X-ray diffraction measurements.
8. The utilization of waste materials such as RHA and fly ash particles are used to reduce material weight mainly used for bearings.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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