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Tribological Study on Effect of Chill Casting on Aluminium A356 Reinforced with Hematite Paticulated Composites

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Abstract
In this paper, an effort has been made to study the influence of copper chill on tribological properties of Aluminium Metal Matrix Composites (AMMCs). Hematite particles are used as reinforcement in the metal matrix of A356. The composite was developed through sand casting process with and without copper chills to get homogeneous and isotropic material properties. Hematite particles were reinforced at different weight percentage ranges from 0 wt% to 12 wt% in phases about 3 wt%. Experiments were conducted to study the wear behaviour using pin on disc type dry sliding wear testing equipment, the parameters like applied loads, sliding velocities, and the co-efficient of friction were varied by keeping sliding distance and time as constant. The composites of casted with copper chills revealed superior wear resistance as compared to the composites of casted without copper chills. Micrographic analysis was performed using XRD (X-Ray Diffraction) patterns and (Scanning Electron Microscope) SEM photos. The existence of Hematite particles was confirmed from XRD and also found that the uniform dispersal of Hematite particles in the A356 matrix alloy of composites casted with copper chills. The fine grained structure was obtained due to rapid cooling which influence in improving wear resistance in the composites with copper chills. It was also observed from SEM photos the worn-out surface is smooth in the composites of 9 wt % casted with copper chills as compare to that off without copper chills.

Keywords A356 · Hematite · AMMCs · Chill casting · Dry sliding wear · Microstructure

1 Introduction

Nowadays in industries, aluminium alloy plays a dynamic role to get better consequences. The aluminum metal matrix composites are extreme use in the zones like automotive, military and aircraft, etc., because of their high toughness, strength, hardness with better wear and corrosion resistance [1–3]. The reinforcement of Hematite particles (hard ceramic particles of iron ore) into the aluminium shows improved Properties towards the application in the areas of wear and tear [4]. The sand casting with superior properties must found by using metallic elements as end chills like copper, which effects on the microstructure, tribological and mechanical properties [4, 5]. Chill casting through sand mould using liquid metallurgical method being one of the most profitable and extensively used for castability of MMCs [6]. Shankar Subramanian et al. [7] reported on exhaustive review on the abrasive wear performance of aluminum alloy blend with several reinforcements. The experimental investigation of wear behaviour on composites reinforced with sugarcane bagasse ash and particles of silicon carbide was carried out and the results shows that the reinforced composite exhibit superior wear resistance than as-cast composites. S. Balakumar et al. [8] studied the wear performance of the casted Al6061 alloy with several reinforcements like fly ash, copper and graphite powder, the results shows wear resistance was improved on composite sampling contrasted along as-cast specimens. Viney Kumar et al. [9] examine the MMC's in which wear characteristics of Al 6061 alloy blend with different reinforcement of fly ash, magnesium, graphite at different weight percentage, result shows increased wear properties of composite specimens as compared to as-cast specimens. S. Mishra et al. [10] examine the wear

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behaviour of Al 7075 reinforced burgundy alongside cinders amalgam composites. The experimental results reveals that burgundy armored Al 7075 amalgam composite designate fewer explicit wear tempo in contrast to cinders armored Al7075 amalgam composite. D Shiva prasad et al. [11] reported tribological characteristics of A356.2 alloy blend with different weight percentage of Rice Hush Ash (RHA) as reinforcement, result proves that the composites exhibit high resistance to wear and hardness as compared to unreinforced Al alloy. J Rodriguez et al. [12] reported wear behaviour of aluminium 8090–alloys of lithium blended with particulates of Sic at different pressure and temperature, it has been observed that the temperature transition exhibits a clear dependency on nominal pressure. The reinforcement benefit is limited to shift the transition temperature to higher values. Within the mild wear regime, composite wear rates are even higher than those of the reinforced alloy and the presence of Mechanically Mixed Layers (MML) on the wear surface with varying morphology and thickness influenced the wear rate. Prasad S V et al. [13] studied the tribological compatibility of commercial aluminium MMCs with graphite as a solid lubricant, the results shows that films burnished on Al–Cu alloy surfaces withstood much higher loads than those burnished on Al-Si alloys. Ahmer S M et al. [14] studied the tribological properties on aluminium metal surface at room temperature of 300 K at a fixed load of 196.2 N. The two different testing configuration like Aluminium pin vs Helix oil-on-steel-disc (AHS) and Aluminium pin vs 10% polytron plus 90% Helix oil-on-steel-disc (APS) were performed, the results shows that on AHS configuration wear of the aluminium surface found to be 70 µm, however in APS configuration wear dropped to be 20 µm. APS has a marked decrement of one-third of the wear of aluminium. Rohatgi P K et al. [15] studied the non metallic materials are embedded into the metals or alloys as reinforcements to get new material with improved tribological performance of various MMCs as a function of several relevant parameters like material parameters, mechanical parameters, and physical properties. The results shows, the nano-composites showed best friction and wear performance when compared to micro-composites. From the earlier literature studies, it was found that little/less work has been carried out on tribological study on A356-Hematite particulated composites.

In this work, an attempt has been made through the study of wear behaviour on effect of copper chills for the development of Hematite particulated reinforced aluminium A356 composites using pin on disc type dry sliding wear testing equipment. EDAX, XRD, and Micrographs are used to study the presence of reinforcement and microstructure in the developed composites. The parameters like applied loads, sliding velocities, and the co-efficient of friction are varied by keeping sliding distance and time as constant during wear test. The composites are casted with copper chills revealed superior wear resistance as compared to the composites of without copper chills.

Table 1 Chemical composition of alloy of A356

Composition	Percentage
Si	7.25
Mg	0.45
Fe	0.086
Cu	0.010
Mn	0.018
NI	0.025
Zn	0.005
Others	0.028
Al	92.12

Table 2 Chemical composition of Hematite

Composition	Percentage
Fe_2O_3	81.13
MnO	0.14
MgO	1.55
TiO_2	0.03
Al_2O_3	0.57
CaO	4.8
SiO_2	4.2
Thrashing of detonation	7.58

2 Materials and Methods

2.1 Material Selection

In the present research work, Alloys of A356 in ingot form has been selected as a matrix material due to its wide range of applications in automobiles and aerospace industries. The particulated Hematite of size 80–100 µm was selected as reinforcement. The chemical composition of both the reinforcement and matrix materials are give in Tables 1 and 2 respectively. The other properties of both materials are also given in Tables 3 and 4 respectively.

2.2 Composite Preparation

The metal matrix composite of A356 alloys reinforced with particulated Hematite was developed by the stir casting method which is explained as follows. The A356 alloy being melted in (6 KW) electric resistance furnace up to 752 °C with 560 rpm stirring speed as shown in Fig. 1. The particulates of Hematite were preheated at 400 °C and poured into the furnace consist of a molten metal alloy of A356 (at 750 °C). The stirring process is continued up to

Table 3 Properties of A356 alloy

Properties	Units	Values
Density	gm/cc	2.67
Colour	–	Silver
Hardness (Brinell)	–	70–105
Tensile strength ultimate	MPa or N/mm^2	234
Tensile strength yield	MPa or N/mm^2	165
Compressive strength	MPa	650
Elastic modulus	GPa	70–80
Poisson's ratio	Nu	0.33
Melting point	°C	557–613

Table 4 Properties of Hematite particles

Properties	Units	Values
Particle size	Mm	80–100
Density	gm/cc	5.17
Colour	–	Red
Hardness (Mohr's Scale)	Kg/mm^2	5.5–6.5
Tensile strength	MPa or N/mm^2	350
Elastic modulus	GPa	211
Poisson's ratio	Nu	0.35

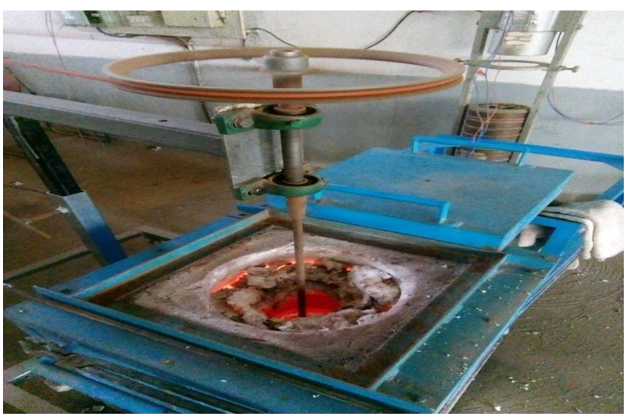


Fig. 1 Electric Furnace

several minutes. Finally, constant stirring being ejaculated well wetting among matrix and reinforcement. The prepared molten metal was dispensed into a preheated sand mould comprising with copper chills and without copper chills as shown in Fig. 2. The casting process was repeated for different compositions of reinforcement with matrix material (weight proportions of Hematite Particles with base alloy from 0 wt% to 12 wt% in steps of 3 wt%). Casting was continued by preparing sand mould with copper chills as shown in Fig. 3 for different compositions of reinforcement with a dimension of 170 × 200 × 25 mm.

2.3 Experimentation

The dry sliding wear test was conducted on the developed composites of A356 reinforced with particulated Hematite separately for the specimens of casted with copper chills and without copper chills. The test samples were prepared as per ASTM standard G 99–95 [16] of size 8 mm diameter and 30 mm length. The wear test was carried out using standard pin on disc wear testing equipment with a track diameter of 120 mm as shown in Fig. 4. The readings were recorded for different intermissions of time varying from 5 to 45 min in steps of 5 min. The force of friction (F_N) was measured by the use of a force transducer (with accuracy 1 N). The schematic diagram of pin on disc equipment is shown in Fig. 5. Experiments were conducted on wear and frictional force at different loads (varying from 10 to 40 N) and sliding velocities (varied from 1 to 4 m/s). The wear rate is calculated using Eq. (1), it can also be calculated using the weight loss method.

$$\text{Specific wear rate} = \frac{\text{Volume of the material removed}\left(\text{mm}^3\right)}{\text{Normal load(N)} \times \text{Sliding distance(m)}} \tag{1}$$

The specifications of the dry sliding wear test are presented in Table 5. The specimens of microstructure were prepared using a typical metallographic process. For microstructure analysis, the specimen of 15 mm diameter and 5 mm height were used. The surface of the specimen was grinded (using 240, 600, and 800 grind paper) and polished by 44-µm thickness polishing paper. It was carried out on polishing machine using velvet cloth to achieve a smooth surface finish. The specimens were cleaned by distilled water to remove impurities like dust or foreign particles present on the surface. The surface of the specimens were finally etched by Keller's reagent [17]. The XRD was performed by a PANA- LYTICAL XRD using CU Kα radiation for analyzing the size, shape and dispersal of Hematite particles present in A356 alloy mixtures. The 2θ range was selected such that all the intense peaks of the material phases predictable were covered [18]. The SEM device (TESCAN VEGA 3 LMU, Czech Republic) was used to study the microstructure of composites. The software JDE 2300 was used for EDX investigation linked with SEM device.

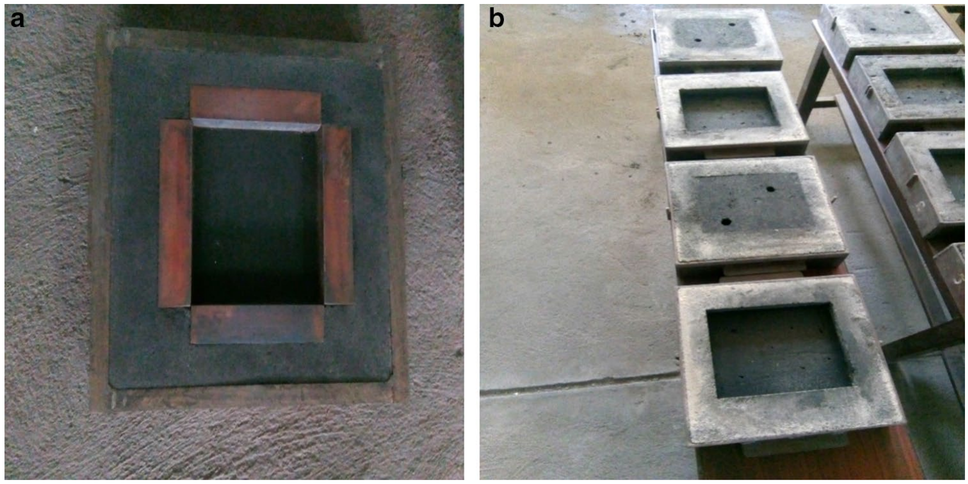


Fig. 2 **a** Mould with copper chill, **b** Mould without copper chill

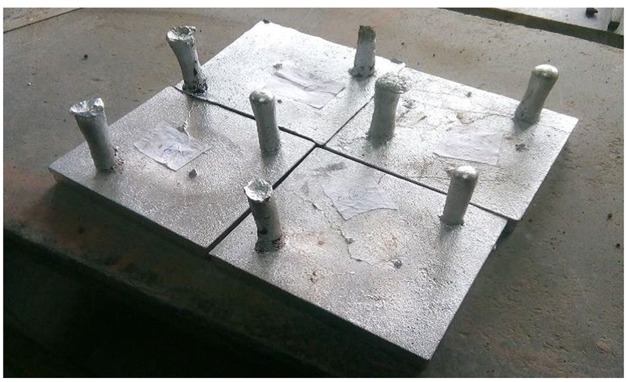


Fig. 3 Prepared Al-A356—Hematite composite with copper chills

3 Result and Discussion

3.1 Variation of Wear Rate with Percentage of Reinforcement at different Loads

The variation of wear rate at different loads on A356-Hematite composites of casted without and with copper chill specimens were recorded and displayed in Figs. 6, 7. Test were carried out for a different loading conditions ranges from 10 to 40 N with a constant sliding velocity of 1 m/s at a constant sliding distance of 1500 m. From the experimental results, it was found that the wear rate is decreases with an increase of applied load up to the 9 wt% of reinforcement, beyond that there is no change in wear rate for the composites of casted without copper chill. The same tendency was obtained for the applied load of 20 N, 30 N and 40 N. It has been found that the same variation of wear

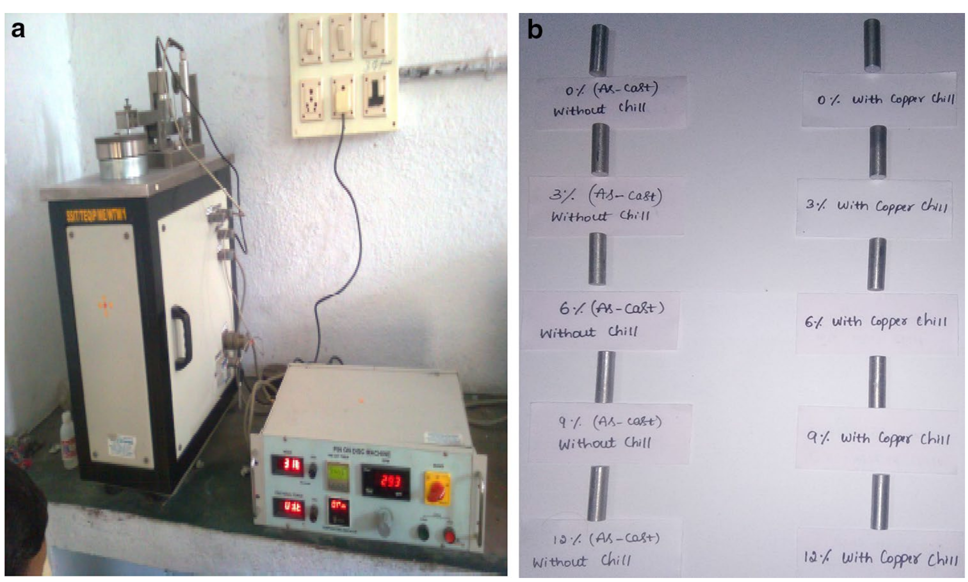


Fig. 4 **a** Pin-on-disc machinery, **b** Specimens

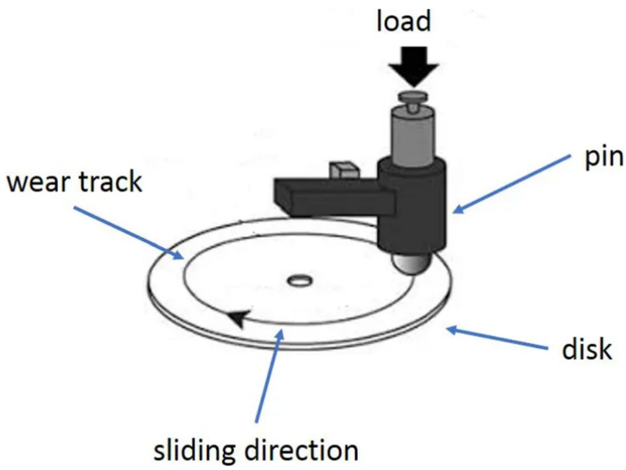


Fig. 5 Schematic diagram of pin on disc equipment

Table 5 Specifications of the Pin-on-Disc machine

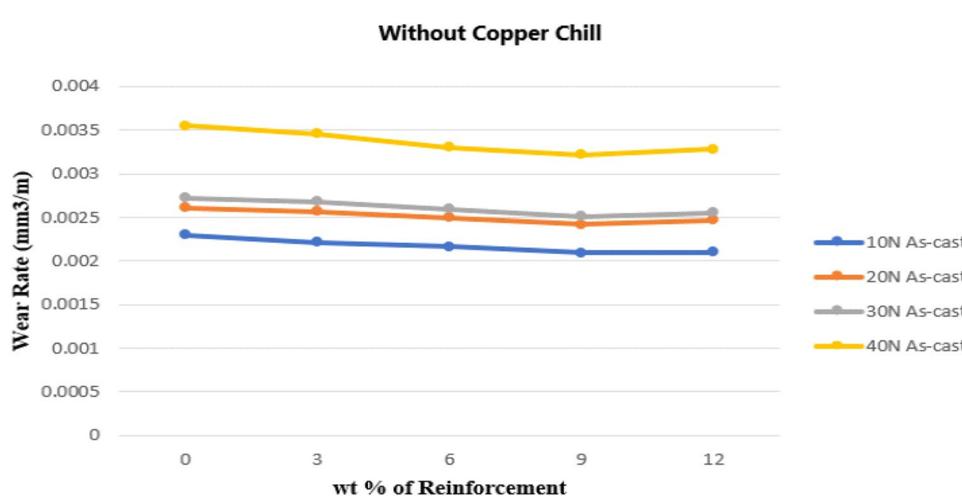
Disc diameter	120 mm
Disc surface roughness (R_a)	0.84 µm
Disc surface	EN 32 steel
Disc hardness	62 HRC
Disc speed	0–1000 rpm
Normal load	0–100 N
Least count	1 µm
Power	230 V,AC50Hz
Disc surface finish	2 µm

rate was obtained for the composites casted with copper chill. It was also observed that the overall wear rate is less for the composites casted with copper chill as compared to the composites casted without copper chill. In general the wear resistance of composites depends on the size and volume fraction and type of reinforcement. From these results, it was clear that the composites casted with copper chill are exhibits high wear resistance because of the presence of Hematite particles (Iron oxide and the Magnesium oxide) those protect the aluminium matrix from wear and minimized severe surface shear strain that was associated with the unreinforced alloy. It is also influences on increase of hardness and toughness. It can be cleared that the composite of 9 wt% of reinforcement is stronger as compared to the other composites due to uniform dispersion of Hematite particles [17, 18].

3.2 Variation of Wear Rate with Percentage of Reinforcement at different Sliding Velocity

Figures 8, 9 shows the outcome of variation of wear rate at different sliding velocity on A356-Hematite composites of without and with copper chill specimens. Tests were carried out with an unvarying (constant) load of 40 N along with the unvarying sliding distance of 1500 m. From experimental results, it can be found that for the composites of casted without copper chill, the wear rate is decreased as the sliding velocity increases up to the 9 wt% of reinforcement, beyond that there was small change in wear rate. The same tendency was obtained for the sliding velocity of 2 m/s, 3 m/s and 4 m/s. It can also be found that the wear rate is less for the composite of casted with copper chill as compared that of without copper chill. It was observed that as the speed increases the temperature also get increased resulting in the formation of oxide layer which causes reduced wear rate of the composites. It was cleared that the composite of 9 wt% of reinforcement is stronger as compared to the other composites due to uniform dispersion of Hematite particles. The obtained results in the present work were similar with the previous research work carried out by other researchers [14].

Fig. 6 Wear rate with percentage of reinforcement at different loads without copper chills



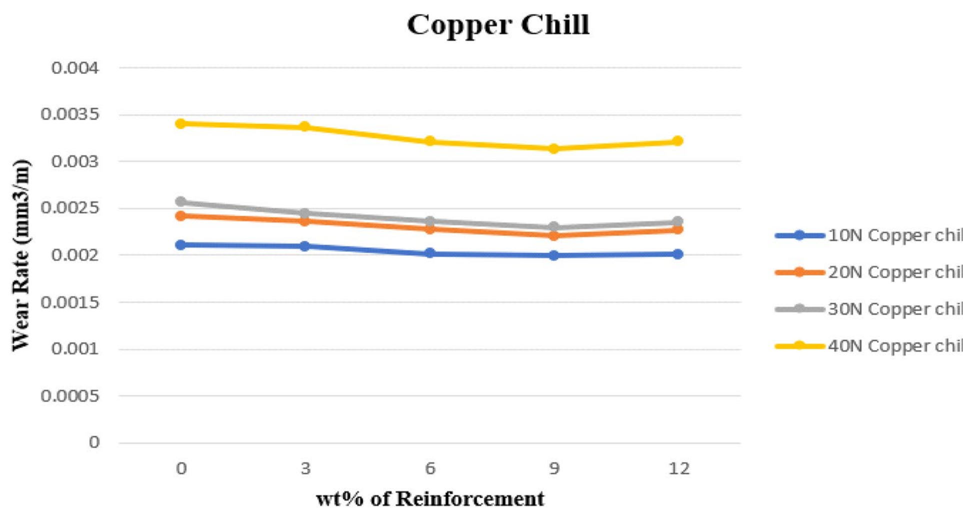


Fig. 7 Wear rate with percentage of reinforcement at different loads with copper chills

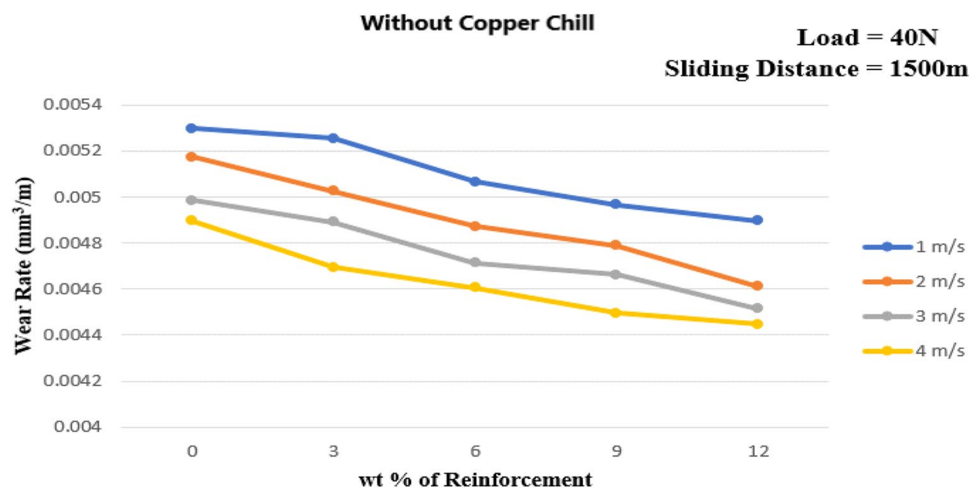


Fig. 8 Variation of wear rate with percentage of reinforcement at different sliding velocity without copper chill

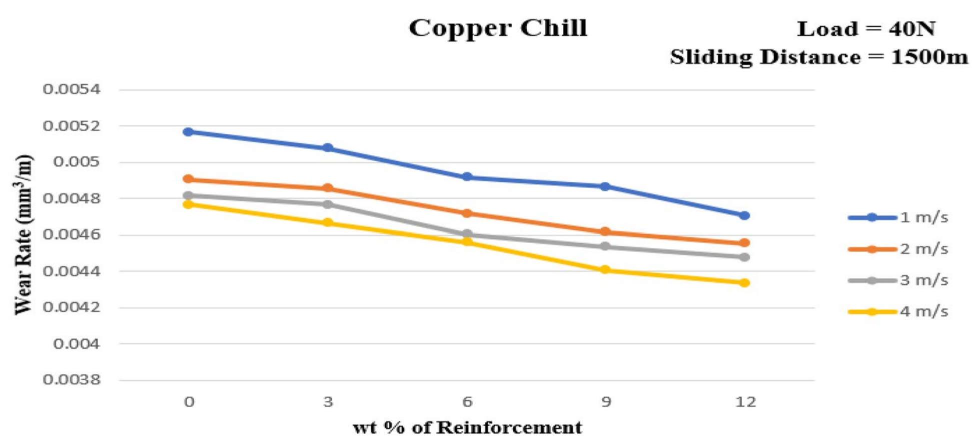


Fig. 9 Variation of wear rate with percentage of reinforcement at different sliding velocity with copper chill

3.3 Effect of Co-Efficient of Friction (COF)

3.3.1 Variation of Co-Efficient of Friction with Percentage of Reinforcement at different loads

Figures 10, 11 displays the outcome of co-efficient of friction with wt% of reinforcement at different loading condition of A356 alloy and its composites of casted without and with copper chill conditions. Tests were conducted with a constant sliding velocity of 1 m/s and time interval of 25 min.

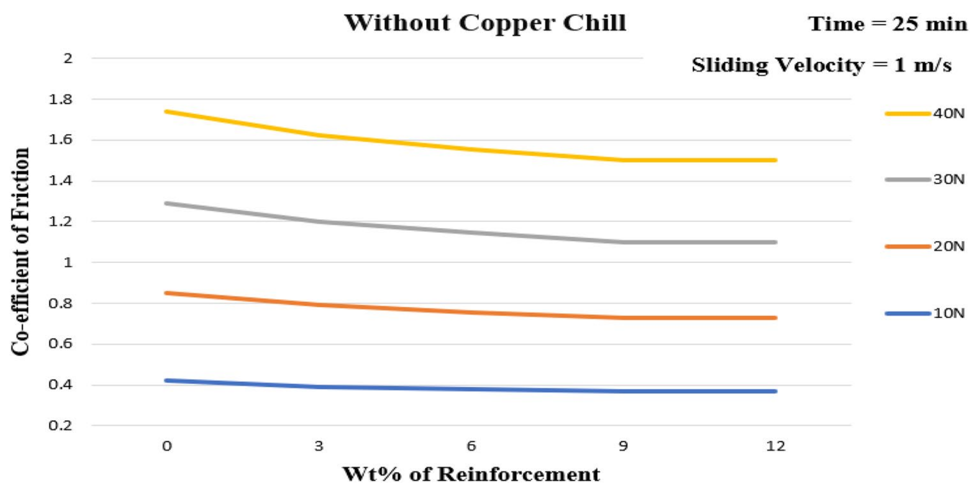


Fig. 10 Variation of co-efficient of friction with percentage of reinforcement at different loads without copper chill

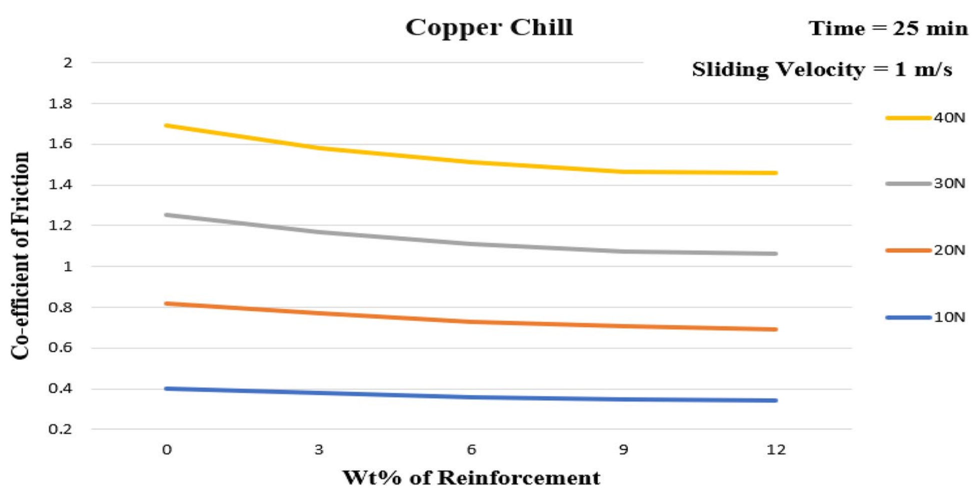


Fig. 11 Variation of co-efficient of friction with percentage of reinforcement at different loads with copper chill

Previous researches mentioned that the addition of ceramic particles as a reinforcement to aluminium alloys protects the aluminium matrix from wear and minimized severe surface shear strain. In agreement with this, the co-efficient of friction increases as the applied load increases for the composites due to the frictional force developed between the disc and the specimen. Similar observations were found in the previous work carried [19, 20]. It was also found that as the percentage of reinforcement increases the co-efficient of friction decreased upto 9 wt% of reinforcement, the reason for the reduction of COF in the composites is due the presence of fine grain size of Hematite particles. At higher loads, discontinuous ridges and deep grooves along the sliding direction can be observed which causes in increase of COF. The same trend was observed for the applied load of 20 N, 30 N and 40 N and the same variation of wear rate was obtained for the composites of casted with copper chill. From experimental results, it can be found that the composites of casted with copper chill shows lesser co-efficient of friction because of the presence of iron oxide and the magnesium oxide in the composites. The use of copper chill in A356-Hematite composite which interns improve the rate of solidification which results in the reduction of co-efficient of friction in the composites [14, 15].

3.3.2 Variation of Co-Efficient of Friction with Percentage of Reinforcement at different Sliding Velocity

The outcome of variation of coefficient of friction with different wt% of reinforcement at different sliding velocity of A356 alloy and its composites of without and with copper chill conditions are displays in Figs. 12, 13. For the composites of casted without copper chill, It has been observed that the coefficient of friction is decreases with as the sliding velocity increases. It was also found that the co-efficient of friction is decreases as the wear rate increases upto the 9 wt% of reinforcement, beyond that there was no change in co-efficient of friction value. The temperature at contact surface is increased by increasing sliding velocity resulting in the oxide layer formation which causes reduction in wear rate. The same tendency was obtained for the different sliding velocity of 2 m/s, 3 m/s and 4 m/s. It has been found

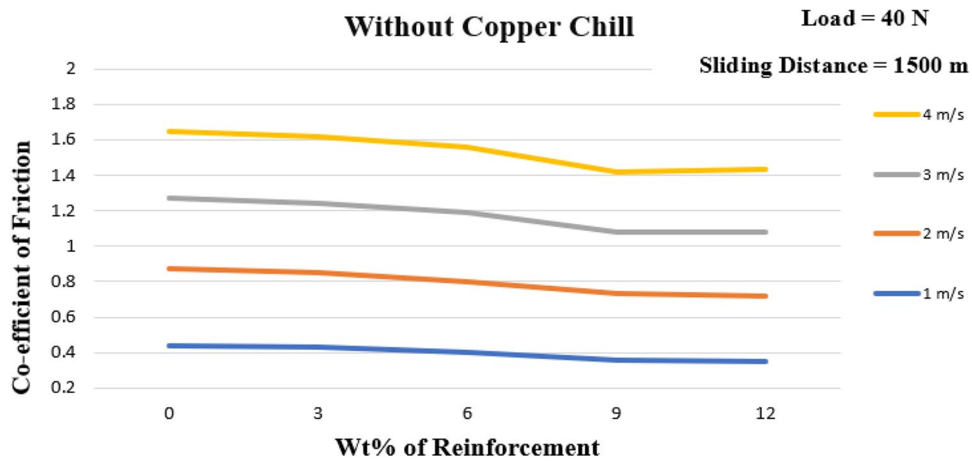


Fig. 12 Variation of co-efficient of friction with percentage of reinforcement at different sliding velocity without copper chill condition

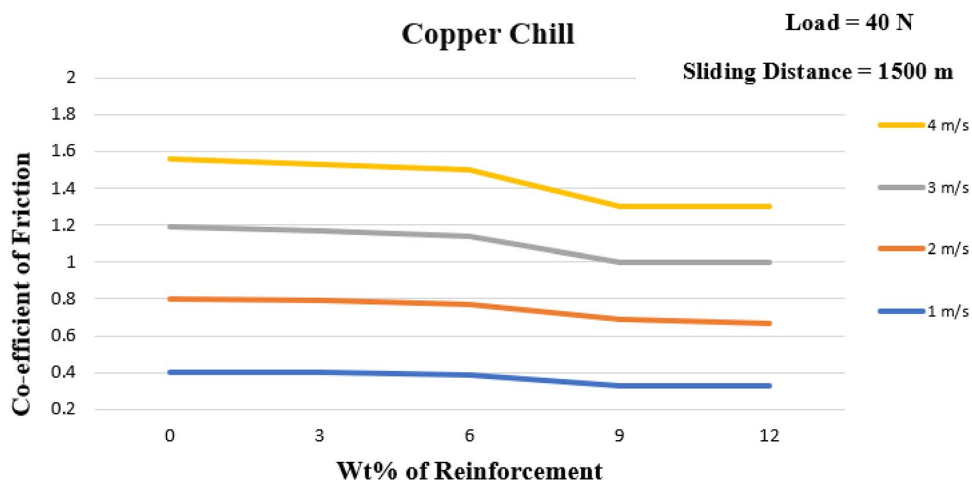


Fig. 13 Variation of co-efficient of friction with percentage of reinforcement at different sliding velocity with copper chill condition

that the same variation of wear rate was obtained for the composites casted with copper chill. From these results it was clear that the composites of casted with copper chill shows lesser co-efficient of friction because of the presence of iron oxide and the magnesium oxide in the composites. The copper chill used in A356-Hematite composite exhibit reduced co-efficient of friction due to enhance in rate of solidification [15–17].

3.4 Micrographic Analysis

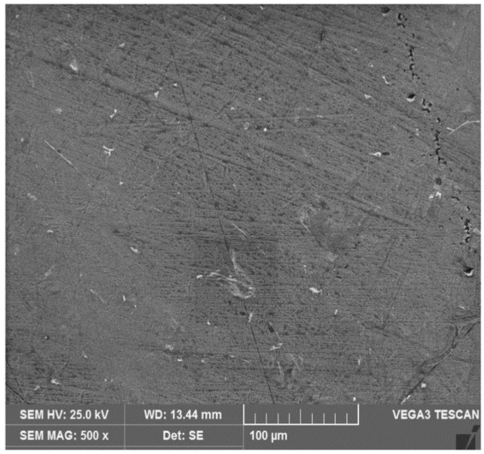
The micrograph results shows that particulates of Hematite seems to be dispersed uniformly throughout the A356 matrix at different weight percentages as displayed in Fig. 14a–e. This can remain accredited to the effective stirring with the use of proper process parameters. Homogeneous dispersal on elements of Hematite is to improve the tribological properties of the mixtures and the rapid cooling rate is enforcing to get fine-grained structure by use of copper chill which in turn improves the tribological properties.

Figure 15 displays the elemental analysis of A356 with 9 wt% of Hematite composite which confirms the presence of elements such as Al, Fe_2O_3, MgO, Cu, CaO, Si, and Zn. The distribution of Hematite particles in A356 alloy composite is confirmed by the existence of Fe_2O_3 and MgO through XRD analysis. Figure 16a represents A356 alloy XRD pattern with different phases of aluminium are available at various peaks. 39°, 45°, 65°, and 78° with various intensities. The highest intensity of the Al phase is 39°. The Fig. 16b shows the XRD pattern of A356 alloy with 9 wt % of Hematite particulates, it specifies phases of Al and Fe_2O_3. The JCPDS pattern of the developed composites is 98–6077 at different 2θ angles with variable intensities, while particles of Hematite phases are identified at 29°, 47°, 56° & 78° [21].

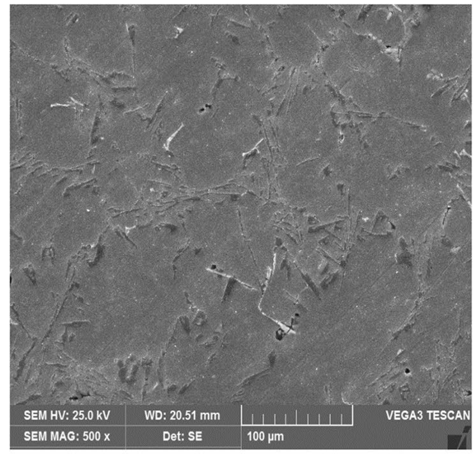
3.5 Worn Morphology

It was most significant to observe the worn-out surface morphology of A356 alloy and A356/9wt% Hematite particulate composites of casted without and with copper chill at 500 × magnifications. During sliding, the A356 alloy matrix

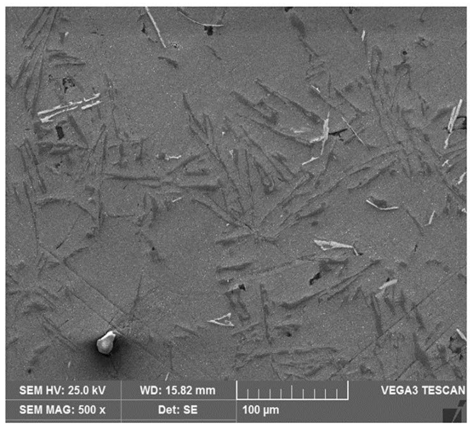
Fig. 14 SEM Micro-graphs with copper chill at 500× magnification



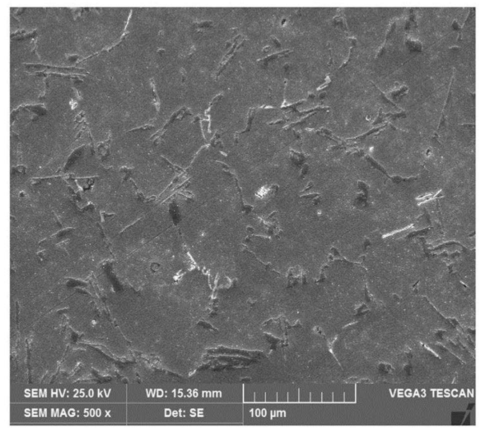
a A356 alloy



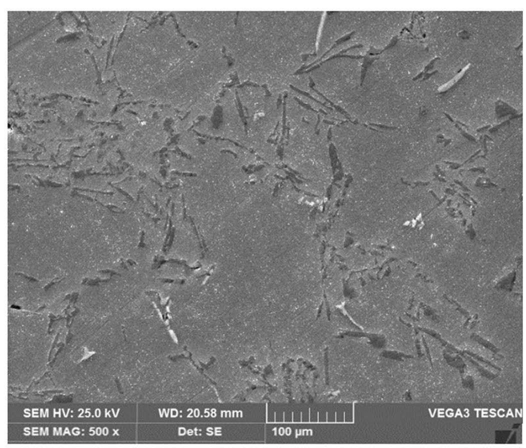
b A356-3 Wt% of composite



c A356/6wt% composites



d A356/9wt% composite,



e A356-12 Wt% of composite

is softer than the rubbing disc material and hence shows the viscous flow of the A356 matrix, which is in the form of a pin causing plastic deformation of the specimen surface, resulting in high material loss. The worn surface of A356 alloy displaces the existence of micro pits, grooves, and fractured oxide layer as shown in Fig. 17a, b which might have caused the increase of wear loss. A356 alloy reinforced with 9 wt% of Hematite restricts the viscous flow of the matrix and also increase in hardness and toughness of the composite material due to the presence of ferric oxide and magnesium oxide as shown in Fig. 17c, d. It was noticed that the erosion or groves have decreased with the addition of particles of Hematite and therefore illustrates that there may be increasingly more resistance to wear loss [22]. The use of copper

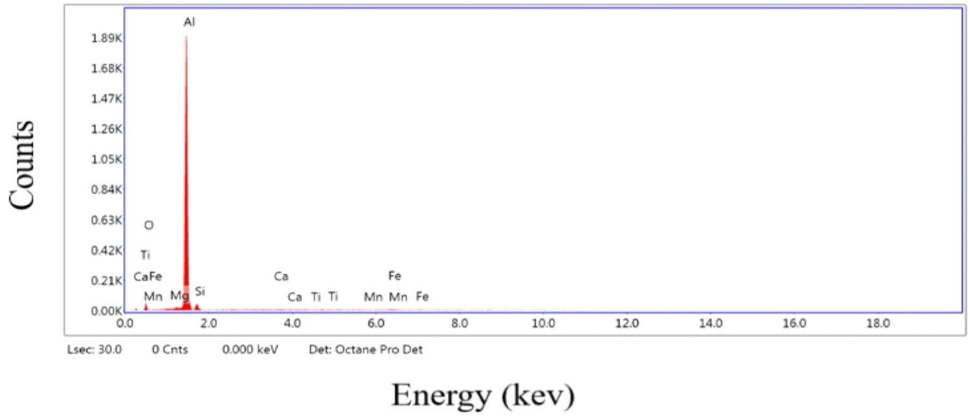
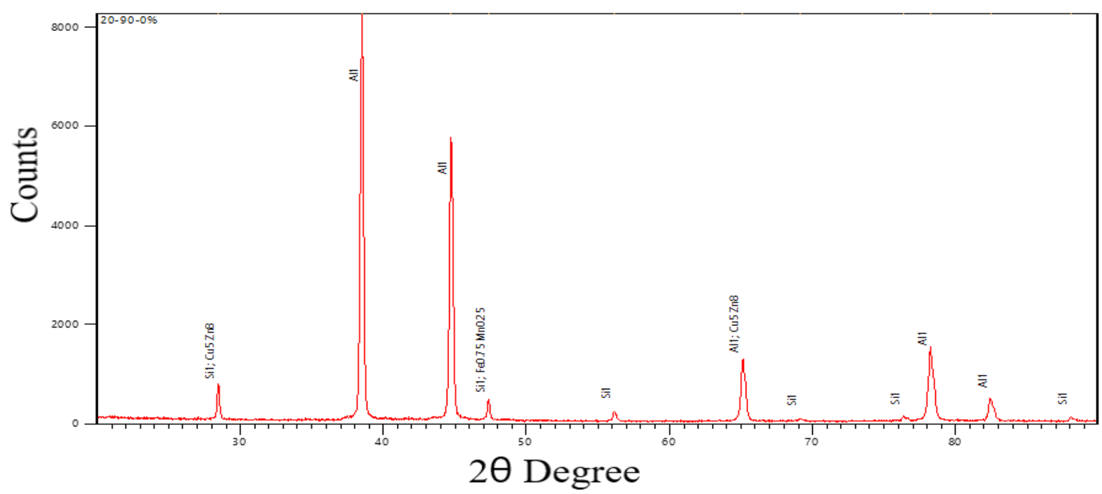
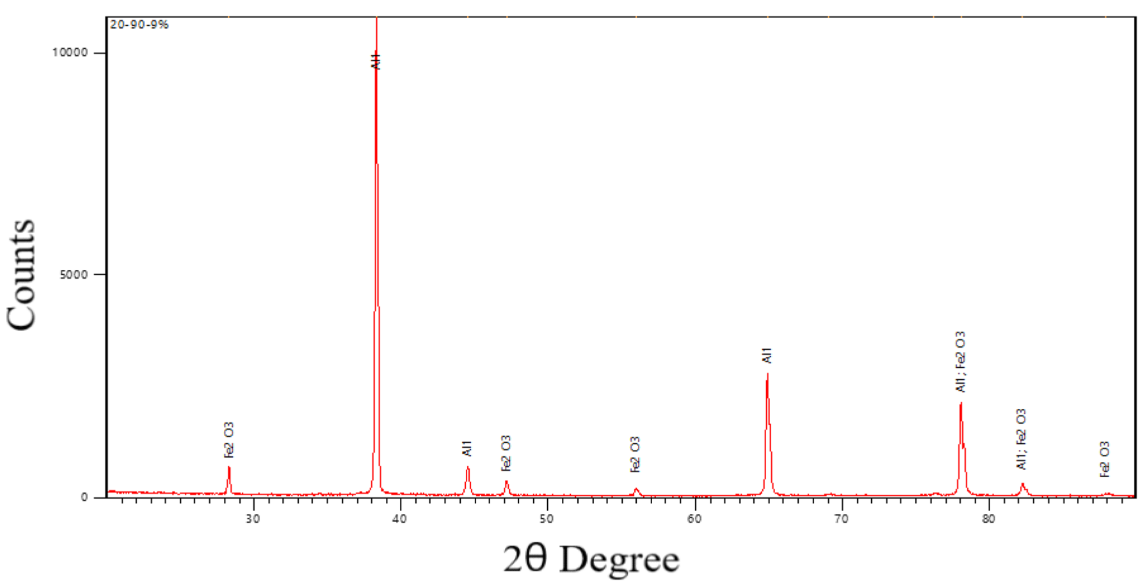


Fig. 15 EDS spectrum of A356 with 9 wt% of Hematite particulate composite showing the presence of Fe_2O_3 particles

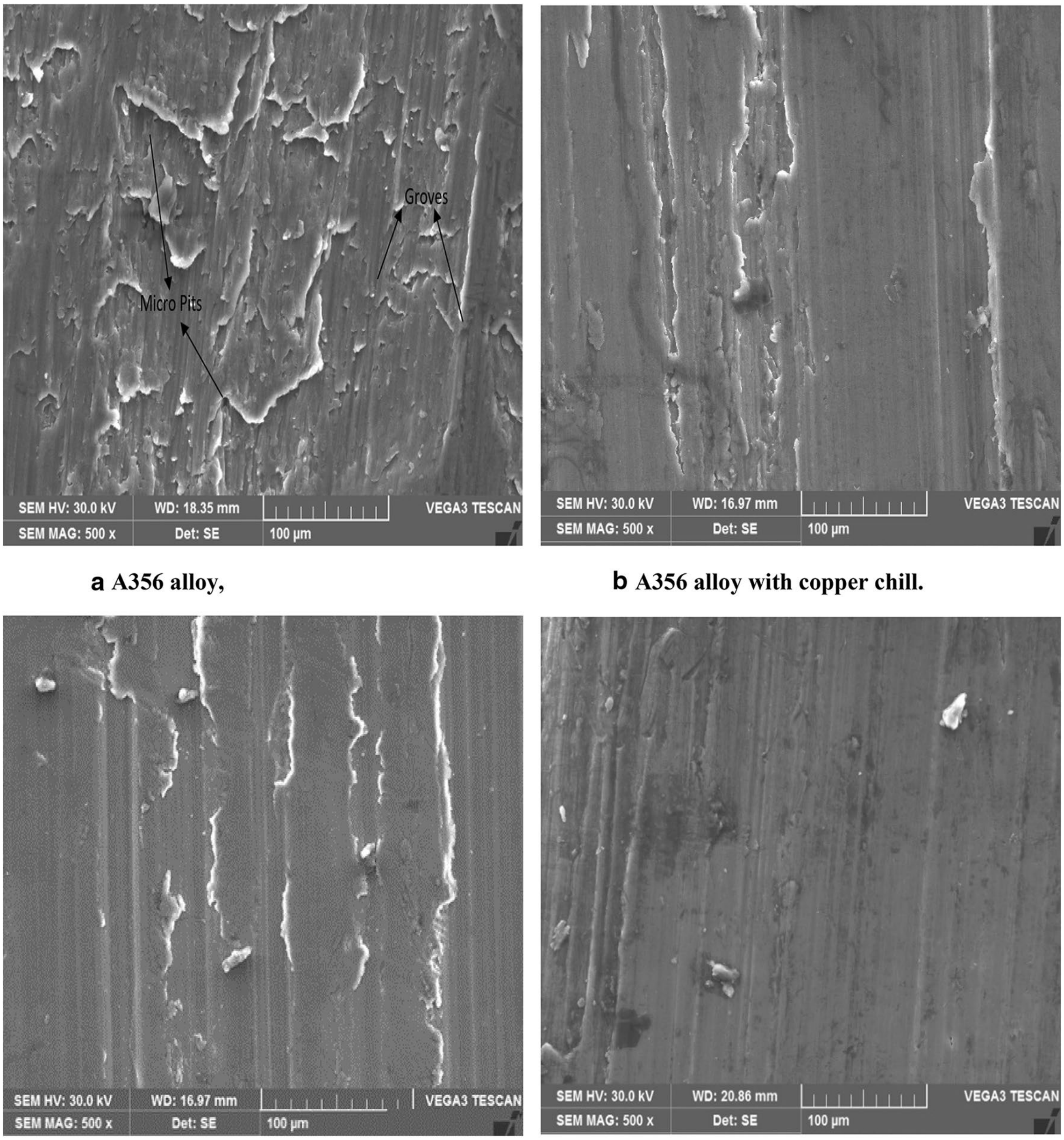


a **X-ray diffraction of A356 alloy**



b **X-ray diffraction of A356-9wt% of Hematite**

Fig. 16 **a** X-Ray diffraction of A 356 alloy. **b** X-Ray diffraction of A356-9 wt% of Hematite



a A356 alloy,

b A356 alloy with copper chill.

c A356/9 wt% composite,

d A356/9wt% composite with coper chill.

Fig. 17 SEM micrograph of worn surfaces

chill, in turn, enhanced the tribological properties of the chilled composite specimen as compared to the without chill specimen. Meanwhile, the stress looks to be transferred on hard particles and strain concentration occurs around these particles and in addition to hard Hematite particles on A356 alloy. The worm surface shows less cracks and grooves. It is observed from micrograph that the wear out surface of the composite material for 9 wt % of reinforcement with copper chills is very smooth has compared to that of without copper chills at 0 wt%. The experimental results of wear test was also evidence for the same [23–25].

4 Conclusions

A356 Hematite particulate reinforced composites were developed through sand casting practice with and without copper chill. The following conclusions were made.

- The Micro-structural analysis clearly shows that uniform spreading of Hematite particles in the matrix of A356 alloy and its composites.
- The XRD examination affirms the presence of Hematite particles and its phases in A356 alloy matrix.

- From the experimental results it was found that the wear rate decreases with increasing wt% of reinforcement and sliding velocity, further wear rate increases with increase of applied load. Wear rate is also depends on the size and volume fraction of reinforcement particles.
- Co-efficient of Friction decreases with increasing wt.% of reinforcement and sliding velocity, further the COF increases with increasing applied load due the presence of fine grain size of Hematite particles.
- The wear resistance of cast A356 alloy was increased due to the presence of Hematite particles. The applied load and sliding speed affects the wear performance of A356 alloy and its composites. It was also found that the wear rate is increased by increasing the parameters like load and sliding speed on A356 alloy and its Hematite particulate composite. The improved wear resistance is exhibited with the aid of the SEM photographs of worn surfaces.
- It was found that the composite having composition of 9% Hematite reinforced with A356 alloy is exhibits strong wear resistance as compared to other compositions and it was also found that the specimens of copper chilled composite are stronger than without copper chill composites due to the presence of iron oxide and the magnesium oxide in the composites which also influences in increase of wear resistance by enhancing Hardness and Toughness.
- From the overall results it is concluded that the Hematite act as major role in enhancing wear resistance of Aluminium Matrix Composite.

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Data Availability All data generated or analyzed during this study are included in this published article.

Declarations

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

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