THE ABRASIVE WEAR BEHAVIOR OF CENOSPHERE-ALUMINIUM METAL MATRIX COMPOSITE

Saravanan Varatharaju[1)], Thyla Pudukarai Ramaswamy[1)], Balakrishnan Sreedhara Rajarathnam [2)]*
[1)] Department of Mechanical Engineering , PSG College of Technology, Coimbatore, India
[2)] Department of Aeronautical Engineering, Nehru Institute of Engineering and Technology, Coimbatore, India

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[*]Corresponding author: Saravanan Varatharaju, e-mail: Saravanan.varatharaj@gmail.com, Tel: +91-7798298537, Research Scholar, Department of Mechanical Engineering, PSG College of Technology, Coimbatore, Tamilnadu, India

Abstract
Wear is the major parameter for various applications in automobile and aeronautical industries. Various researches are going on to improve the wear by either alloying the material or using the composite material. Current study focuses on wear improvement through composite material with aluminium as matrix and cenospheres as re-inforcement. The abrasive wear behavior of cenosphere particle reinforced aluminium alloy (AA) 6063 was investigated using pin-on-disc technique. Aluminium – cenosphere metal matrix composite was fabricated by adding various percentages of cenosphere particles using stir casting technique and its abrasive wear behavior was compared with AA6063. The uniform distribution of particles was ensured with the help of scanning electron microscopy (SEM).

Keywords: Aluminium, MMC, Wear, Cenosphere, Stir casting

1 Introduction
Fly ash particle used in the current work is called cenosphere or micro balloon. It is a hollow sphere made up of ceramic outer surface. It replaces the glass micro spheres which due to its high cost of production have limited applications. It is also used in many applications like structural, paint, coating, composites etc., as it reduces the cost of the product without compromising the strength. Cenospheres as filler in aluminium casting reduces cost, decreases density and increases hardness, stiffness, wear and abrasion resistance [1, 2]. The presence of cenosphere increases the damping capacity and coefficient of friction [3, 4] making them suitable in industries like automotive, aerospace etc. [5, 6].
The use of aluminium in light vehicles has increased dramatically with the need to reduce the automobile weight and improve fuel efficiency. Aluminium alloy based metal matrix composites (MMCs) with ceramic particulate reinforcement have shown greater promise for such applications [7]. These materials having a lower density, higher thermal conductivity and higher coefficient of friction as compared to the conventionally used gray cast irons are advantageous from the technical and economical point of view for wear application [8]. As aluminium based metal matrix composites have the potential to perform better under severe service conditions it is used for high performance tribological applications [9]. Aluminium matrix composite has 25-

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30% times higher coefficient of friction compared to cast iron and it has better wear properties [10]. Light weight metallic alloys and metal matrix composites are the requirements for friction brakes. Properties of composite will vary based on the bonding between matrix and re-inforcement and it can be controlled by alloying [11].The method of manufacturing adopted is important to reduce the cost of the product. Liquid state process is the low cost and easiest way to produce MMCs. It includes stir casting or compo casting, infiltration, spray casting and reactive processing. Of the above methods stir casting method can be used as it is cost effective [12, 13]. Dispersion and proper mixing of particles were ensured to achieve the desired properties [14]. To manufacture the Al-Cenosphere MMC stir casting technique was used in the current work. The stir casting method involves incorporation of the pre heated ceramic particulate into liquid aluminum alloy melt. Wettability is the most significant problem in producing cast metal matrix composites. Magnesium or silicon addition to the matrix solves the above problem by reducing the surface tension of the particle and consuming oxygen from the surface of the particle. The impeller was used to transfer the particles into liquid metal and maintain the particle in the state of suspension. Impeller type and dimension are important to get better particle distribution [15]. Pre heating of fly ash particles is necessary to remove the moisture content, to accommodate the sudden temperature change and to facilitate dispersion in alloy with minimum agglomeration and porosity [16].

2 Experimental Material and Methods

2.1 Raw material

The matrix material used in the experiment was aluminium alloy AA6063. The standard controlling its composition is issued by The Aluminium Association. It has good mechanical properties and is heat treatable and weldable. It has a specific gravity of 2.6 g/cm^3. The chemical composition of AA6063 used in the present study is shown in **Table 1**.

Table 1 Chemical composition of AA 6063

Si	.42	Ni	.008	Be	.00004
Fe	.28	Pb	.016	Sr	.00003
Cu	.034	Sn	.003	Co	.008
Mn	.07	Na	.0002	Cd	.0003
Mg	.27	Ca	.0002	Sb	.01
Zn	.055	B	.003	Ga	.012
Ti	.16	Zr	.002	P	.003
Cr	.006	V	.01	Al	98.63

Cenosphere particles used in this study are generally spherical in shape and range in size from 1 μm to 500 μm. They mainly consist of silicon dioxide in two forms (amorphous and crystalline), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3). The mixture of glassy crystalline particles like quartz, mullite and various oxides forms cenosphere making it heterogeneous. The characteristics of the particulate composite greatly depend upon the nature, size, density and its distribution. The composite produced possess dispersion and reinforcement due to the size range of cenospheres. Particles were separated into different size range using hand sieves which is made up of brass to avoid wear while sieving.

The desired amount of AA6063 and cenosphere particles were taken. The volume of cenosphere particles used for dispersion was 5 %, 10 %, 15 % and 20 % with aluminum alloy. AA6063 was

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melted in a resistance furnace at 730ºC and stirred with a stirrer. It was stirred upto 5-7 min at an impeller speed of 480 rpm. The cenosphere particles were dispersed in the melt using vortex method simultaneously maintaining the temperature at 700ºC. The melt with reinforced particulates were poured into sand mould and allowed to solidify. The composite was made using different volume of cenospheres. In this experimental work, Pin-on-Disc machine was used to study the wear behavior and coefficient of friction of Al-Cenosphere MMC at different compositions.

2.2 Pin-On-Disc Tester

Sliding wear tests were performed using a DUCOM Pin-On-Disc machine shown in the **Fig. 1**. It is a versatile unit designed to evaluate the wear and friction characteristics of materials exposed to sliding contacts in dry or lubricated environments. The sliding friction test occurs between a stationary pin stylus and a rotating disk. The normal load, rotational speed, and wear track diameter can be varied. Electronic sensors monitor wear and the tangential force of friction as a function of load, speed, lubrication and environmental condition. These parameters and the acoustic emissions at the contact were measured and displayed graphically utilizing the TriboDATA software package. It conforms to ASTM G99 standard.

Fig. 1 Pin-On-Disc Tester

Sliding wear test was conducted at a rotating speed of 200, 400 and 600 rpm over a range of applied loads for a predetermined time of 3 minutes or prior to seizure. The applied load on the specimens was increased gradually from 1 kg to 3 kg. A schematic representation of the test configuration is shown in **Fig. 2**.

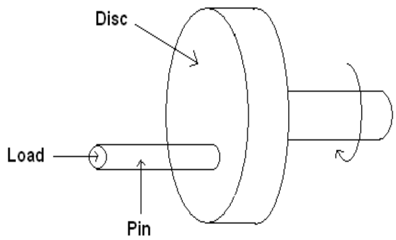

Fig. 2 A schematic representation of the wear test configuration

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The disc was fabricated using EN25 (corresponding to AISI 4340) steel. The track diameter used was 60 mm. The load on the samples was applied using a manual loading mechanism. An experiment was conducted to determine the tribological properties of wear surface in dry condition.

2.3 Specimen Preparation

The cylindrical specimens were prepared thirty in number and machined for the required dimensions. The test was carried out at a temperature between 10˚C and 35˚C. The required number of specimens were prepared with the dimension of length 30 mm and diameter 10 mm.
The three major parameters such as magnesium percentage, size range and percentage of the cenosphere are important to decide the strength of the composite among which magnesium % and size range of cenospheres were kept constant. To achieve good wettability and dispersion of particles the Mg weight proportion was taken constantly at 2 %. Cenosphere particle size range used for the specimen was 1-101 micron. When the particle size was decreased below the specified range, there was no significant improvement in the strength of the composite corresponding to the increase in the processing cost of the cenosphere. The specimens were prepared at different percentages of cenospheres such as 5 %, 10 %, 15 % and 20 % using the stir casting setup specified above.

3 Results and Discussion

3.1 SEM Analysis

The specimens were made using 5 %, 10 %, 15% and 20 % of cenospheres to conduct SEM analysis. The cylindrical specimens of diameter 25 mm and length 50 mm were polished and etched using ferric chloride to facilitate imaging. The SEM analysis was carried out for each specimen at different magnifications such as 5000, 7500 and 27000 under an accelerating voltage of 20 kV. The results of the SEM analysis is shown in the following **Fig. 3, Fig. 4, Fig. 5** and **Fig. 6**.

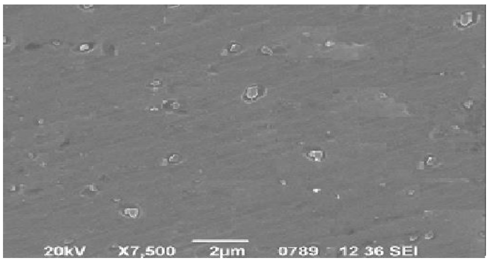

Fig. 3 SEM Image of 5 % Cenosphere particulate reinforced with AA6063 at 7500 X magnification

The above Fig. 3 shows particles that are fractured due to machining and polising undertaken for SEM analysis. The particles shown are in different size which is the result of various ranges used in this study. In 5% cenosphere addition the particle has wide distribution compared to higher % of particle re-inforcement. Since cenosphere particles are harder then AA6063, the addition of cenosphere changes basic properties like hardness and brittleness. The change in hardness of the composite varies the other properties like tensile, wear etc.,

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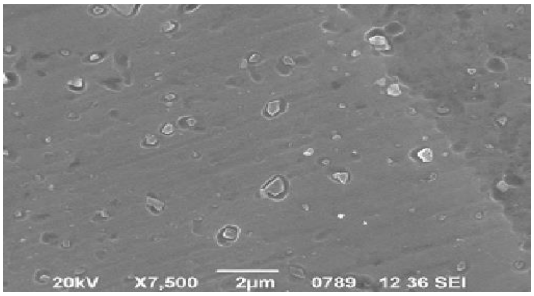

Fig. 4 SEM Image of 10 % Cenosphere particulate reinforced with AA6063 at 7500 X magnification

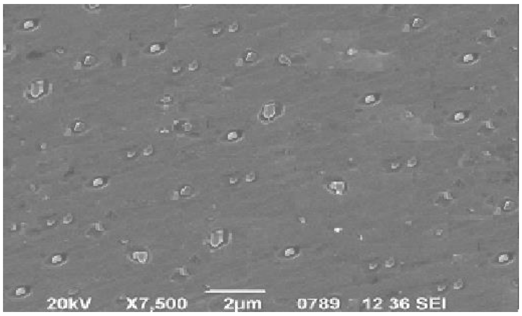

Fig. 5 SEM Image of 15 % Cenosphere particulate reinforced with AA6063 at 7500 X magnification

Fig. 4 and Fig. 5 shows more dense distribution than 5% particle inclusion. But it maintains the uniformity in the particle distribution which is required to carry out the analysis. The variation in size range is clearly visible here.

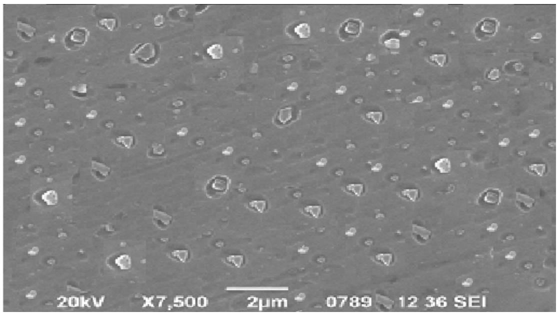

Fig. 6 SEM Image of 20 % Cenosphere particulate reinforced with AA6063 at 7500 X magnification

Above Fig. 6 shows even more dense distribution of particles at 20% cenosphere reinforcement. In the current study 20% is kept as maximum for observing the wear behavior of the composite. At higher % more care is required to prepare the specimen by avoiding agglomeration and sedimentation. Since the cenosphere density is lower than AA6063 there would be considerable weight reduction in the composite.

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3.2 EDX Analysis

Energy Dispersive X-ray spectroscopy (EDX) is a form of atomic analysis, used for elemental characterization. This method is based on the emission of characteristic X- ray by the atoms when they collide with high energy particles like electrons moving with high velocity. The EDX test equipment is built in the SEM apparatus itself. The following **Table 2** shows the composition of the individual elements in the composite excluding the minor elements formed due to the chemical reaction between reinforcement and matrix. EDX results also show the bonding between reinforcement and matrix.

Table 2 EDX Results in Weight %

Sl. No	Element	Specimen A	Specimen C	Specimen B
1.	Silicon	2.46	3.22	4.23
2.	Magnesium	0.33	0.52	0.76
3.	Aluminium	83.2	80.1	77.2
4.	Oxygen	5.30	6.91	7.42
5.	Nickel	2.20	2.51	2.76

3.3 Determination Hardness

The hardness value increases for 5, 10 and 15 percent of cenosphere with AA6063 and it decreases at 20 %. This implies hardness increases up to certain percentage and then decreases. It is shown in the following **Table 3**.

Table 3 Brinell and Vickers Hardness result

S.No	Specimen	Brinell hardness number (HBW)	Vickers hardness number (HV)
1	AA6063 + 5 % C	65	62
2	AA6063 + 10 % C	75	73
3	AA6063 + 15 % C	81	80
4	AA6063 + 20 % C	80	78

The change in hardness value is because of the increase in brittleness due to the increase in cenosphere percentage. Hardness is the basic mechanical property which leads to changes in other properties. Addition of cenosphere upto certain limit will increase the hardness thereby improving wear resistance and reducing the weight of the composite. But this increase in hardness is more in lower % and less after certain limit and then the hardness decreases.

3.4 Wear Behavior

The wear rate was computed by weight loss method and an average of five observations were considered. The cleaned pin samples were weighed prior to and after the wear tests using a Mettler microbalance with a precision level of 0.01 mg. The wear rate was measured as a function of applied load at a fixed sliding speed of 200, 400 and 600 rpm. The wear rates of AA6063 and AA6063 with 5 %, 10 %, 15 % and 20 % of cenosphere were measured. Each experiment was repeated three times and an average value is listed in the **Table 4, 5** and **6**.

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Table 4 Wear rate of A6063 and AA6063 with cenosphere at speed of 200 rpm

Load (kg)	Wear rate (m^3/min)				
	Pure Al (e^{-10})	**Al + 5 % C** (e^{-10})	**Al + 10 % C** (e^{-10})	**Al + 15 % C** (e^{-10})	**Al + 20 % C** (e^{-10})
1	2.61	2.58	2.56	3.34	2.94
3	5.46	4.78	4.44	4.755	5.64
5	6.21	5.17	4.71	4.955	6.43

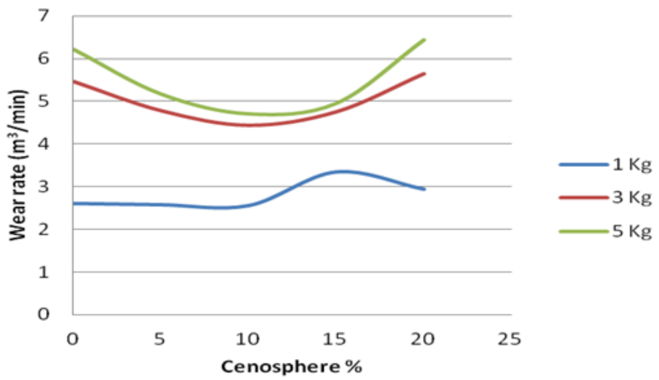

Fig. 7 Wear rate Vs Cenosphere % at 200 rpm

From the above graph it can be predicted that there is not much differences in wear upto certain % of cenosphere for 1 Kg of load. The addition of cenosphere increases the brittleness of the composite. The wear resistance is directly proportional to hardness which is higher at 10% as shown in the above specified hardness results. But for other weights like 3 kg and 5 kg wear rate initially decreases and then increases. Wear can be displayed clearly at higher load conditions. When there is higher load and speed, co-efficient of friction will decrease which is to be discussed in the following analysis.

The wear behavior at 400 rpm is similar to the speed at 200 rpm and there is no significant difference in wear between 3 kg and 5 kg. The high speed & load produces more kinetic energy which in turn emits heat leading to increased wear in addition to that from the load applied. Therefore every experiment was conducted after a considerable duration of time to avoid heat generated during the previous experiment.

Table 5 Wear rate of AA6063 and AA6063 with cenosphere at speed of 400 rpm

Load (kg)	Wear rate (m^3/min)				
	Pure Al (e^{-10})	**Al + 5 % C** (e^{-10})	**Al + 10 % C** (e^{-10})	**Al + 15 % C** (e^{-10})	**Al + 20 % C** (e^{-10})
1	4.10	3.23	2.29	3.34	4.39
3	5.09	4.65	4.31	4.755	5.20
5	5.59	5.04	4.17	4.955	5.74

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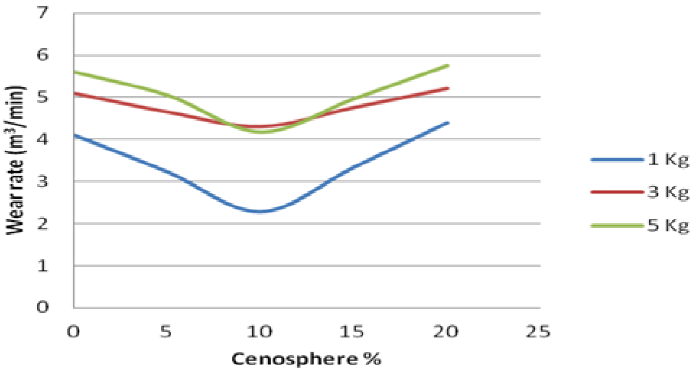

Fig. 8 Wear rate Vs Cenosphere % at 400 rpm

Table 6 Wear rate of A6063 and AA6063 with cenosphere at speed of 600 rpm

Load (kg)		**Wear rate (m^3/min)**			
	Pure Al (e^{-10})	**Al + 5 % C** (e^{-10})	**Al + 10 % C** (e^{-10})	**Al + 15 % C** (e^{-10})	**Al + 20 % C** (e^{-10})
1	3.23	2.84	1.35	2.57	3.79
3	4.47	3.87	3.04	3.945	4.85
5	4.97	4.39	4.17	4.805	5.44

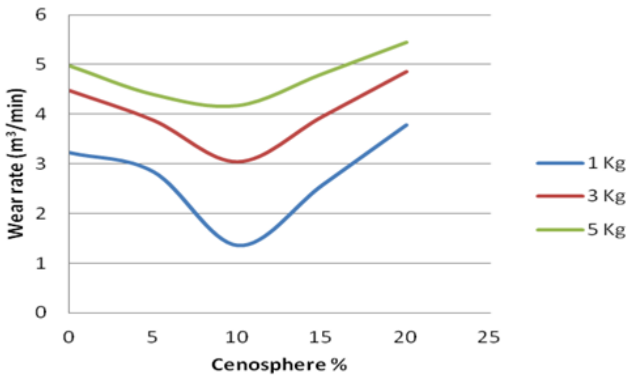

Fig. 9 Wear rate Vs Cenosphere % at 600 rpm

From the above Fig. 7, Fig. 8 and Fig. 9, it can be implied that the variation in wear rate depends mainly on the composition of cenosphere and not due to the difference in applied load or rotating speed. The wear rate decreases with the increase in composition of cenosphere added to the aluminium alloy. But when the composition of cenosphere in AA6063 increases above 15 % then there is an increase in wear rate due to the decrease in hardness value compared to pure AA6063. So the optimized composition of cenosphere in aluminium alloy was 15 % in which the wear rate results in minimum.

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3.5 Coefficient of Friction (COF)

In this work, friction coefficients were determined to compare the characteristics of AA6063 and the composite. The friction coefficient was ascertained for AA6063 and the composite at various loads applied (1, 3, 5 kg) and at fixed speeds of 200, 400 and 600 rpm. Each experiment was repeated three times and an average value is listed in the **Table 7, 8** and **9** at a fixed sliding speed of 200, 400 and 600 rpm respectively.

Table 7 Coefficient of friction of pure A6063 and AA6063 with cenosphere at speed of 200 rpm

Load (kg)	Coefficient of friction				
	Pure Al	Al + 5 % C	Al + 10 % C	Al + 15 % C	Al + 20 % C
1	0.4077	0.3674	0.3058	0.43325	0.5607
3	0.5097	0.4247	0.3568	0.4774	0.598
5	0.6014	0.5505	0.4689	0.56165	0.6544

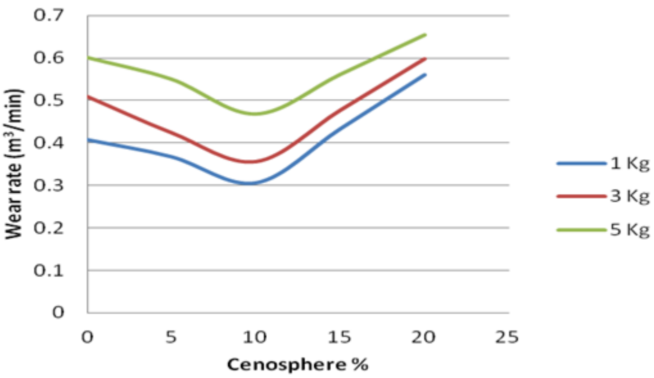

Fig. 10 Coefficient of friction Vs Cenosphere % at 200 rpm

When the censophere percentage was increased, COF decreases up to certain limit and then increases. COF of a material depends on the hardness of the material and is a crucial factor in choosing new material for some applications like friction pairs. Generally COF will be inversely proportional to the hardness of the material which increases up to a certain percentage of cenosphere. But after certain limit, COF decreases due to the increase in brittleness.
COF is a vital mechanical property used to ascertain other properties and behavior of the material. Each specimen was surface finished at the point of contact by machining to avoid rough surface.

Table 8 Coefficient of friction of A6063 and AA6063 with cenosphere at speed of 400 rpm

Load (kg)	Coefficient of friction				
	Pure Al	Al + 5 % C	Al + 10 % C	Al + 15 % C	Al + 20 % C
1	0.3874	0.3262	0.2854	0.3611	0.4368
3	0.4587	0.4009	0.3568	0.43495	0.5131
5	0.5607	0.4995	0.4281	0.51985	0.6116

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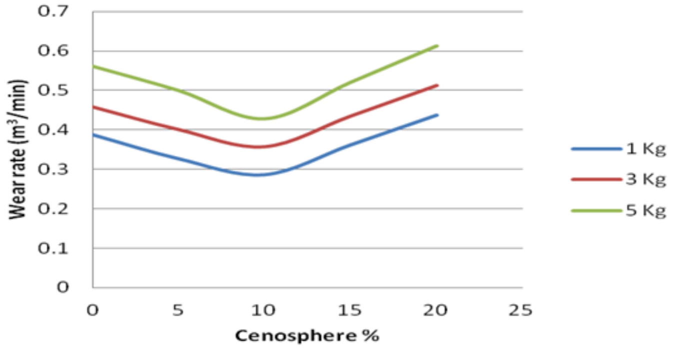

Fig. 11 Coefficient of friction Vs Cenosphere % at 400 rpm

Table 9 Coefficient of friction of A6063 and AA6063 with cenosphere at speed of 600 rpm

Load (kg)		Coefficient of friction			
	Pure Al	**Al + 5 % C**	**Al + 10 % C**	**Al + 15 % C**	**Al + 20 % C**
1	0.3466	0.3058	0.2446	0.36185	0.4791
3	0.4077	0.3674	0.3228	0.41625	0.5097
5	0.4954	0.4077	0.3669	0.46885	0.5708

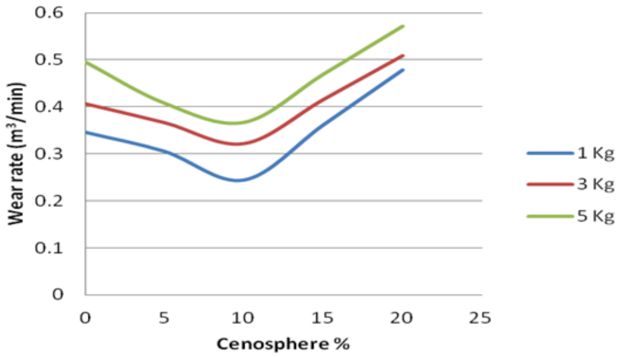

Fig. 12 Coefficient of friction Vs Cenosphere % at 600 rpm

From the above Fig. 10, Fig. 11, Fig. 12, it can be inferred that similar to the wear rate there is a decrease in coefficient of friction when there is an increase in the composition of cenosphere. But when the composition of cenosphere in aluminium alloy increases above 15 % there is an increase in coefficient of friction due to the decrease in hardness value compared to pure aluminium.

4 Conclusion

Many researches are being undertaken on improving the wear resistance by various means. The current study focused on increasing the wear resistance through composite material. The specimens were prepared by stir casting route to find out the wear properties of the composite. The proper dispersion of the particle is important to decide the property of the particulate

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composite which was ensured by SEM and EDX study. Various volume % of cenospheres were reinforced out of which 10% cenosphere addition results in good wear resistance. It increases upto certain limit of cenosphere addition and decreases afterwards. The quantity of cenosphere addition can be determined depending on the other characteristic requirements of the composite and specific to the application. Hence this study is a proof that addition of cenosphere to aluminum improves the wear resistance of the alloy.

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