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Comparison between Single rare earth and mixed rare earth reinforced Aluminium metal matrix composites on the basis of wear properties

Divyanshu Aggarwal
Masters Students, Department of Mechanical Engineering,
Thapar Institute of Engineering and Technology, Patiala,
Punjab,142001

Vipin Kumar Sharma
Research Scholar, Department of Mechanical Engineering,
Thapar Institute of Engineering and Technology, Patiala,
Punjab,142001

Dr.Vinod Kumar
Associate Professor, Department of Mechanical Engineering,
Thapar Institute of Engineering and Technology, Patiala,
Punjab,142001

Dr. Ravinder Singh Joshi
Assistant Professor, Department of Mechanical Engineering,
Thapar Institute of Engineering and Technology, Patiala,
Punjab,142001

Abstract
The paper presents the study on comparison of wear properties of Aluminium metal matrix composites reinforced with single rare earth metal i.e. CeO_2 with mixed rare earth m*etal*s i.e. $CeO_2 +$ LaO_2 along with mixture of ($Al_2O_3 + SiC$) used as reinforcements in both types. For this purpose the composites were prepared using stir casting process. The constant weight percentages of 10% of (SiC + Al_2O_3) mixture was used, 0.5, 1.5, 2.5 % of CeO_2 was used in one composite sample and 0.5, 1.5, 2.5 % of ($CeO_2 +$ LaO_2) mixture was used in another composite. The focus of the research was to investigate and compare the tribological properties of both types of composites in a pin-on-disc configuration using universal tribometer . Wear rates were examined against different sliding velocities i.e. 0.5, 1, 2 m/sec at a constant load of 30N and different sliding distance upto 2000m. Microstructure analysis of the wear specimens before and after the test was done with the help of SEM technique. It was concluded that the composites reinforced with single rare earth metal shows better tribological properties as compared to the composites with mixed rare earth in it. Better microstructure refinement can be seen from the micrographs of the samples before applied to wear testing.

Keywords: Metal matrix **C**omposites, Wear Properties, Scanning Electron Microscopy.

1. Introduction
In the era of globalization, the demand of new products with advanced materials and process technologies is increasing. Stronger, lighter, and less expensive materials are current requirement of engineering applications. MMCs are the alloys of metals that are reinforced with various types of reinforcement materials and especially ceramic materials. Metal matrix composites (MMCs) offer such properties required in a wide range of engineering applications [1]. Most of these properties consist of high specific strength, lower coefficient of thermal expansion, high thermal resistance, excellent wear resistance, high specific stiffness and excellent corrosion resistance [2-4]. Alloys of light metals such as Al, Mg and Ti are the common metallic alloys utilized today. Metal matrix composites can be manufactured by various techniques which are divided into three class's i.e. solid, liquid and vapor out which liquid state method comprising of stir casting technique is the most commonly used method due to its low cost and availability. Aluminum metal matrix composites (AMCs) are one of the most common and widely used materials in the industrial world today. AMCs are widely used in aerospace, automobiles, defense etc. [5]. To increase the properties of aluminum MMCs they are reinforced with various other reinforcing materials such as SiC, Al_2O_3, B_4C, TiC, TiB_2, MgO, TiO_2 etc. [6] Reinforcements are mainly added to enhance the properties of base metal like strength, stiffness, conductivity etc. The reinforcements in the AMCs are in the form of fibers (continuous or discontinuous), whiskers or particulates in volume which has a range from few percentages to 70% [3]. The different reinforcements used in the formation of AMCs can be classified as ceramic particulates, industrial wastes, agro wastes and reinforcements

with traces of rare earth elements [1]. Stability of reinforcement is necessary in the given temperature and non-reactive too.

Rare earth elements, also known as rare earth metals are one of the set of seventeen chemical elements in the periodic Table. It consists of 15 lanthanides as well as scandium and yttrium. Zhang *et.al* [7] reported that by addition of mixed rare earth additive i.e. Nd, Ce, La and Pr in the composites with 9.5 vol % AlTiC, 0.5 vol. % mixed RE and 90 vol. % alumina bending strength, toughness and hardness were observed to be 617.6 MPa, 5.77MPa and 20.7 GPa. But when the percentage reaches above it i.e. 3% there was sudden decrease in properties of the composites. Xu wang *et.al* [8] (2011) presented the study on effect of Nd content on mechanical and microstructural properties of Gr/Al composites. M40 graphite fiber reinforced Al-17Mg matrix composite was used with different contents of Nd i.e. 0.2, 0.5, 2 weight percentage. Microstructure of the composite was observed by using various techniques like SEM, XRD, TEM, and HRTEM. Various phases of $Al_{11}Nd_3$ and Al_3Mg_2 followed by segregation of Nd and Mg at carbon aluminum interface were also observed and it was concluded by the author that with the increase in addition of Nd content in matrix there was sudden decrease in the bending strength of Gr/Al composites.

Ravinder Singh Rana *et.al* [9] optimized the wear performance of Al 5083 reinforced with 10 weight% SiC using Taguchi method considering the objective as 'smaller the better' and resulted that applied load has the highest influence on the wear rate of the composite followed by sliding distance and sliding speed. K. Soorya Prakash *et.al* [10] investigated wear as well as mechanical behavior of Mg/SiC/Gr hybrid composites and reported that the properties like density, wear resistance and micro-hardness increased with increase in SiC content but as the Gr content increases micro-hardness decreased due to brittle fracture occurring in the structure which was observed from SEM images. K.R. Padmavathi *et.al* [11] (2014) showed the tribological behavior Al hybrid MMCs using SiC and multi walled carbon nanotube (MWCNT) as reinforcements. Varying percentage of 0.5% and 1.0% of MWCNT was used along with fixed volume percentage of 15% of SiC. The author observed that specific wear rate decreases with the increase of the wt % of MWCNT. There was a sudden decrease in hardness value at 0.5% MWCNT but when the value reaches 2% the hardness value increases. Sidesh Kumar *et.al* [12] (2014) showed the mechanical and wear behavior of Aluminum MMCs using Al2219 as base alloy and B_4C and MoS_2 as reinforcements. The weight percentages taken were 3, 4, 5 % keeping B_4C at 3% constant. The author concluded that on increasing the %age of reinforcement density, hardness increases but tensile Strength and Yield Strength Decreases. Hongying Li *et.al* (13) (2013) investigated the effect on precipitation and recrystallization of pure aluminum by adding Er and Zr to it. The reinforced composites formed were Al-0.2Er-0.2-Zr and Al-0.2Er. The results showed that the recrystallization temperature of the Al-0.2Er-0.2-Zr (wt %) was about 450°C, which was significantly higher than Al-0.2Er (wt %) alloy (350°C). Youming Liu *et.al* (14) (2004) investigated effects and behavior of rare earth CeO_2 on in-situ TiC/Al composite. It was concluded by the author that an addition of 0.5 weight % addition of CeO_2 promotes the generation and refinement of TiC particles, prevents the formation of Al_3Ti, increase the wettability between the TiC particles and the Al matrix as well as improvement in the mechanical properties of the composites was observed. H.S.Arora *et.al* (15) (2013) investigated friction stir processed Mg alloy wear behavior. Pin-on-disc machine (using universal tribometer) was used for performing wear test. The wear rates were examined under various load conditions i.e. 5 to 20 N under different sliding velocities varying from 0.33 to 3 m/sec. SEM and XRD techniques were used for analyzing worn surface and wear debris. It was observed that the friction stir processed (FSPed) AE42 alloy showed noticeable decrease in the wear rate was observed, which was due to the microstructural refinement that results an increased hardness and ductility of the FSPed alloy. It was also observed by the author that maximum wear rate occurred at higher loads & lower velocities. The maximum wear mechanisms at higher velocities were found to be plastic deformation along with some part of delamination.

From the literature it can be observed that various researches have been done on studying the wear behaviour of metal matrix composites containing SiC, TiC, Al_2O_3, Gr, B_4C, CaC_2 as reinforcements and some contain rare earth elements as an additive to improve properties of the composites, but very few researches has been carried out on Al 6061 reinforced with mixture of ($Al_2O_3 + SiC$) and rare earth element as an additive and comparing the effects of different rare earth elements on these composites. The current work deals with the comparison between single rare earth reinforced composites (consisting of CeO_2) and mixed rare earth composites (consisting of $CeO_2 + LaO_2$) along with mixture of ($Al_2O_3 + SiC$) as reinforcements.

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2. Experimental Details

The chemical composition of Al 6061 alloy is shown in Table 1. Cylindrical specimens of size 10×12mm were prepared from the alloy ingot of size 20×220 mm. Stir casting was carried out for fabrication of the composites. The details of the reinforcements used along with rare earth elements are shown in Table 2. The process consists of melting of the alloy at a temperature of 600-700ºC followed by inclusion of reinforcements which were preheated at a temperature of about 400ºC so as to remove moisture from them making them suitable for mixing. After addition of reinforcements in the molten pool the mixture is thoroughly mixed with the help of a graphite stirrer for 10-15 minutes and after that the molten metal mixture is poured into the cast iron die. After solidification of the molten metal it was removed and afterwards machined to bring them to the size of specimens required for wear testing (i.e. 10×12mm). Both the composites were prepared with the same techniques. A small amount of magnesium was also added so as to increase the wettability of the composites. The different specimens fabricated are mentioned in Table 3.

Table 1: Chemical composition of Al-6061 alloy

ELEMENT	Mg	Si	Cu	Zn	Ti	Mn	Cr	Al
AMOUNT (Weight %)	0.84	0.69	0.22	0.07	0.05	0.30	0.08	Balance

Table 2: Details of Al_2O_3, SiC, CeO_2 and LaO_2

Reinforcement	Average particle size (µm)	Density (g/cm^3)	Melting point (°C)
Al_2O_3	40	3.95	2,072
Sic	220	3.20	2,700
CeO_2	5	7.22	2,400
LaO_2	10	6.51	2,315

Table 3: Fabricated parts of composites

Part No.	Composite specification	Wt% of ($Al_2O_3 + SiC$) mixture	Wt% of Rare earth added
Single Rare (SR) earth composites			**CeO_2**
A	($Al_2O_3 + SiC$) + CeO_2	10	0.5
B	($Al_2O_3 + SiC$)+ CeO_2	10	1.5
C	($Al_2O_3 + SiC$) +CeO_2	10	2.5
Mixed Rare (MR) earth composites			**($CeO_2 + LaO_2$)**
A	($Al_2O_3 + SiC$) + ($CeO_2 + LaO_2$)	10	0.5
B	($Al_2O_3 + SiC$) + ($CeO_2 + LaO_2$)	10	1.5
C	($Al_2O_3 + SiC$) + ($CeO_2 + LaO_2$)	10	2.5

For microstructure studies, both the composites were prepared by standard metallographic techniques and etched with a solution of 7ml acetic acid, 100ml ethanol, for 30 sec. Microstructure study of the composites was done with the help of scanning electron microscopy (SEM: JEOL JSM - 6510LV, Oxford instruments). The microstructure of the specimens was observed before and after the test also.

2.1 Wear test

Cylindrical pins with cross-section 10×12mm were machined from the casted alloy through mechanical tools for wear test. Dry sliding wear test was carried out on a pin-on-disc tribometer (Ducom India). The counter face material used was a stainless steel disc (EN31) of hardness 105 HRB and dia of 160mm. Before wear test the specimens were ground using different grades of emery paper. All the wear tests were conducted at three different sliding speeds i.e 1, 2 and 3 m/sec under normal loads of 10, 20 and 30 N and sliding distance upto 2000m. Before and after the test both the specimens and disc were cleaned with acetone and were dried properly in air to avoid contaminations. All the parameters used for wear test are shown in Table 4.

3. Results

3.1 Microstructure: Before the wear test

The SEM images of the specimens are shown in Figure 1. The preheated rare oxide reinforcement in powder form is mix into the liquid-aluminum alloy to produce the hybridization effect into the composites. The irregular shape of the SiC particles tends to increase the bonding between the particles which tends to increase the tensile strength of the particles also the fine structure of the Al_2O_3 particles provide better strength to the composites and are very difficult to pull-out from the matrix.

It can be seen from the SEM images of the rare earth composites that the degree of agglomeration in the composites having mixed rare earth addition is more as compared to single rare earth composites which can be seen from Figure 1(c) and 1(d). Figure 1(b) and 1(f) shows various cracks and micro-cuts on the surface of both the composites and it is perceptible from the Figures that the percentage of cracks and various other surface defects are more on the composites with mixed rare earth reinforcements. Also it can be seen from Figure 1(f) that there are some air holes or micro-holes on the surface which can be due to fracture caused by inter-granular failure due to addition of high amount of mixed rare earth element but when the same amount of pure CeO_2 is added to the composites no such failure can be seen and this can be due to better grain refinement in single rare earth composites.

3.2 Wear testing

3.2.1 Test procedure

The dry sliding wear test was performed on samples of composites with size 10×12mm cross-section through a pin-on-disc tribometer. Figure 2 shows the variation of wear rate with different sliding distances under different sliding velocities keeping the normal load constant at 30N. It can be seen from graphs shown in Figure 2 that at the initial stage the there is a sudden increase in wear rate but as the sliding distance increases then with the passage of time the wear rate decreases and finally becomes constant. This occurs due to the different stages undergo by the specimens. It was observed that during the initial stage i.e. run-in period the wear rate becomes very high because it is the primary stage of wear and at this stage surfaces adapt to each other and maximum wear rate can be observed in this stage. Once this stage is crossed the next sage that comes into picture is secondary stage or mid-age process in which the wear tends to reduce and further remains constant. Steady wear is observed under this stage. Most of the components operational life is spent in this stage. The various stages undergone by the composite specimens are shown through a graphical representation as shown in Figure 2. Comparing the specimens of both the composites it can be seen that the wear rate in mixed rare earth composites is much higher as compared to the single rare earth reinforced composites. This can be due to the fact observed from the SEM images of the composites that the surface of mixed rare earth composites consists of various defects which are more as compared to others and due to which it can be predicted that due to these defects occurring in the initial stage before test has given poor results after the testing also.

Table 4: Details of sliding wear parameters

PARAMETERS	DESCRIPTION
Testing specimens and samples	Pin-on-disc (a) Al 6061 alloy + Al_2O_3 + SiC+ CeO_2 (b) Al 6061 alloy + Al_2O_3 + Sic + CeO_2 +LaO_2
Counter disc	Material of disc = EN 31 Steel Hardness of disc = 105 HRB Diameter of disc = 160 mm
Sliding distance (m)	500, 1000, 1500, 2000
Sliding Velocity (m/sec)	1, 2, 3
Normal load (N)	30 (Constant)
Lubrication Condition	Dry condition
Temperature (°C)	Atmospheric temperature

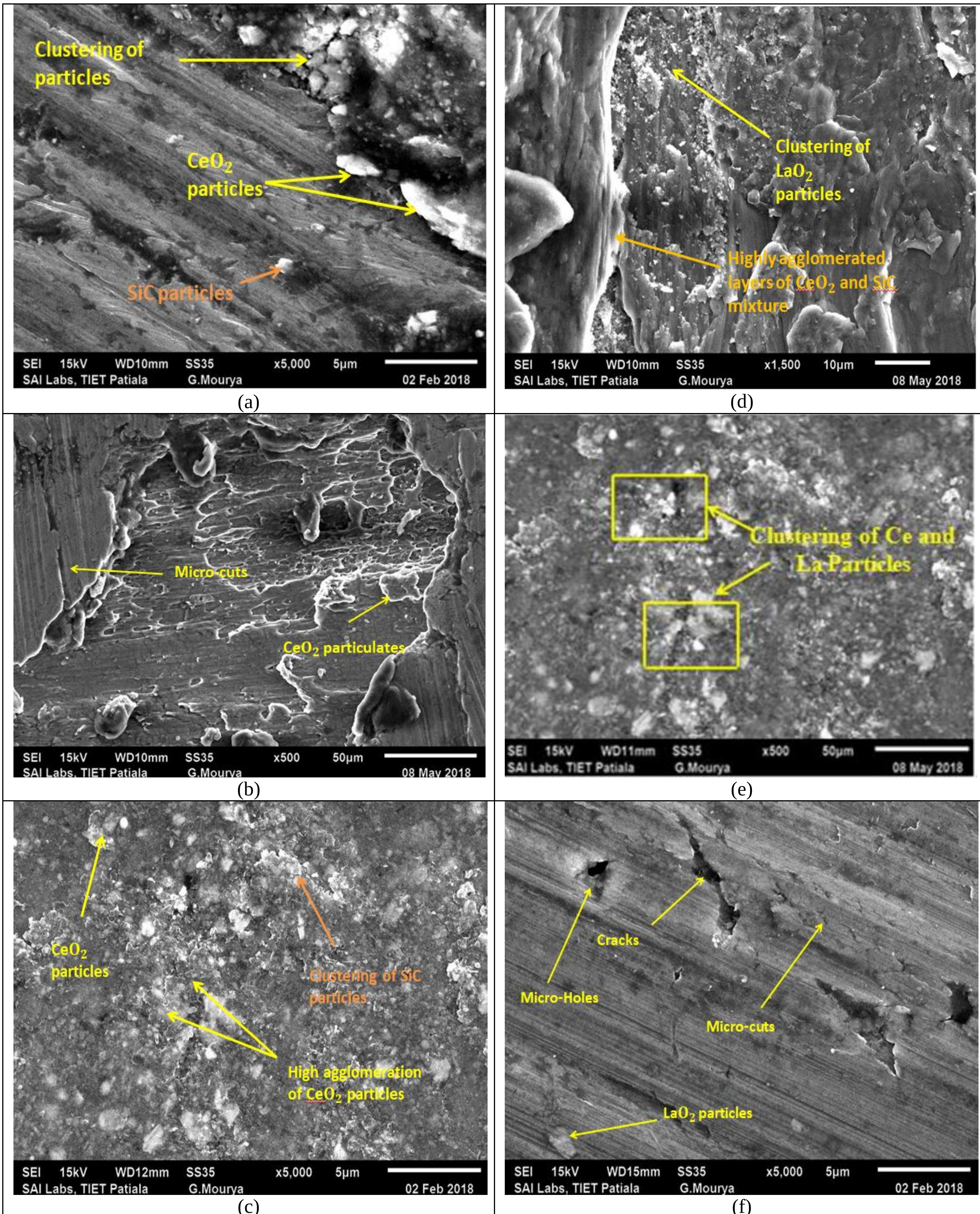


Figure 1: SEM micrograph images of (a) $(Al_2O_3 + SiC)$ + 0.5% CeO_2 (d) $(Al_2O_3 + SiC)$ + 0.5% $(CeO_2 + LaO_2)$ (b) $(Al_2O_3 + SiC)$ + 1.5% CeO_2 (e) $(Al_2O_3 + SiC)$ + 1.5% $(CeO_2 + LaO_2)$ (b) $(Al_2O_3 + SiC)$ (c) $(Al_2O_3 + SiC)$ + 2.5% CeO_2 (f) $(Al_2O_3 + SiC)$ + 2.5% $(CeO_2 + LaO_2)$

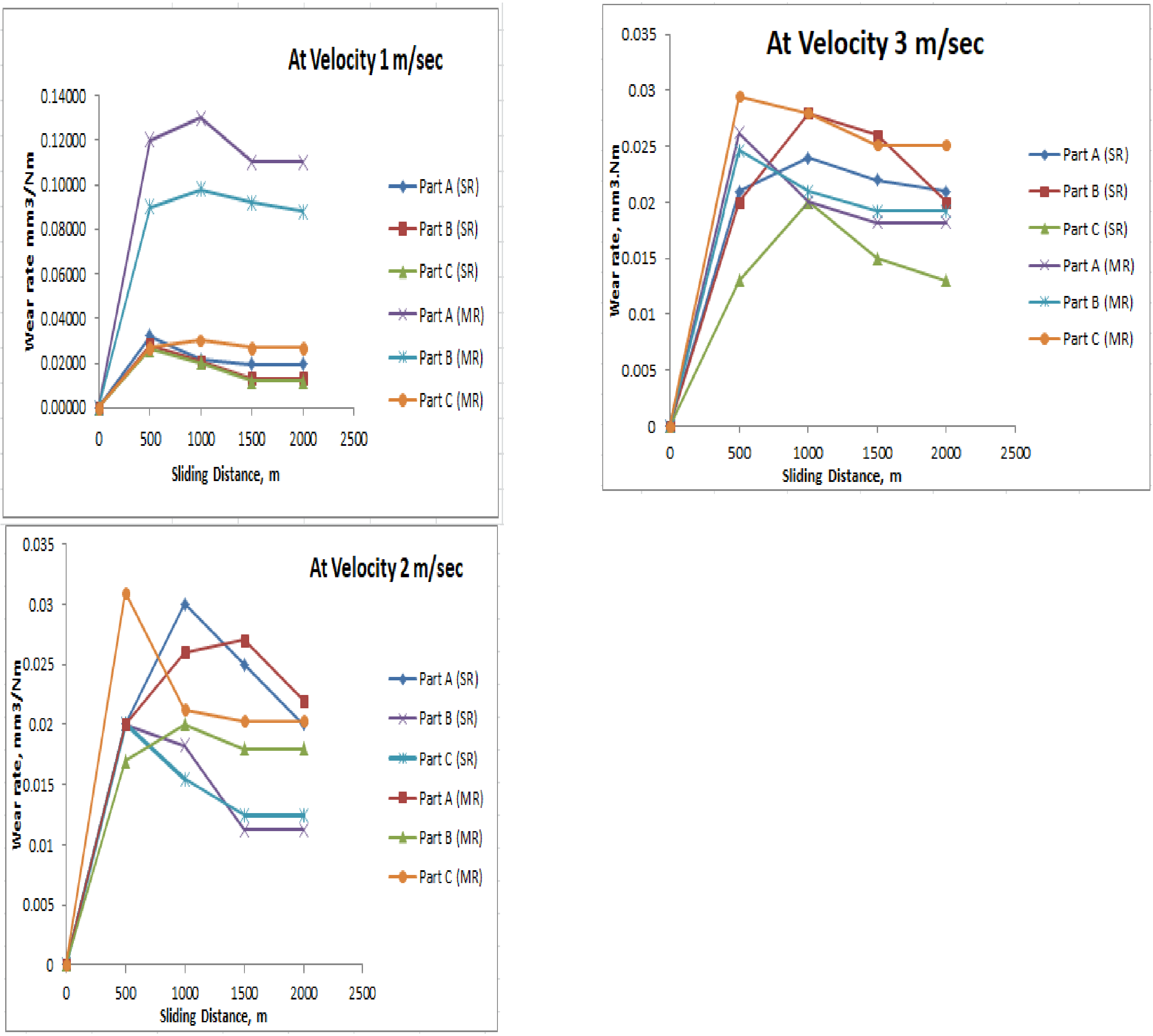


Figure 2: Variation of Wear rate with different sliding distances under different sliding velocities at a constant normal load of 30N.

The SEM images of the tested specimens were analyzed as shown in Figure 4 and it was observed that wear surfaces of the specimens were characterized by fractured surfaces, long continuous grooves, and micro-cuts and ploughing, all indicative of abrasion. The wear rate of both the composites shows higher wear rate at lower values of velocity. A thinner and less adherent lubricant layers peels off from the surface when the sliding velocity increases. Further increase in sliding speed reduces the contact time between the pin and the disc which further results in decrement of wear loss. But still the rate of wear was seen more in mixed rare earth composites and this may be due to the fact that that the rate of plastic deformation is such more severe in these composites also by addition of mixed rare earth composites causes certain chemical reactions inside the material which tends to soften the material by changing the properties of material from ductile to brittle hence more surface abrasion takes place due to which wear rates in these composites seems to be more as compared to single reinforced composites.

The combined effect of all the parameters taken under consideration for the test against the wear test is shown in Figure 3. From each group of every part a case was selected which shows maximum wear rate. It shows that part A consisting of 0.5wt% of mixed rare earth shows maximum amount of wear rate in the composites followed by part B then part C, at velocity 1 m/sec, similarly maximum wear rate in Single rare earth reinforced composites can be seen in Part B at 3 m/sec followed by part A at 1 m/sec then part C at 2 m/sec. These selected parts which shows maximum amount of wear rate were selected and there microstructure images can be seen in Figure 4.

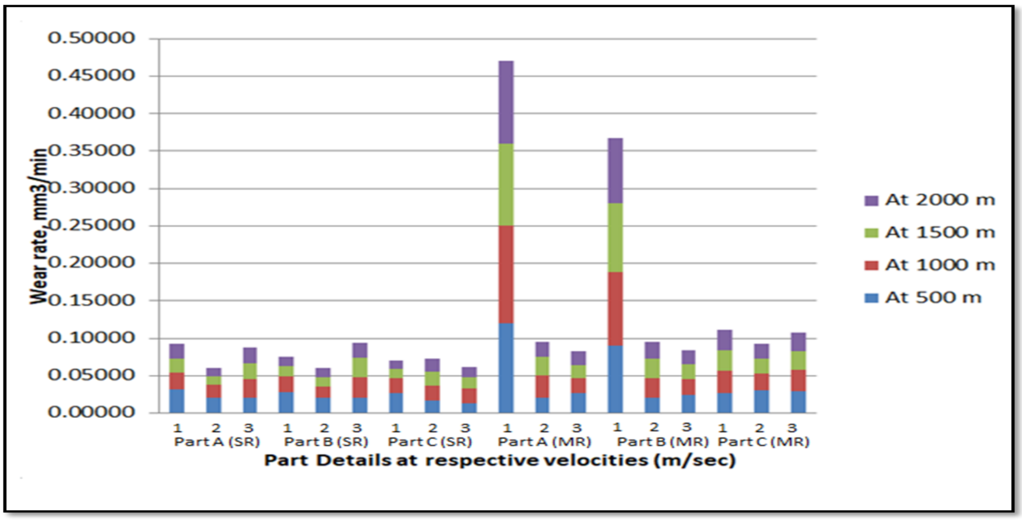
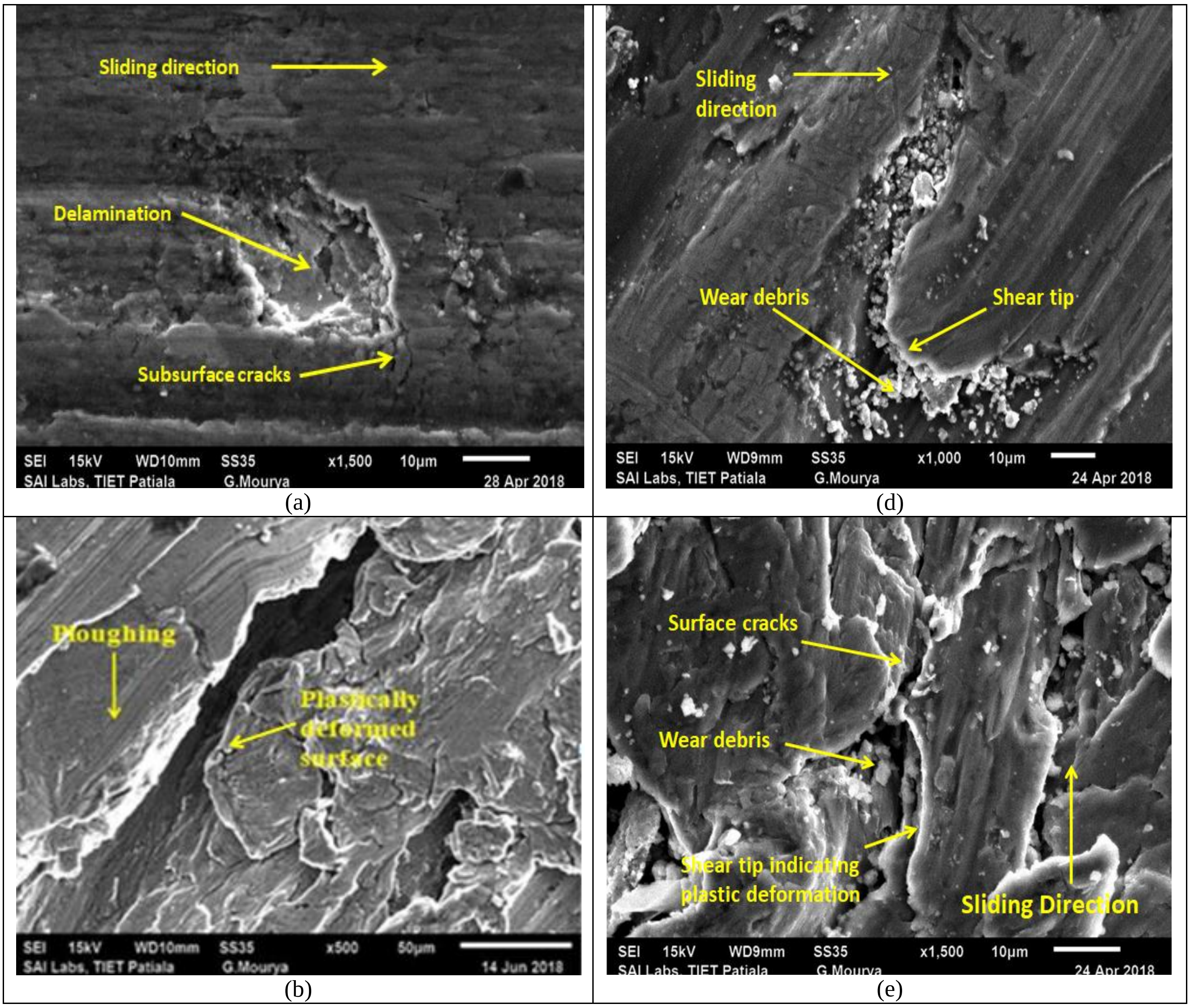
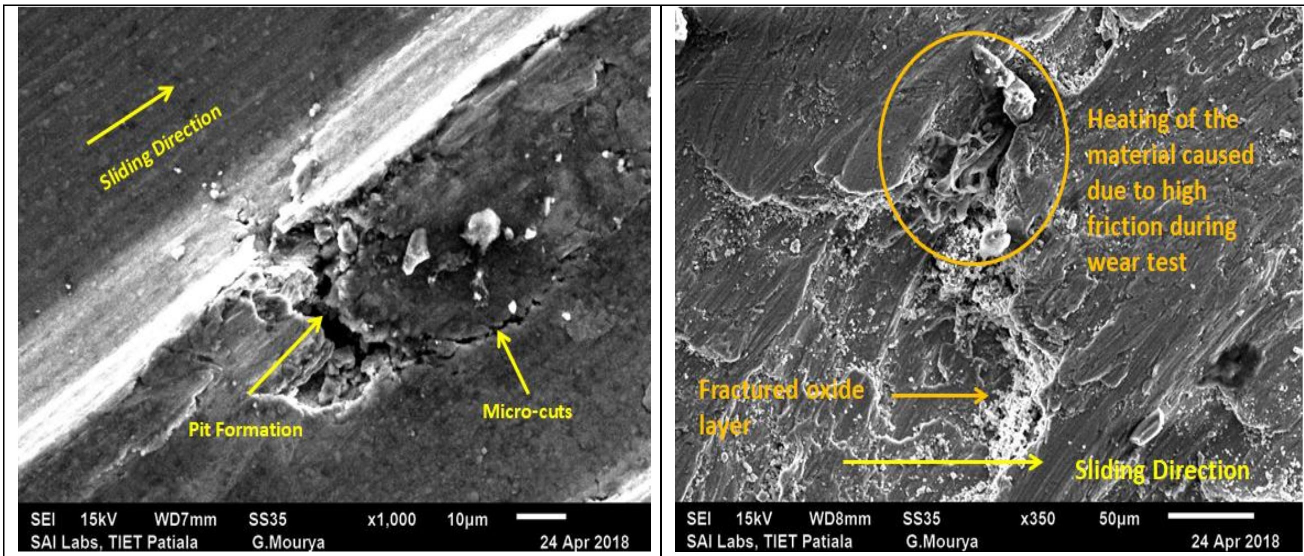


Figure 3: Combined effects of sliding velocity and sliding distance on the wear rates of composites





(c) (f)

Figure 4: SEM micrograph images of (a) ($Al_2O_3 + SiC$) + 0.5% CeO_2 (d) ($Al_2O_3 + SiC$) + 0.5% ($CeO_2 + LaO_2$) (b) ($Al_2O_3 + SiC$) + 1.5% CeO_2 (e) ($Al_2O_3 + SiC$) + 1.5% ($CeO_2 + LaO_2$) (b) ($Al_2O_3 + SiC$) (c) ($Al_2O_3 + SiC$) + 2.5% CeO_2 (f) ($Al_2O_3 + SiC$) + 2.5% ($CeO_2 + LaO_2$)

Conclusions

The various conclusions that can be drawn from the results obtained from the testing are:

1. For the range of sliding velocities and sliding distance investigated single reinforced composites shows better tribological properties as compared to mixed rare earth reinforced composites.
2. The major factor that contributed to the increased wear rate in mixed rare earth composites were found to be inter-granular failure, softening of the material due inter-molecular reactions caused due to addition of two different rare earths which tends increase the wear rate in the composites.
3. It was also found that maximum mass loss/sliding distance (wear rate) occurred at lowest velocities.
4. The SEM images of the tested specimens clearly showed that the surface defect rate were more in mixed rare earth composites as compared to single rare earth, which showed the poor surface properties of such composites.

References

[1] Bodunrin O.M, Alaneme K.K, Chown L.H, Aluminum matrix hybrid composites: a review of reinforcement philosophies; mechanical corrosion and tribological characteristics, *J Mater research of technology* 2015, 4(4), 434-445.

[2] Kok M, Production and mechanical properties Al_2O_3 particle- reinforced 2024 aluminum alloy composites, *J Mater processing technology 2005*, 161, 381-387.

[3] Surappa M K, Aluminum matrix composites: Challenges and opportunities, *Sadhana* 2003, 28, 319-334.

[4] Alaneme K. K and Bodunrin M.O, Corrosion behavior of alumina reinforced aluminum 6063 metal matrix composites, *J Mineral & mater characterization & engg* 2011, 10(12), 1153-1165.

[5] Rajan T.P.D., Pillai, R.M., Pai, B.c., Satyanarayana, K.G., Rohatgi, P.k, Fabrication and characterization of Al-7Si-0.35Mg/fly ash metal matrix composite processed by different stir casting routes, *Composite science and technology* 2007, 67(15-16), 3369-3377.

[6] B. Vijaya Ramanath, C. Elanchezhian, RM. Annamalai, S. Aravind, T. Sri Ananda Atreya, V. Vignesh and C. Subramaniam, Aluminum metal matrix composites- a review, *Adv mater sci* 2014, 38, 55-60.

[7] Xihua Z, Changxia L, Musen LI and Jianhua Z, Research on toughening mechanisms of alumina matrix composites material improved by rare earth additive, *J Rare earth* 2008, 26(3), 367-370.

[8] Wang Xu, Chen G, Yang W, Hussain M, Wang C, Gaohui Wu and Jiang D (2011), Effect of Nd content on microstructure and mechanical properties of Gr/Al composite, *Material science and engineering A*, 528, 8212-8217.

[9] Ravinder Singh Rana, Rajesh Purohit, Anil Kumar Sharma, Saraswati Rana, Optimization of wear performance of Al 5083/10 wt% SiC composites using Taguchi method, *Procedia Materials Science* 2014, 6, 503-511.

[10] Soorya Prakash. K, Balasundar. P, Nagaraja. S, Gopal. P.M and Kavimani. V (2016), Mechanical and wear behavior of Mg-SiC-Gr hybrid composites, *Journal of magnesium and alloys*, 4, 197-206.

[11] Padmavathi K.R, Dr. R. Ramakrishnan (2014), Tribolological behavior of aluminum hybrid metal matrix composite, *Procedia engineering*, 97, 660-667.

[12] Kumar Siddesh, Ravindranath VM and Shiva Shankar GS (2014), Mechanical and wear behavior of aluminum metal matrix hybrid composites, *Procedia materials science*, 5, 908-917.

[13] Li. Hongying, Gao. Z, Yin. H, Jiang. H, Xiongjie Xu and Bin. J (2013), Effects of Er and Zr additions on

precipitation and recrystallization of pure aluminum, *Scripta materialia*, 68, 59-62.

[14] Liu Youming, Li Wenyi, Xu. B, Cai. X, Liuhi Li and Chen. Q (2004), The behavior and effect of rare earth CeO_2 on In-situ TiC/Al composite, *Metallurgical and materials transactions*, 35A, 2511-2515.

[15] Arora H.S., Singh. H and Dhindaw B.K (2013), Wear behavior of a Mg alloy subjected to friction stir processing, *Journal of wear*, 303, 65-77.