ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

Mechanical & Tribological Behavior of Stir Cast LM6 – Fly ash Composite

Asim Kumar Dhar[1,2]

[1] Institute of Engineering & Management, Kolkata, India

[2]Jadavpur University, Kolkata, India

Goutam Sutradhar[3]

[3] National Institute of Technology, Manipur, India

***Corresponding author:** Asim Kumar Dhar, Email: asim.dhar@iemcal.com

Abstract

Industry waste, fly ash found useful applications in constructions and high-end research activities as possible substitute for conventional metals. Fly ash metal matrix composites has found applications in aviation, automotive sector, defense, commercial usage for its specific advantages over base metal. It has generated considerable interest with light weight composite as aluminum alloy as viable support in order to enhance characteristics while minimizing the cost of production. Fly ash (2%, 5%, and 8% by weight) was used to make Al alloy MMC through stir casting method. Optical microscope and SEM, used to examine the microstructure of AMCs reveals that fly ash is distributed uniformly. XRD and EDAX examination are also made to carry out structural analysis of the composites. Tribological test is performed on block on roller tribotester to ascertain the wear and Cof properties of composites under load of 25N, 50N, and 75N at sliding speeds of 400rpm, 500rpm, and 600rpm.

Keywords: LM6, fly ash, Stir Casting, Optical Microscope, SEM, XRD, EDAX, Tribology

1. Introduction

The automobile industry is constantly working to reduce fuel consumption by reducing the weight of the vehicle without sacrificing performance, which necessitates the use of lightweight materials [1]. Aluminum, one of the most lightweight fundamental materials and one of the most widely available, is widely used due to its “ease of access, machinability, rigidity, high strength and stiffness to weight ratio, simple casting process and flexibility” [2]. As a result, automotive manufacturers are gradually replacing ferrous components with aluminum and aluminum alloys, such as intake manifolds, oil containers, valve covers, and alternator covers [3]. Better stability at elevated temperatures and superior resilience to wear and abrasion, aluminum matrix composites are utilized in different ranges of applications in automobile, aerospace and defense [4] [5]. In addition to automotive industries AMCs are becoming more relevant in the aviation and space sector, as a result of these advancements in features [6]. Aluminum LM6 matrix is a eutectic alloy containing 11 to 13% silicon and 85.95 percent aluminum. Uses of fly ash composite is becoming a popular choice for aviation, automobile and space applications because of its “heat fracture resistance, pressure tightness, die-filling capacity, and corrosion resistance” [7]. For these purposes, particle-reinforced aluminum matrix composites (AMCs) are a good choice because of their inexpensive cost and higher performance. [8][9]. Traditional reinforcements like SiC, BN, B4C, TiB2, Al2O3 and others, on the other hand, are prohibitively expensive. Economical reinforcements i.e., rice husk, fly ash, natural minerals etc. must be used in place of traditional reinforcements in order to reduce production costs. Fly ash is a low-cost, easily accessible reinforcement with better mechanical properties, high electrical resistance, poor thermal conductivity and low density. Precipitator and cenosphere particles are the two forms of fly ash particles. Precipitator fly ash is used in AMMC as reinforcing particles in this study. Present study attempts composites made of Al alloy and fly ash (strong) (2, 5, 8 percent fly ash by wt) with a stir casting process, with the goal of describing hardness, toughness and density as better mechanical properties. The projected benefits of reducing the weight of the component, increasing the life of the composites and better recyclability should be considered when considering the broader application of AMCs in present day industry [10].

The only approach to cut costs is to simplify fabrication techniques use less expensive reinforcements and increase production numbers [11]. These composite materials provide manufacturers a new product option for enhancing the performance of the composite with reduced prices. “Powder metallurgy” [12], “mechanical alloying” [13], “squeeze casting” [14], “compo casting” [15], and “spray deposition” [16] have all been made used to produce AMCs with different reinforcements mixing. The AMCs' characteristics are also influenced by the processing procedure. Fly ash acts as a support and filler in aluminum alloy matrix composites that has become the subject of recent work. A large volume of metal matrix composites can be made with less expensive reinforcement using a simple production technique, cutting the cost of MMCs. Out of all the casting processing processes known, the most effective way of manufacturing composites is stir casting or liquid metallurgy [17] technique. The Ultimate rigidity has increased with an increase in fly debris content, according to Vivekanadan et al. [18]. This is due to the vast range of particle sizes. Dr. Selvi S et al. [19] hypothesized and tentatively found out the mechanical characteristics of AMMCs, assuming that the composites' hardness rises as the amount of fly debris in them rises. When the SiC and fly debris content increased, a pattern of hardness extension was seen, according to Mahendra Boopathi et al. [20]. The hardest mixture is Al/ (10 percent SiC+10 percent fly) ash. According to P. K. Rohatgi [21], the pliability of the composite decreases as the weight division of strengthened fly debris increases and decreases as the molecular size of the fly debris increases. However, the stiffness of composites containing more than 15 wt% of fly debris particles is expected to decrease. Sudarshan et. al. [22] studied the portrayal of A356 Aluminum - fly debris molecule composites with fly debris particles of restricted reach (53-106 m) and large size range (0.5-400 m), and discovered that increasing the amount of fly debris enhanced hardness, young's modulus and yield stress. Basavarajappa et. al. [23] “studied the mechanical properties of an Al alloy (Al2024) reinforced with graphite particles and SiC”. They claim that as the volume component of reinforcement increased, the composite's mechanical characteristics increased as well. According to Dinaharan et al., 2016 [24], with the increase in fly ash wt percentage in the composites, there is change in the coefficient of friction, wear rate, and mechanical behaviour. Lim et al. [25] investigated the wear behaviour of Al-Cu/SiC composites and found that the rate of wear increased as the applied normal load increased. The wear and friction properties of an Al (12 percent SiC) matrix composite augmented with fly ash particles were studied by Ramachandra et al. (2007) [26]. The authors discovered that when the weight percent of fly ash in the composite grew, its wear resistance reduced, but normal load and sliding velocity increased. Moorthy et al. [27] “used the Taguchi method to investigate the dry sliding wear and mechanical behaviour of Aluminum/Fly ash/Graphite hybrid metal matrix composites, finding that load was the most important element determining the composites' wear rate, followed by sliding speed and fly ash content”. As the amount of fly ash in the hybrid composites increased, the hardness of the composites improved. FA can also be utilised to prevent interfacial reactions between the matrix and reinforcing particles. “Tribological properties of an AlSi10Mg/fly ash/graphite hybrid metal matrix composite were investigated by Prasat and Subramanian” [28]. The hybrid composite outperformed the alloy and alumina–graphite composites which are unreinforced in terms of tensile strength, hardness, and wear resistance. The enhanced wear performance was attributed to FA's load carrying capacity and graphite's lubricating action; wear rate was noticed to decrease as FA concentration increased. The aim of this study is to do further research on the fly ash with a micron size (150–175), which is mostly ignored in most research studies yet plays a critical role in improving MMC performance.

Table 1: LM6 Chemical Composition

Composition	Zn	Ni	Mg	Pb	Ni	Sn	W	Mn	Fe	Si	Al
%	0.1	0.1	0.1	0.1	0.1	0.05	0.2	0.5	0.6	10 – 13	Bal

Table 2: Physical characteristics of Fly Ash powder

Category	Specification of Fly ash
Size of Particle	150 to 175 μm

Density of FA FA Color Form of FA	2.2 gm/cc Grey Solid Spherical

Table 3: Composition of Fly Ash

Composition	Al_2O_3	Fe_2O_3	SiO_2	Na_2O	TiO_2	CaO	MgO	K_2O	P_2O_5	Mn_2O_3	SO_3	LOI
%	29.61	10.72	49.45	0.31	1.76	3.47	1.3	0.54	0.53	0.17	0.27	1.45

2. Experimental Methods

2.1 Composite fabrication

Fly ash particles with sizes between (145–180 μm) were used in this study as the particulate materials and aluminum composite was used as the matrix material. Aluminum metal matrix composite is prepared with varying weight percent (2, 5, 8) of fly debris by using double step stir casting technique with a small amount (1.5 percent) of Magnesium. In a muffle furnace, the fly ash particles were warmed above 600 ^{0} C for a period of 3 hours for complete removal of moisture and prepare an oxide layer on the fly ash particle. It eventually improves the mixing strategy with the Al alloy. Aluminum scraps were charged into the crucible, and the temperature was raised at 750 ^{0} C to completely melt the scraps, then lowered to below liquidus temperature to achieve the semi-solid condition. Magnesium powder was put into the furnace of the bottom-poured furnace, followed by preheated fly-ash particles. Mg was used to enhance the wettability between the Al composite and the fly debris particles in the mold. For 20 minutes, a stirrer was used to stir the liquid aluminum composite slurry at 400 rpm. Because considerable power was required to mix the composite paste in a semi-solid state. A speed regulated mechanical stirrer with a variable attachment was used. The dispersion of fly ash and magnesium with aluminum was improved using a two-step stir casting route. At the end, the fabricated composite was softened to 750°C before being poured into cylindrical mold.

Fig. 1: Fabrication Unit

2.2 Characterization

On as-projected composites, microstructural concentration was performed using an optical magnifying equipment & Scanning electron microscope on polished specimen. Multiple Emery paper of different grade ranging from 120 to 3000 were used to clean the test. After that, a non-ferrous cleaning fluid is used to clean the velvet fabric for a scratch-free mirror sheen. Additionally, with 100 ml refined water, keller's etchant creates hydrochloric corrosive 1.5 ml, 2.5 ml of nitric corrosive from keller’s and corrosive hydrofluoric – 1 ml. Reinforcing particles in the molten matrix form a dendritic structure during casting. These tests begin with unprocessed bars and go through different processes i.e, molding, turning, and cleaning. SEM micrograph is carried out in FEG QUANTA 250. EDX was completed in EDAX

GENESIS with three spectrums for three different weight percent of reinforcement. XRD is conducted to ascertain the different mixes on the composites.

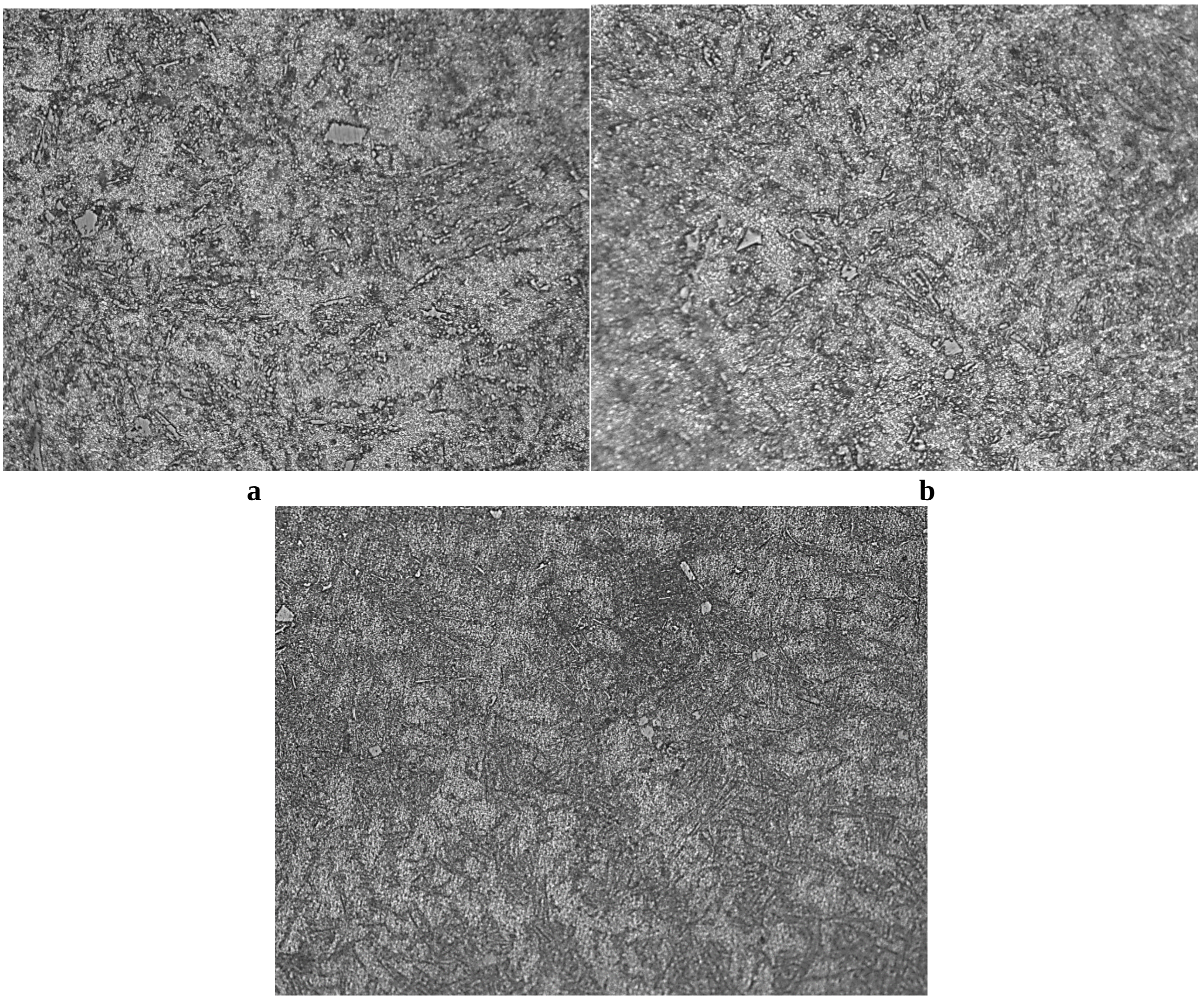
2.3 Tribology

Tribology tests are performed according to ASTM standards using a block on roller type multi-tribo tester (TR208M2, DUCOM, India) at an ambient temperature of 30 ° C and a relative humidity of 85%. Three distinct loads (25 N, 50 N, 75 N) and three different speeds (400 rpm, 500 rpm, 600 rpm) were tested with three different types of reinforcement specimens (2, 5, 8%).

3. Results and discussions

3.1 Composite microstructure

Figure 2 shows a light micrograph of the manufactured Al-FA metal matrix composite (a through c). The fly ash particles are spherical, but the Al matrix is light, the Si needles are gray, and the black phase looks mostly like pores. FA particles and Si needles are evenly distributed throughout the Al-FA matrix of the cast Al-FA composite. Separation will impair the mechanical and tribological properties of the composite, as micrographs show. Figure 2 (c) shows the microstructure of the Al10wt. Composite material containing Al dendrites and primary Si. Equiaxial particles are also found in composites manufactured using light micrographs. Fly ash particles caused recrystallization, as evidenced by the presence of equiaxed particles. A similar pattern of fly ash particles was found in MMC micrographs. Particle distribution has a significant impact on the mechanical and physical properties of composite materials.



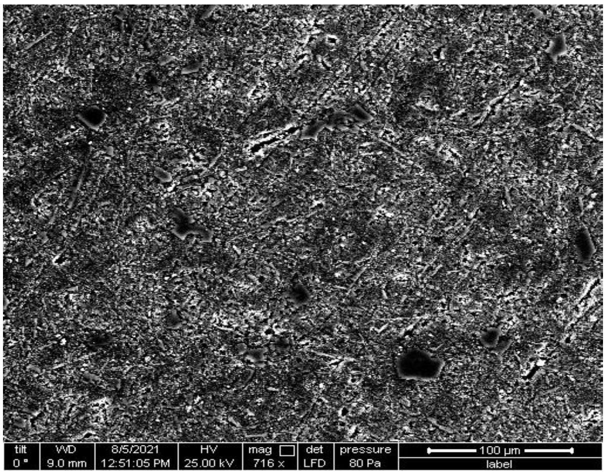
a b

c

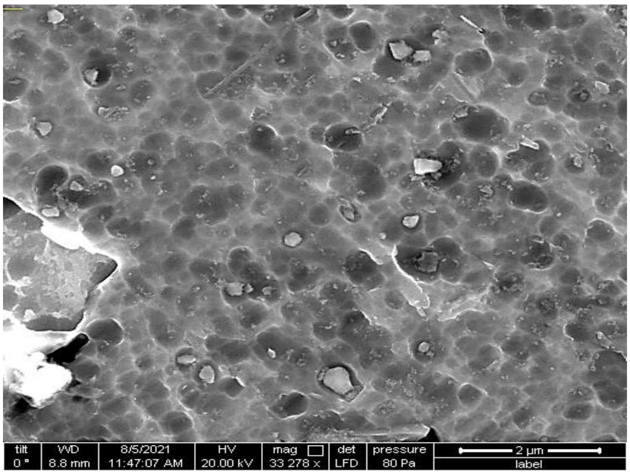
Fig. 2: Microscopic images (500X) Composite with (a) 2% Fly ash (b) 5% Fly ash (c) 8% Fly ash

3.2 SEM Analysis

In Figure 3 (a), the Al matrix is bright, the Si needles appear gray, the black phase predominantly represents pores, and the fly ash particles appear circular. FA particles and Si needles are evenly distributed throughout the aluminum matrix of the cast Al-FA composite. Segregation would damage the composite's mechanical and tribological properties, as seen by the micrographs. A SEM image of Al Alloy reinforced with 8% fly ash particles is shown in Figure 3 (b), revealing uniform grains and fine grain boundaries.



a



b

Fig. 3: SEM Images for (a) 2 % Fly ash (b) 8 % Fly ash

3.3 XRD

Figure 4 displays the XRD pattern of composite samples' which corroborate the EDX findings that the fly ash particles include substantial amounts of silica, alumina, and iron oxides. In comparison, the XRD pattern of Aluminum with 8 percent of fly ash composite reveals that the cast composite has additional Si peaks in addition to Al, Al_2O_3, SiO_2, and Fe_2O_3. The existence of Si peaks suggests that during the casting process, in situ reactions may have happened.

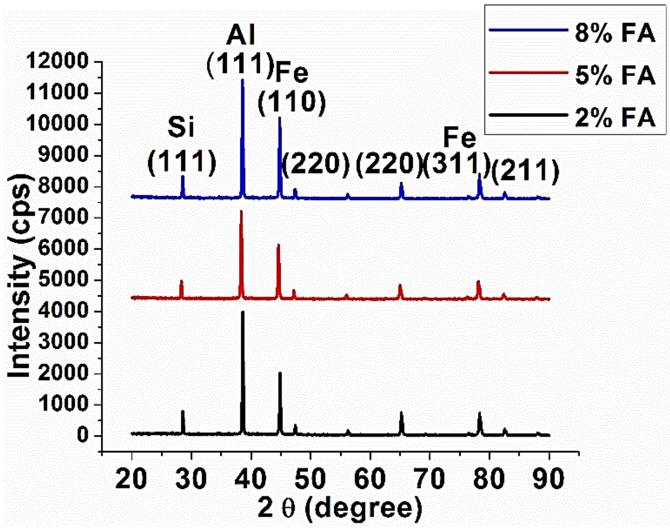


Fig. 4: XRD plot of Composites

3.4 EDAX Analysis

Figures 4 (a to c) depict the EDS patterns of several phases seen in Al–FA composites. It describes about the availability of different elements i.e Fe, Al, Si, Ca, K etc. for all the spectrums. It is also observed from the weight percent of elements of all the three spectrums that there is variation of minerals according to the increase of reinforcement.

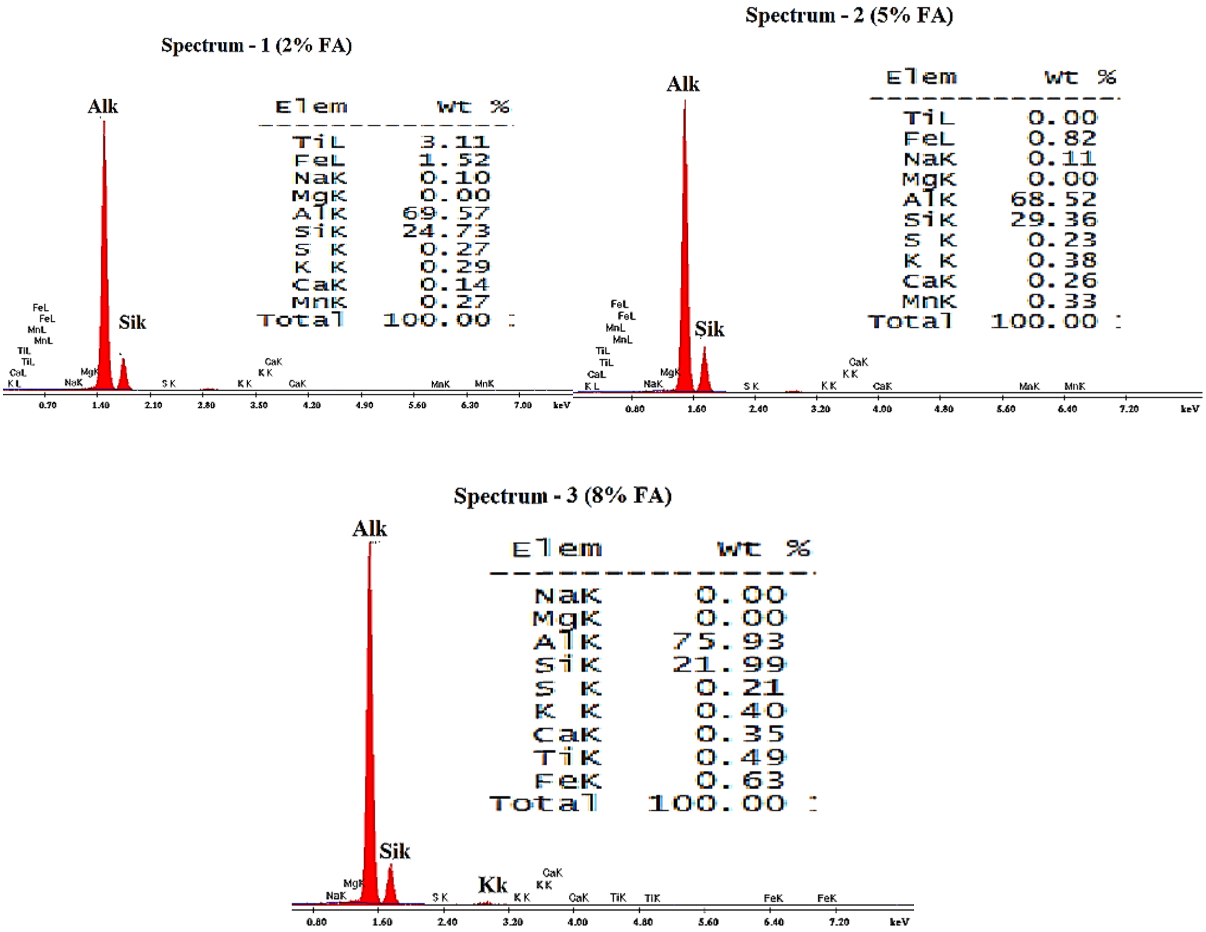
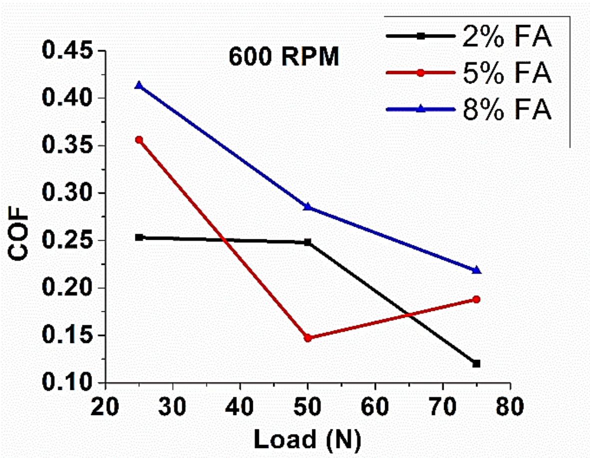


Fig. 5: EDAX Spectrum

3.5 Tribological Behavior

3.5.1 Effect of load & sliding speed on COF

The cof of the Al-Fly ash matrix alloy and composites varies with varied loads (25N, 50N, 75N) at 600 rpm and speeds (400 rpm, 500 rpm, 600 rpm) at 25 N, as shown in Figures 6 and 7. The cof of the matrix alloy and composites reduced as the load was increased. As the Fly ash weight percent increases, the friction coefficient drops. The friction coefficient between an Al-1.5 percent Mg alloy strengthened with SiCp was investigated by Rana et al., [29] (1989). They discovered that as the volume proportion of SiC particles increased, the friction coefficient decreased. [30] Saka et al. (1985) investigated friction and wear in Cu reinforced with Al2O3 particles. They discovered that as the alumina content increased, the friction coefficient decreased. Zhenfeng et al.,[31] reported a similar observation (1994). The rise in temperature of the contact surface rises and softens the surface of the pin, resulting in a drop in cof as the load increases. As a result, the friction coefficient falls. Another cause could be that as the load increases, the pin surface wears out more, and the wear debris becomes lodged between the pin and the counter surface, acting as a roller ball. As a result, the cof falls.



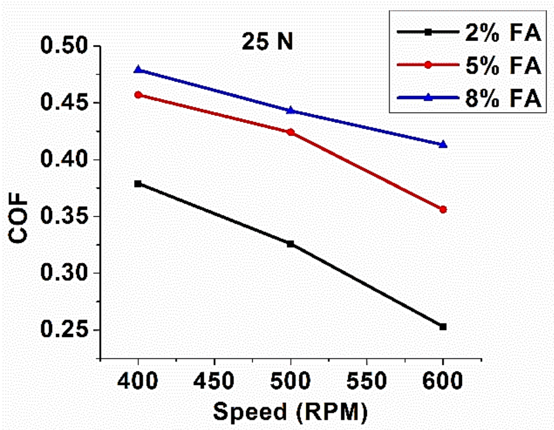


Fig.6: COF at different loads

Fig.7: COF at different speeds

3.5.2 Influence of applied load & Speed on Wear rate

Figures 8 and 9 depict the wear rate of matrix alloys and composites as a function of load (25N, 50N, 75N) at 600 rpm and with speeds (400 rpm, 500rpm, 600 rpm) at 25 N. As the load grew, the wear rate increased. This is an agreement with studies of some researchers (Basavarajappa *et al.*, [32] 2006; Sahin and Ozdin, et al [33] 2008. A similar observation was examined by Alpas *et al.*,[34] (1992), and Moustafa, et al [35] (1995).

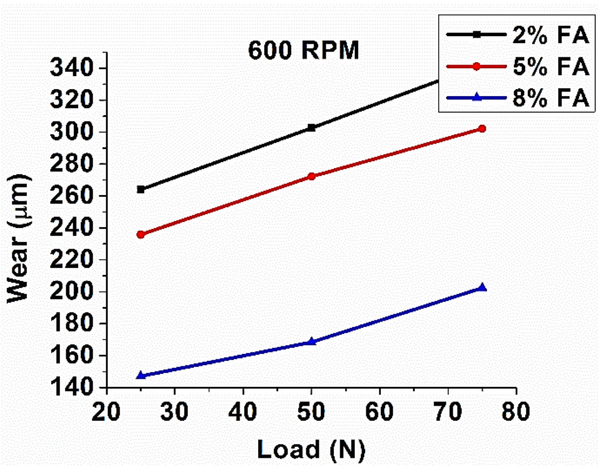


Fig. 8: Wear rate at different loads

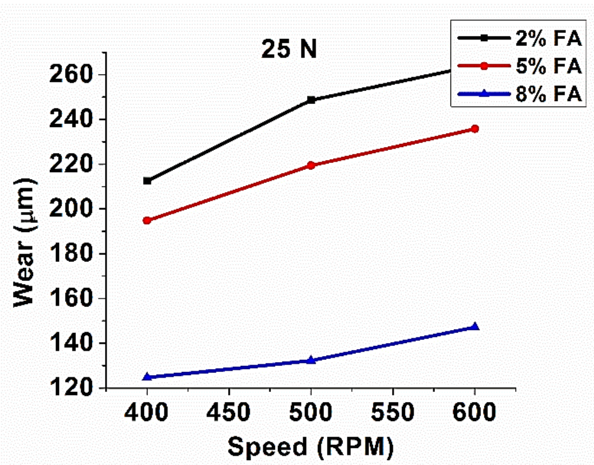


Fig. 9: Wear rate at different speeds

4. Conclusion

The following conclusions can be derived based on the findings:

- In this study, Al – fly ash composites were formed using by two steps Stir casting technique.
- Fly ash particles were found scattered throughout the aluminum matrix composite, as evidenced by optical micrographs and SEM. It is undeniable that increased uniformity in molecular circulation leads to improved mechanical characteristics. As a result, there is little doubt that the use of this material in the vehicle and space sectors will continue to grow in the future.
- As the strain on the composites grew, so did the coefficient of friction. The friction coefficient decreases as the amount of fly ash in the mixture increases. The wear rate, on the other hand, increased as the load expanded.
-

5. References

1. M.K. Kulekci, Int. J. Adv. Manuf. Technol. 39 (9–10) (2008) 851–865.
2. K K Chawla and N Chawla, Metal Matrix Composites, Boston: Kluwer Academic Publishers, 2004.

3. Anthony Macke* B.F. Schultz Pradeep Rohatgi ADVANCED MATERIALS & PROCESSES • MARCH 2012, Vol 170 No 3.

4. Miller W., Zhuang L, Bottema J, et al. Recent development in aluminum alloys for the automotive industry. Mater. Sci. Eng. A. 2000; Vol.280: pp.37–49.

5. Surappa MK. Aluminium matrix composites: Challenges and opportunities. 2003; Vol.28, pp.319–334.

6. Sethi V. Effect of ageing on abrasive wear resistance of SiC particulate reinforced aluminum metal matrix composites;2007 (M.S. thesis).

7. Sourav Kayal, R. Behera, G. Sutradhara, (2012), Mechanical properties of the as-cast silicon carbide particulate reinforced Aluminium alloy Metal Matrix Composites, *International Journal of Current Engineering and Technology*, Vol.2, No.3, 318-322.

8. YouGL, HoNJ and Kao PW2013 In-situ formation of Al2O3 nanoparticles during friction stir processing of Al\SiO2 composite Mater. Charact. 80 1–8.

9. Rohatgi, P.K., 1994. Low-cost, fly ash-containing aluminium-matrix composites. JOM 46, 55-59.

10. Hashim J., Looney L., Hashmi M.S.J., 2001. The enhancement of wettability of SiC particles in cast aluminium matrix composites, Journal of Material Processing Technology, Vol. 119, pp. 329–335.

11. Shorowordi K.M., Laoui T., Haseeb A.S.M.A., Celis J.P., Froyen L., 2003. Microstructure and interface characteristics of B4C, SiC and Al2O3 reinforced Al matrix composites, Journal of Material Processing Technology, Vol. 142, pp. 738–743.

12. Rahimian M, Ehsani N, Parvin N, Baharvandi HR, "The effect of particle size, sintering temperature and sintering time on the properties of Al–Al2O3 composites, made by powder metallurgy", Journal of Materials Processing Technology 209 (2009) 5387–5393.

13. Srinivasarao B, Suryanarayana C, Oh-ishi K, Hono K, "Microstructure and mechanical properties of Al–Zr nanocomposite materials", Materials Science and Engineering A 518 (2009) 100–107.

14. R. Soundararajan, A. Ramesh, S. Sivasankaran, and A. Sathishkumar, "Modeling and Analysis of Mechanical Properties of Aluminium Alloy (A413) Processed through Squeeze Casting Route Using Artificial Neural Network Model and Statistical Technique". Advances in Materials Science and Engineering, Volume 2015.

15. J. David Raja Selvam, D.S. Robinson Smart, I. Dinaharan, "Microstructure and some mechanical properties of fly ash particulate reinforced AA6061 aluminum alloy composites prepared by compo casting", Materials and Design 49 (2013) 28–34.

16. Srivastava VC, Ojha SN. Microstructure and electrical conductivity of Al–SiCp composites produced by spray forming process. Bull. Mater. Sci., Vol. 28, No. 2, April 2005, pp. 125–130.

17. Rajeshkumar Gangaram Bhandare, Parshuram M. Sonawane, "Preparation of Aluminum Matrix Composite by Using Stir Casting Method", International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-3, Issue-2, December 2013.

18. Vivekanandan.P, Arunachalam.V. P, "The Experimental Analysis of Stir Casting Method on Aluminum-Fly Ash Composites", IJCET, 2013, Vol.3.

19. Dr. Selvi.S, Dr. Rajasekar. E, Sathishkumar. M, Ramkumar. B, "Theoretical and Experimental Investigations of Mechanical Properties of Aluminum based Metal Matrix Composite", Engineering Science and Technology: An International Journal, 2013, vol.3.no.2.

20. Mahendra Boopathi, M., K.P. Arulshri and N. Iyandurai, "Evaluation of Mechanical Properties of Aluminum Alloy 2024 Reinforced with Silicon Carbide and Fly Ash Hybrid Metal Matrix Composites", American Journal of Applied Sciences, 2013.

21. P. K. Rohatgi, "Method of producing metal matrix composites containing fly ash," U. S. Patent 5711362, 1998.

22. Sudarshan, and M. K. Surappa, "Synthesis of fly ash particle reinforced A356 Al composites and their characterization," Material Science and Engineering- A, vol. 480 (1-2), pp. 117-124, 2008.

23. S. Basavarajappa, G. Chandramohan, and A. Dinesh, "Mechanical properties of MMC's-An experimental investigation," in Proc. ISRME'04, 2004, paper 01, p. 1-8.

24. Dinaharan, I., Nelson, R., Vijay, S., & Akinlabi, E. T. (2016). Microstructure and wear characterization of aluminum matrix composites reinforced with industrial waste fly ash particulates synthesized by friction stir processing. *Materials Characterization, 118*, 149-158.

25. Lim, S. C., Gupta, M., Ren, L., & Kwok, J. K. M. (1999). The tribological properties of Al–Cu/SiCp metal–matrix composites fabricated using the rheocasting technique. *Journal of Materials Processing Technology, 89*, 591-596.

26. M. Ramachandra, K. Radhakrishna, 2007, Effect of reinforcement of fly ash on sliding wear, slurry erosive wear and corrosive behavior of aluminum matrix composite, Wear 262, 1450–1462.

27. Moorthy A, Natarajan DN, Sivakumar R, Manojkumar M, Suresh M. Dry sliding wear and mechanical behavior of aluminum/fly ash/graphite hybrid metal matrix composite using taguchi method. Int J Mod Eng Res IJMER2012;2(3):1224–30.

28. Venkat Prasat S, Subramanian R. Tribological properties ofAlSi10Mg/fly ash/graphite hybrid metal matrix composites. Ind Lubr Tribol 2013;65(6):399–408.

29. Rana, F. & Stefanescu, D.M.,1989. "Friction properties of Al-1.5 Pct Mg/SiC particulate metal-matrix composites, *Metallurgical Transactions A*, Vol20, No. 8, pp.1564-1566.

30. Saka, N. & Karalekas, D.P., 1985. Friction and wear of particle-reinforced metal-ceramic composites, *Wear of Materials*, pp.784.

31. Zhenfang, Z., Liangchi, Z. &Yiu-Wing, M., 1994. Modelling friction and wear of scratching ceramic particle-reinforced metal composites. *Wear*, Vol176, No. 2, pp. 231-237.

32. Basavarajappa, S., Chandramohan, G., Subramanian, R. & Chandrasekar, A., 2006. Dry sliding wear behavior of Al 2219/SiC metal matrix composites, *Materials Science-Poland*, Vol24, No. 2/1, pp. 357-366.

33. Sahin, Y., & Özdin, K., 2008. A model for the abrasive wear behavior of aluminum-based composites, *Materials & Design*, Vol29, No. 3, pp. 728-733.

34. Moustafa, S.F., 1995. Wear and wear mechanisms of Al-22% Si/A12O3f composite. *Wear*, Vol185, No. 1-2, pp. 189-195.

35. Alpas, A.T. & Zhang, J., 1992. Effect of SiC particulate reinforcement on the dry sliding wear of aluminum-silicon alloys (A356), *Wear*, Vol 155, No.1, pp. 83-104.