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Influence of temperature on tribological behaviour of dual reinforced aluminium MMCs

The aim of this study is to explore the sliding wear behaviour of aluminium alloy LM 25, Al/10 wt.% fly ash (FA) composite, AA/10 wt.% steel particles (SP) composites and AA/5wt.% FA/5 wt.% SP hybrid composites with respect to load, velocity and pin temperature conditions employing a pin on disc friction and wear machine. The wear characteristics such as coefficient of friction and wear loss are considered for the study. Results raveled that the wear loss of Al alloy and composites increases when the pin temperature was increased. Wear loss of Al/SP composite was lower than that of Al/FA composite. However Al/FA/SP hybrid composites exhibited superior wear resistance compared to Al alloy, Al/FA and Al/SP composites. It is obvious that the inclusion of the dual reinforcements such as FA and SP into the Al alloy increases the wear resistance as compared to single reinforced AMCs such as AL/FA and AL/SP composites.

Keywords: *Aluminium alloy LM 25 coefficient of friction; fly ash; hybrid composites; steel particles; wear loss*

1. Introduction

Various researchers have done experiments for investigating the wear characteristics of AMCs. Wear behaviour of 6061Al alloy reinforced with B_4C composite was analyzed with respect to high temperature. They reported that the presence of oxide layer improves the wear of MMC largely, compared to unreinforced alloy at 150°C (Akash et al, 2018). Wear and friction characteristics of A356 reinforced SiC particles AMC against semi-metallic materials were investigated. It was reported that the micro ploughing was seen when the AMC subjected to below 200°C, whereas delamination was seen on the surface above 200°C (Like Pan et al, 2018).

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The influence of temperature on the wear loss of alloy and MMCs was investigated. The wear loss of the AMC is lower compared to matrix alloy irrespective of the temperatures (Muratoðlu and Aksoy, 2000). The wear loss of the SiC reinforced Mg alloy composites was studied with respect to load, speed and temperature range between 25°C and 200°C. Composites experience better wear resistance compared to the Mg alloy (Labib et al, 2016). Wear resistance of Al alloy 2024 and Al alloy 2024-SiCp AMC were investigated at high temperatures. Due to the addition of SiC, the transition temperature and the wear resistance of the composite increased significantly (Mousavi Abarghouie and Seyed Reihani, 2010). Wear resistance of aluminum oxide reinforced 6061 AMC and an unreinforced AA6061 were studied in the range of temperature from 25°C to 500°C against a bearing steel. (Singh and Alpas, 1995). Wear loss of SiC reinforced AA2618 and unreinforced AA under the temperature between 20°C and 200°C. Transition of mild wear to severe wear occurred in both the AMC and AA when the transition temperature reaches beyond the critical value. Transition temperature was 50°C higher in the AMC compared to AA due to the addition of SiC (Martín, 1996). Sliding wear resistance of fly ash reinforced AA6061 AMC was analyzed by varying the temperature. Wear type is appreciably influenced by the temperature. Abrasive wear was noticed at room temperature while adhesion was seen at higher temperature. An inclusion of fly ash reinforcement enhances the wear resistance considerably (David Raja Selvam, 2017). Sliding wear resistance of B4C reinforced AMC was investigated by varying the temperature. They reported that the load had higher significance than sliding velocity, temperature and weight fraction. The wear loss increases with load and temperature while wear loss decreases with velocity (Canute X and Majumder, 2018). Wear resistance of graphite reinforced AMC was investigated under the ambient as well as elevated temperature. Wear decreases with increase in temperature (Rajaram et al., 2010). Tribological behaviour of polymer composites has been studied (Rajesh et al., 2017). Sliding and slurry erosive wear resistance of fly ash reinforced AMC was investigated. AA (12 wt% SiC) -15 wt% of FAMMC demonstrated enhanced abrasive wear resistance. Wear and frictional force increased with load and velocity (Ramachandra and Radhakrishna, 2007). Incorporation of 6 wt% of fly ash particulates into AA356 showed better wear resistance at low loads 10N to 20 N, whereas 12 wt% of fly ash AMC showed better wear resistance compared to the AA356 from 20 N to 80 N. Subsurface delamination was the primary wear mode for both the AA356 and AMC at higher load (Sudarshan and Surappa, 2008).

This study was initiated to explore the sliding wear behaviour such as wear resistance and co-efficient of friction of aluminium alloy LM 25, LM 25/10 wt.% fly ash (FA) composite, LM 25/10 wt.% steel particles (SP) composites and LM 25/ 5 wt.% FA/5 wt.% SP hybrid composites with respect to load, velocity and pin temperature conditions employing a pin on disc friction and wear machine.

2. Materials and methodology

2.1 Matrix material

LM 25 aluminium ingot was used as the matrix material. LM25 alloy is mostly employed where enhanced mechanical properties and resistance to corrosion are the main considerations. It offers excellent castability and machinability. Table 1 provides the chemical composition of LM25 Al alloy.

2.2 Reinforcement materials

Particles of fly ash (FA) and steel particles (SP) with size of 100ìm were used as the reinforcements. Fly ash (class F) was received from Mettur thermal power plant and its chemical composition is provided in Table 2. Composition of steel powder is provided in Table 3. Both the reinforcement particles were cleaned by magnetic separation and then shifted to the size of 100ìm. SEM illustration of FA particulates and steel particles are portrayed in Figs.1 and 2 respectively.

2.3 Preparation of composites

In the modified squeeze casting, stirring was performed in two steps. Stirring was done in liquid state of composite melt followed by semi solid state. After the stirring, slurry was

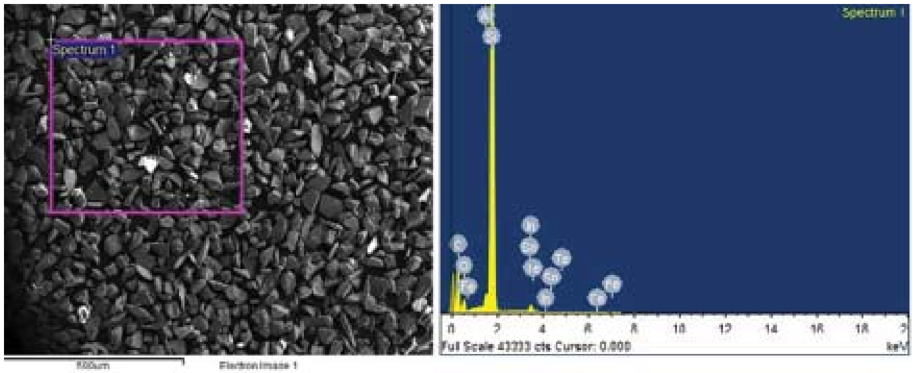


Fig.1 : SEM image of fly ash particles

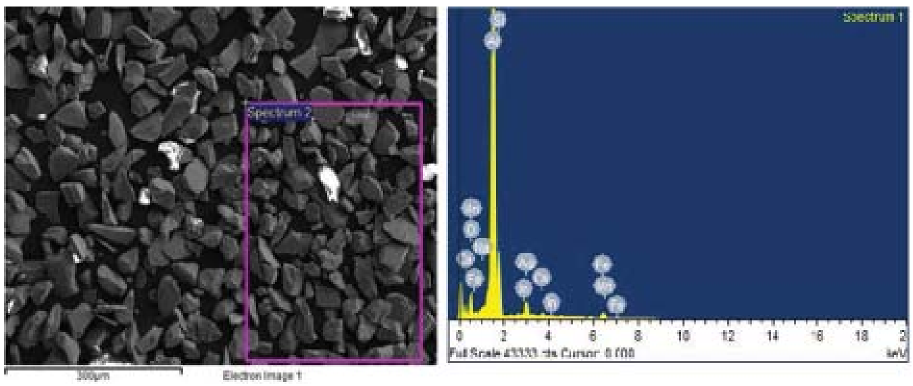


Fig.2 SEM image of steel particles

Table 1: Chemical composition of LM25 aluminium alloy

Element	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Sn	Pb	Al
Wt %	6.5	0.4	0.1	0.2	0.05	0.09	0.06	0.012	0.01	0.1	92.478

Table 2: Chemical composition of Fly ash

Compound	CaO	MgO	Fe_2O_3	SiO_2	Al_2O_3
%	2.4	2.1	6.1	54.27	34.73

Table 3: Chemical composition of steel powder

Element	Composition (%)	Element	Composition (%)	Element	Composition (%)	Element	Composition (%)
C	0.27588	Cu	0.19824	Ni	0.09356	Al	0.00022
Si	0.21646	W	0.01037	Cr	0.07784	Nb	0.00078
S	0.06229	Ti	0.00132	Mo	0.00932	Fe	98.4063
P	0.08671	Sn	0.2547	Mn	0.52829	Co	0.00789

poured into the mold cavity and pressure applied by the punch on the melt to produce composite.

Schematic of modified squeeze casting method is shown in Fig.3. In a modified squeeze casting, the same procedure is adopted as that of squeeze casting. But the impeller was allowed to rotate and move vertically within the melt using control unit. The melt was again heated till it attains the liquid condition and stirred for 5 minutes at 300 rpm. Finally, the melt was poured into the mold. A radial four blade impeller with 0.7 I_{OD}/C_{ID} ratio (impeller outer dia/crucible inner dia ratio) was employed for stirring the melt. After stirring, 50MPa pressure was exerted on the melt for 40s by a punch. After the solidification, punch was withdrawn and the specimen was removed from the mold assembly.

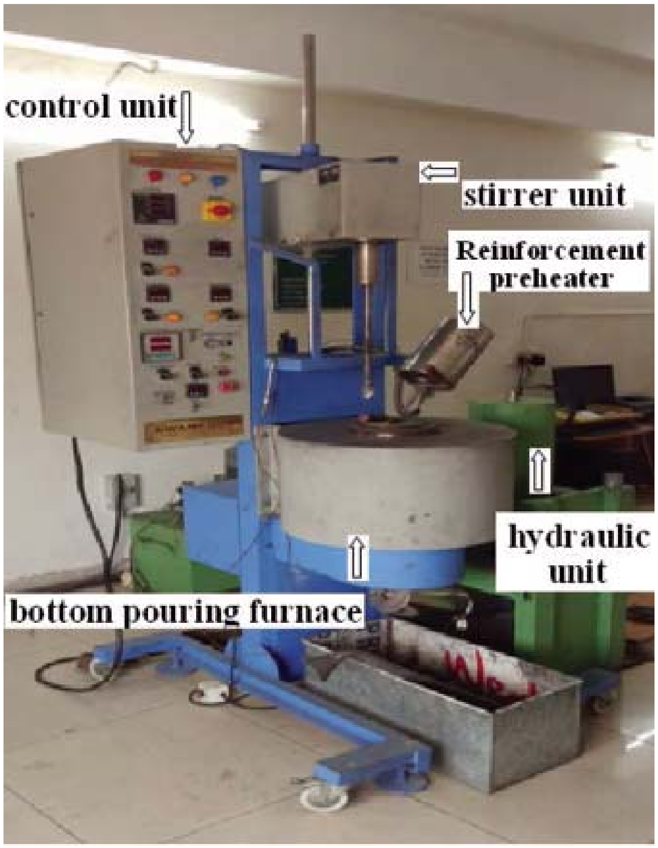


Fig.3 Modified squeeze casting set up

2.4 Dry sliding wear test

The tests were conducted under a four different loads, two different velocities and temperatures by employing testing machine (Magnum Engineers, Bangalore, India) which is displayed in Fig.4. Carbon counter disc having hardness of 60HRC (material EN 31) was attached to the motor shaft. The wear loss was measured by the differential transducer in microns. Pin specimen size was 1 cm dia and 3 cm height was used. 500 grit SiC paper was used to polish the surface of the pin before testing and its surface finish was measured using Mitutoya tester (SJ-210). Pin surface roughness value was

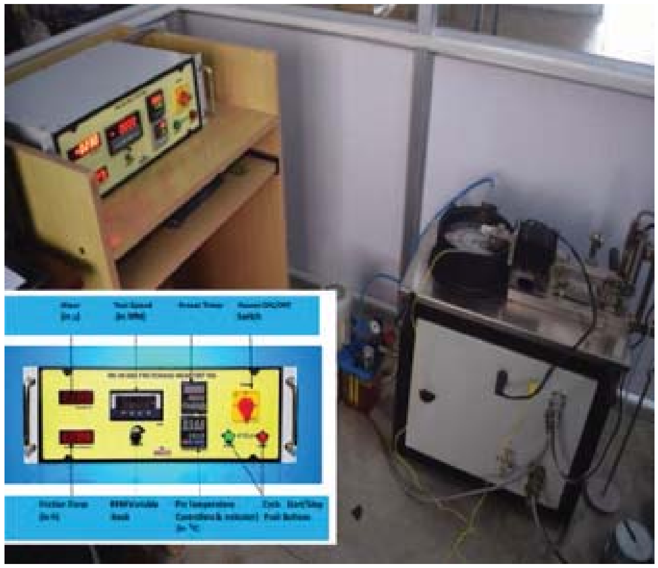


Fig.4 Schematic of pin-on-disc friction and wear testing rig

maintained at Ra= 0.02μm. During the wear tests, the pin was loaded with dead weights and tests were conducted. Wear loss in terms of μm was recorded at the end of 600 seconds. For each condition two specimens were tested. The data are received, displayed and stored on the PC using Magview Software.

Pins were tested under four different loads such as 10N, 20N, 30N and 40N, two different sliding velocities such as 1.575m/s and 3.142 m/s and two different pin temperatures of 27°C and 90°C. Sample wear pins with die are shown in Fig.5.

The effect of reinforcement particles, load, velocity and temperature on sliding wear at the dry condition characteristics of Al alloy LM 25, Al alloy LM 25 – 10 wt% fly ash (FA) composite, Al alloy LM 25–10 wt% steel particles (SP) composite and Al alloy LM-5 wt% FA and 5 wt% steel

Fig.5 Wear pins with die

particles (SP) hybrid composites are discussed in the following sections. Wear mechanism was analyzed employing SEM. Average wear and co-efficient of friction (CoF) of the composites was examined with respect to fly ash and steel particle reinforcement, four different loads, two different sliding velocities and temperature conditions. Wear test readings were taken for 10 minutes.

3. Results and discussions

3.1 Wear loss

Wear of composites with respect to load, velocity of 1.575 m/s at a pin temperature of 27°C is illustrated in Fig.6. The wear of the both Al alloy and composites increases when the load increases. Wear loss of Al/FA/SP hybrid composite increased from 68.5 to 112.4 µm when the load was increased from 10N to 40N. The wear of Al alloy was observed to be more than the MMCs irrespective of load. A drastic decrease in wear was noted with the incorporation of reinforcement content. Al/FA/SP hybrid composites showed higher wear resistance. Wear loss of Al alloy and Al/FA/SP hybrid composite were found to be 165.7µm and 112.4µm respectively at 40N, 1.575 m/s and pin temperature of 27°C. Al/FA/SP hybrid composite displays wear resistance 32% more than that of unreinforced Al alloy. Presence of fly ash and steel particles increases the hardness of the composite considerably. Moreover, wear loss of Al/SP composite was lower than that of Al/FA composite. It may be due to the fact that iron oxide (Fe_3O_4) that appears on the pin surface during sliding action enhances the wear resistance. Moreover improved interfacial bonding among reinforcement particulates and matrix aids in enhancing wear resistance.

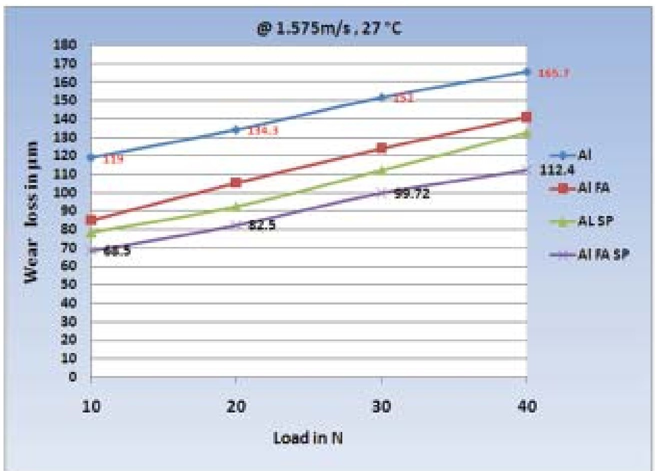


Fig.6 Wear loss of composites with respect to load, sliding velocity of 1.575 m/s at 27°C

Wear loss of composites with respect to load, velocity of 1.575 m/s at 90°C is shown in Fig.7. Wear loss of Al alloy and composites increases when the pin temperature was increased. However Al/FA/SP hybrid composites exhibited superior wear resistance compared to Al alloy, Al/FA and Al/SP composites when the temperature of the specimen was raised from 27°C to 90°C. The wear loss of Al FA/SP hybrid composite increased from 112.4µm to 127.14µm, when temperature of the pin was increased from 27°C to 90°C at 40N and1.575m/s. Wear loss increased by 13%. It can be concluded that the addition of the dual reinforcements such as FA and SP into the Al alloy improves the wear resistance compared to AL/FA and AL/SP single reinforced composites. In addition with reinforcing materials, interfacing strength between alloy and reinforcement particles provide a better wear resistance.

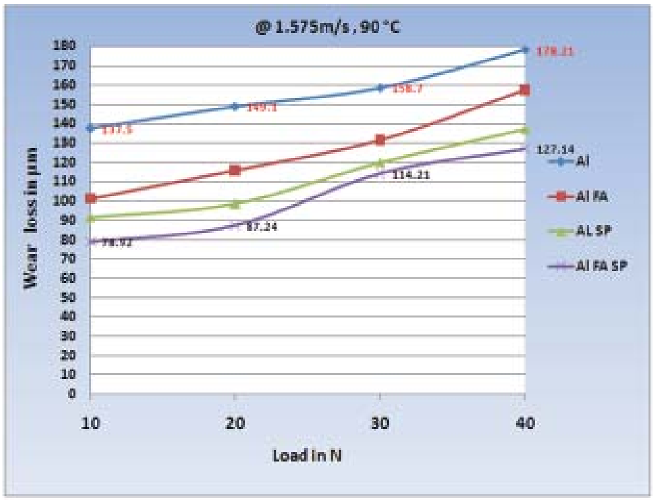


Fig.7 Wear loss of composites with respect to load, sliding velocity of 1.575 m/s at 90°C

Wear of composites with respect to load, velocity of 3.142 m/s at 27°C is shown in Fig.8. The wear resistance improved when the velocity was raised from 1.575m/s to 3.142 m/s for both alloy and composite. The wear of alloy decreased from 165.7 to 161.87µm when the velocity was raised from 1.575 m/s to 3.142 m/s, at 40N, 27°C. The reduction of wear was 2.31%. When compared to the alloy, composites exhibited the lower

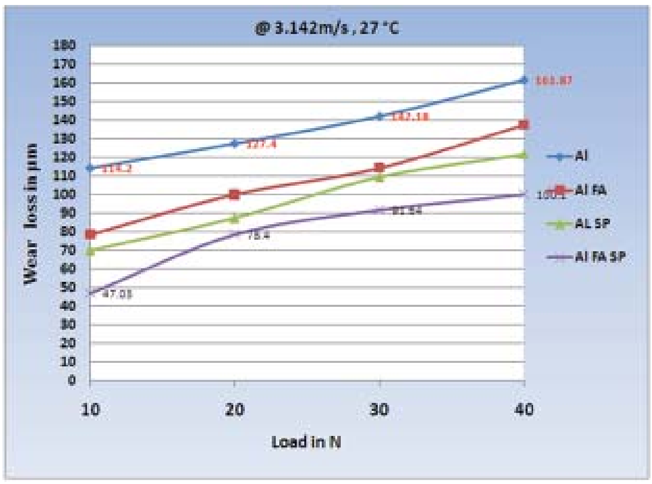


Fig.8 Wear loss of composites with respect to load, sliding velocity of 3.142 m/s at 27°C

wear loss. The wear of Al/ FA/SP hybrid composite decreased from 112.4 to 100.1µm when the velocity was raised from 1.575m/s to 3.142 m/s, at 40N, 27°C. The reduction of wear was 10.94%. As interface temperature increases, oxide layer forms at the interface which prevents the direct contact between the specimen and disc. Oxide layer acts as a protective layer which augments the wear resistance of the MMCs.

It can be inferred from the Figs.9 and 10 that when the load was increased from 10N to 40N in the sliding velocity of 3.142 m/s at 27°C, wear of Al/FA/SP AMCs increased from 47.03 µm to 100.1µm. The wear loss is increased by 112.8%. It can be ascribed to the fact that presence of oxides on the surface tends to decline the wear at higher loads.

Wear loss of composites with respect to load, velocity of 3.142 m/s at a pin temperature of 90°C is portrayed in Fig.11.

Fig.9 Wear loss of Al/FA/SP hybrid composite with respect to load of 10N, velocity of 3.142 m/s at 27°C.

Fig.10 Wear loss of composites with respect to load, sliding velocity of 3.142 m/s at 90°C

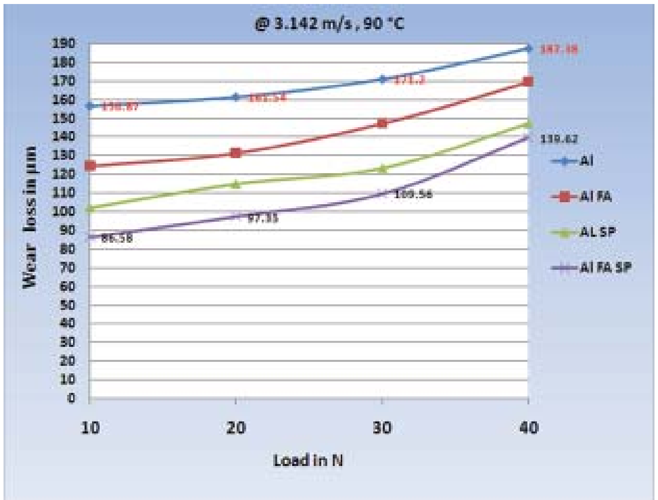


Fig.11 Wear loss of Al/FA/SP hybrid composite with respect to load of 40N, velocity of 3.142 m/s at 27°C

As the temperature of the pin increases, the wear resistance of the alloy and LM25/FA/SP hybrid composites tends to decrease. When the temperature was raised from 27°C to 90°C at 40N and 3.142 m/s, the wear loss of Al/FA/SP hybrid composite increased from 100.1µm to 119.62µm; wear loss increased by 19.5%. Alternatively the wear loss of Al alloy increased from 161.87µm to 207.38µm when the temperature of the pin was increased from 27°C to 90°C at 40N and 3.142 m/s; wear loss increased by 28.11%.

It is obvious that the inclusion of the dual reinforcements such as FA and SP into the Al alloy increases the wear resistance as compared to single reinforced AMCs such as AL/FA and AL/SP. LM25/FA/SP hybrid AMC exhibits higher wear resistance compared to Al alloy LM25, LM25/FA and LM25/SP composite. Hence the hybrid AMCs offer better wear resistance compared to single reinforced MMCs such as LM25/FA and LM25/SP.

3.2 Coefficient of friction (CoF)

The CoF of the LM25 /FA/SP MMC was estimated for four different loads, velocities such as1.571 m/s and 3.142 m/s and pin temperatures of 27°C and 90°C.

Co-efficient of friction of LM25/FA/SP hybrid composite with respect to load, velocity at 27°C is portrayed in Fig.12. CoF of composites increases with load. Conversely, CoF tends to decrease with increasing sliding velocity. CoF of the LM25/FA/SP hybrid composite decreased when the velocity was increased. CoF decreased from 0.3287 to 0.2891 when the sliding velocity was increased from 1.571 m/s to 3.142 m/s at 40N, 27°C; CoF increased by 12%.

Co-efficient of friction of LM25/FA/SP hybrid MMC with respect to load, velocity at 90°C is illustrated in Fig.13. The CoF tends to decrease with velocity and pin temperature. As the temperature of the pin increases, the material becomes softer and hence wear resistance tends to decrease thereby

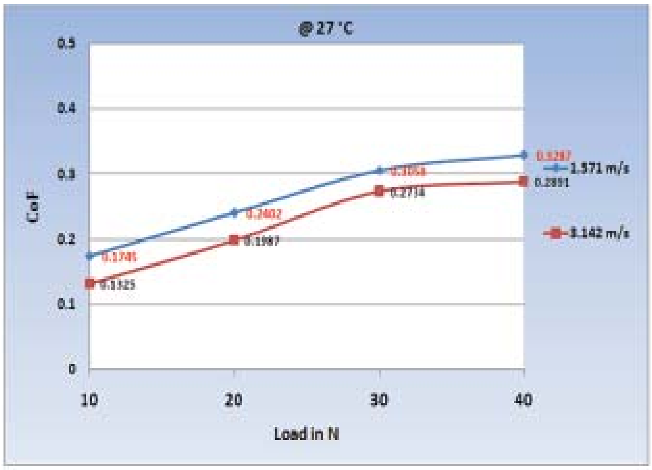


Fig.12 Co-efficient of friction of LM25/FA/SP hybrid composites as a function of load, sliding velocity at 27°C

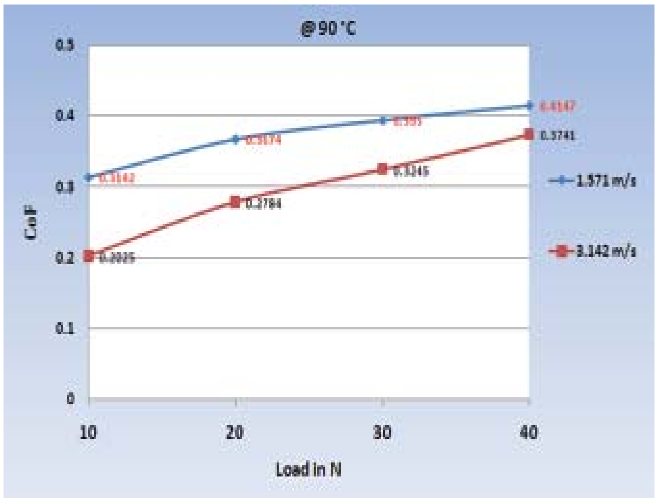


Fig.13 Co-efficient of friction of composites with respect to load, sliding velocity at 90°C

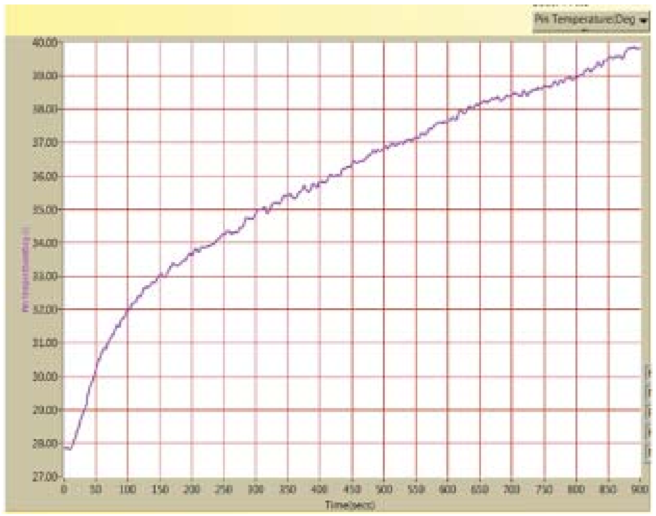


Fig.14 SEM image of the worn surface of the AI LM25 (normal load of 40N, 1.571 m/s sliding velocity at a pin temperature of 27°C

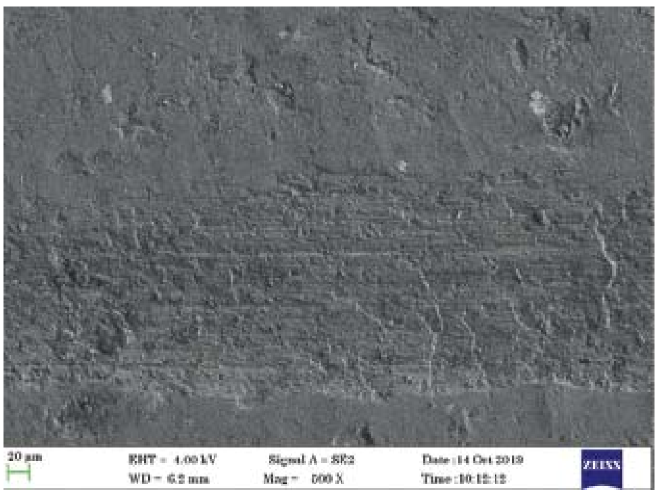
more material is removed from the wear surface. The CoF decreased from 0.2891 to 0.3741 when the pin temperature was increased from 27°C to 90°C at 40N; CoF increased by 29.4%.

4. Surface morphology of worn surface

Fig.14 shows the SEM image of the worn surface of the AI LM25. It can be observed that relatively long grooves were seen on the surface of alloy. The material is removed as thin sheets. Fig.15 demonstrates that the temperature of the pin increases from 27°C to 40°C during sliding action. Alloy is softer than the material of the counter disc the asperities tend to pierces in to the alloy surface. Plastic deformation was noticed occurred at the groove edges as shown in Fig.16.

Fig.17 shows the SEM image of the worn surface of the AI LM25/FA/SP hybrid composite. Relatively less plastic deformation was observed on the worn surface compared to

Fig.15 Rise of temperature of the wear pin during dry sliding



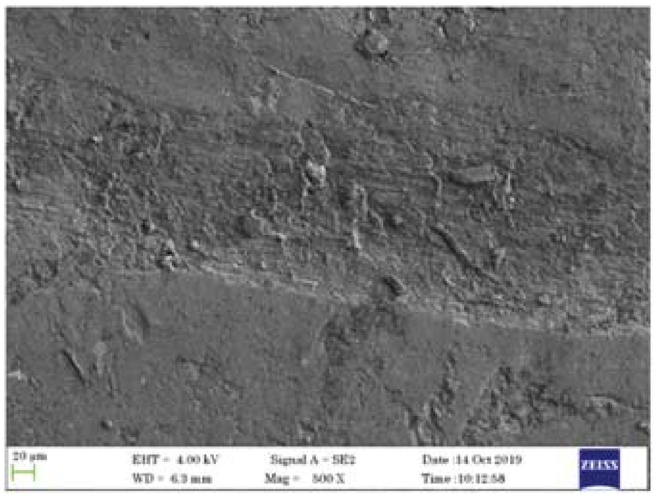


Fig.16 SEM image of the worn surface of the AI LM25 (normal load of 40N, 1.571 m/s sliding velocity at a pin temperature of 90°C)

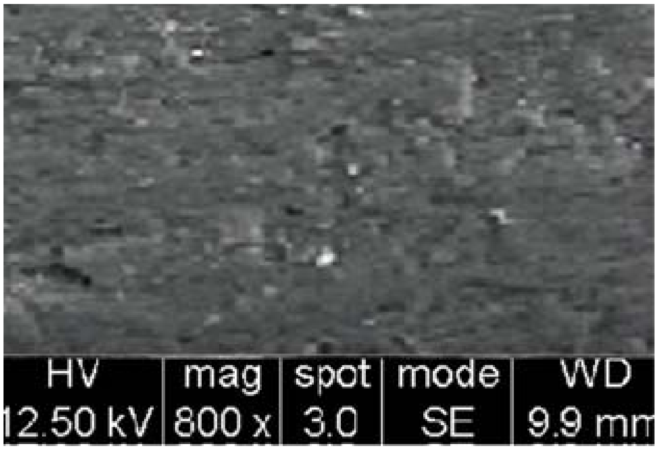


Fig.17 SEM image of the worn surface of the AI LM25/FA/SP hybrid composite (normal load of 40N,1.571 m/s sliding velocity at a pin temperature of 90°C)

alloy. Moreover wear scars are lesser as a result of the reinforcements.

5. Conclusions

Wear loss of Al alloy and composites increases when the pin temperature was increased. Wear loss of Al/SP composite was lower than that of Al/FA composite. It may be due to the fact that iron oxide (Fe_3O_4) that appears on the pin surface during sliding action enhances the wear resistance. Oxide layer acts as a protective layer which augments the wear resistance of the MMCs. However Al/FA/SP hybrid composites exhibited superior wear resistance compared to Al alloy, Al/FA and Al/SP composites.

It is obvious that the inclusion of the dual reinforcements such as FA and SP into the Al alloy increases the wear resistance as compared to single reinforced AMCs such as AL/FA and AL/SP composites. The wear resistance improved when the velocity was raised from 1.575m/s to 3.142 m/s for both alloy and composite. As interface temperature increases, oxide layer forms at the interface which prevents the direct contact between the specimen and disc.

CoF of composites increases with load. Conversely, CoF tends to decrease with increasing sliding velocity. CoF of the LM25/FA/SP hybrid composite decreases when the velocity is increased. The CoF tends to decrease with velocity and pin temperature. As the temperatures of the pin increases, the material become softer and hence wear resistance tends to decrease thereby more material is removed from the wear surface. At high load and temperature, delamination is found to be the major wear mode.

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