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Effect of SiC weight percentage on tribological properties of Al-SiC metal matrix composites under acid environment

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HIGHLIGHTS

- *Al-SiC metal matrix composites are prepared by liquid stir casting technique.*
- *SiC percentage is varied as 5 wt.%, 7.5 wt.% and 10 wt.%.*
- *Tribological behavior of the MMCs is investigated under acidic environment.*
- *COF decreases with increase in normal load while it fluctuates with sliding speed.*
- *Wear increases with increase in load and speed.*

ABSTRACT

In this paper, Al-SiC MMCs reinforced with different weight percentages of SiC content (5 wt.%, 7.5 wt.% and 10 wt.%) are fabricated through the liquid stir casting method. The effect of weight percentage of SiC on friction and wear properties of Al-SiC MMC is investigated. Tribological tests are conducted under acid environment in a pin-on-disk tribotester by varying the design parameters (applied normal load and sliding speed) while the duration of each experiment is kept constant for 30 minutes. It is seen from the result that wear increases with increase in applied load and sliding speed but friction coefficient shows a decreasing trend with increase in load. The addition of SiC reinforcement increases the wear resistance of the metal matrix composite. The scanning electron microscope (SEM) and energy dispersive X-Ray (EDX) technique are used to analyse the wear mechanism of worn surface. From the microstructure study, it is seen that adhesive, abrasive and corrosive wear mechanisms are present for removal of material from the Al-SiC MMCs.

Keywords:
| Al-SiC MMC | Wear | COF | Corrosive environment |

1.0 INTRODUCTION

Enhanced wear resistance, high strength to weight ratio and improved corrosion resistance create huge demands for metal matrix composite (MMCs) (Iwai et al., 2000; Bai et al., 1995; Chen and Alpas, 1996; Sharma, 2001; Al-Rubaie et al., 1999a; Shorowordi et al., 2006). Aluminum based metal matrix composite (AMCs) materials are preferred in numerous applications; for instance, defense, space application and automobile industries (Bindumadhavan et al., 2001; Prasad and Asthana, 2004; Pradhan et al., 2016a; Natarajan et al., 2006; Hunt, 2000). Industrial machine components made of aluminium metal matrix composites come across various corrosive environments particularly in the field of mines and mineral industries (Pardo et al., 2005; Das et al., 2006; Pradhan et al., 2016b). The favorable corrosion resistance property of Al MMC reinforced with SiC particles makes it popular to use in chemical and food processing industries.

There are different techniques through which metal matrix composites may be manufactured such as squeeze casting, powder metallurgy, compo-casting etc. (Pradhan et al., 2016b; Zamzam et al., 1993; Mortensen et al., 1993; Vijayaram et al., 2006). From the fabrication context, powder metallurgy is costly whereas liquid metal mixing is a cost effective and also good infiltration quality is obtained by squeeze casting (Sahin, 2003). In case of mixing of molten aluminum with SiC particles, aluminium carbide (Al_4C_3) phase is produced and then $Al(OH)_3$ is formed due to interaction of Al_4C_3 with the moisture in the atmosphere (Iseki et al., 1984). Many researchers have produced Al-SiC metal matrix composite by varying SiC weight percentage and investigated their properties. Ghosh et al. (2015) have fabricated Al-SiC MMCs using sand casting process by mixing weight percentage of SiC reinforcement in the range of 5% to 10%. Rehman et al. (2012) have manufactured Al-SiC matrix composite by stir die casting technique using 10% and 15% SiC particles by weight as reinforcement.

Many researchers have tried to investigate the tribological properties of composites (Jumahat et al., 2015; Chua et al., 2014) and to find the effect of tribological test parameters on friction and wear. Venkataraman and Sundararajan (2000) have investigated properties of the aluminium metal matrix composites reinforced with 10% and 40% SiC in dry condition and compared the results with Al-7075 alloys. From the study, they have established correlation between the characteristics of mechanically mixed layer and wear behavior. Wear properties of Al-SiC MMCs have been studied by Singla et al. (2009) in a dry sliding pin-on-disk machine. Metal matrix composites are prepared through casting method by varying their weight percentage of SiC reinforcement. With increase in load both wear rate and average coefficient of friction increases. The abrasive wear of Al-SiC MMCs composites have been investigated by Al-Rubaie et al. (1999b) in a pin-on-disk apparatus. The composites are prepared through powder metallurgy route by varying different volume percentage of SiC particles as reinforcement. It is observed that within studied range, abrasion resistance of MMCs increases with increase in volume fraction of SiC particles.

From literature review, it is found that there are many researchers who have fabricated Al-SiC MMC using different methods and investigated their tribological properties also. But mostly, the tribological properties are investigated under dry condition. However, the studies of tribological properties under corrosive environment are limited. But there are many applications of Al-SiC MMC under corrosive environments. In this regard, the present study investigates the tribological properties (friction and wear) of Al-SiC under one corrosive environment i.e. acid environment varying two design parameters viz. applied normal load and sliding speed. The effect of SiC percentage on friction and wear of Al-SiC MMC are also investigated. Also, attempts are made to analyse the microstructure of the worn out surface with the help of SEM and EDX technique.

2.0 EXPERIMENTAL PROCEDURE

2.1 Fabrication of MMC

LM6 is used as the metal matrix with the chemical composition as shown in Table 1. SiC particle is used as reinforcement. Here, three different weight percentages of SiC viz. 5 wt.%, 7.5 wt.% and 10 wt.% are used to fabricate three types of Al-SiC MMC. In order to get high level tribological properties in the metal matrix composite, a good interfacial bonding between the matrix and reinforcement phase needs to be obtained. Out of various fabrication methods, stir casting technique is selected as it is the easiest process and also it is cost effective for manufacturing the MMCs. Here, a clay graphite crucible is used to melt the small iongots of LM6 using an electric resistance furnace which is shown in Figure 1. The required weight percentage of preheated SiC reinforcement is added to the molten metal. A box furnace is used to preheat the SiC particles to 900˚C using a box furnace as shown in Figure 2. A strong bond is obtained by adding 3 wt.% Mg to the mixture of molten metal. The mixture is stirred constantly for 5-10 minutes with the help of mild steel impeller run by the motor attached with the melting furnace in order to incorporate the reinforcement into the matrix properly. Then the molten metal is poured into the green sand mould at a temperature of 720°C. After cooling down, from the Al-SiC MMC, the desired pin samples for the tribological test are cut and machined from the castings.

2.2 Microhardness Test

Micro-hardness of Al-SiC MMCs specimen is found out with the help of a Vickers diamond indenter (Model - VMHT MOT, Sl. No. 1002001, Technische

Mikroskopie) before the tribological tests. The dwell time is kept constant at 15s, indentation speed is fixed at 50 μm/s and indentation load of 1 Kgf is set as operating condition for conducting the hardness test. The micro-hardness values of Al-SiC for 5 wt.%, 7.5 wt.% and 10 wt.% of SiC are found to be 81, 90 and 98 HV1 respectively. The hardness of counter alumina disk is 1680 HV1.

Table 1: Chemical composition of LM6 element

Element percentage (%)											
Elements	Si	Cu	Mg	Fe	Mn	Ni	Zn	Pb	Sb	Ti	Al
Percentage	10-13.0	0.1	0.1	0.6	0.5	0.1	0.1	0.1	0.05	0.2	Rest

Figure 1: Electric resistance furnace used for fabrication of Al-SiC MMC

Figure 2: Box furnace used for pre-heating of SiC reinforcement.

2.3 Tribological Test

Tribological tests have been conducted in a pin-on-disk type tribo-tester (TR-208-M2, Ducom, India) at room temperature under acid environment as shown in Figure 3 and Figure 4. The pin sample (6 × 6 × 6 mm) slides against the alumina (Al_2O_3) disk with the help of a sample holder. The sliding speeds are given to the disk and loads are applied to the pin through the loading lever. A sensor attached to the lever is used to measure the frictional force which is displayed on the monitor and coefficient of friction is obtained by dividing the respective applied load with frictional force value. The weight loss in terms of wear is calculated by subtracting the weight of sample before and after the test. The details of the design parameters with their levels for the tribological tests are shown in Table 2.

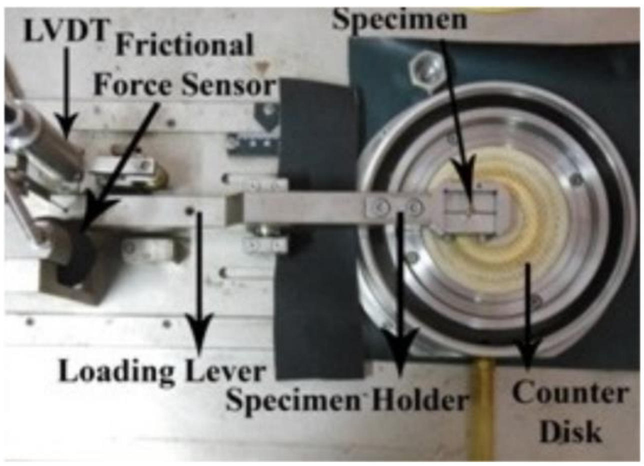


Figure 3: Pin-on-disk tribotester with corrosive environment chamber

Figure 4: Wear and friction monitor attached to tribotester.

Table 2: Design parameters with their ranges

Level	Load(N)	Speed (RPM)	Time (Min)
1	10	20	
2	30	60	
3	50	100	30
4	70	140	
5	90	180	

3.0 RESULTS AND DISCUSSION

Friction and wear tests of Al-SiC metal matrix composite reinforced with different weight percentages of SiC particles are conducted in a pin-on-disk type tribotester by varying the normal load and sliding speed under acid environment. The duration of the sliding is kept constant for 30 minutes. The effects of applied normal load and sliding speed on the tribological properties (friction coefficient and wear) are studied and microstructural characterization is investigated in this section.

3.1 Frictional Behavior

Friction coefficient of different weight percentages of Al-SiC metal matrix composite varying with applied normal load under acid environment is shown in Figure 5. From the figure, it is seen that in general, with the increase in applied normal load, the friction coefficient decreases for all three Al-SiC compostites. Generally, pure aluminium shows a high friction coefficient while slides against the hard counter surface (Prasad et al., 1997). This is the main drawback of the pure aluminium which is overcome by the development of Al-SiC MMCs. The Al-SiC material composites show the decreasing coefficient of friction with increase in applied load. Singla et al. (2009) have studied the wear behaviour of Al-SiC MMCs and also have got the decreasing coefficient of friction with increase in load. This may happen due to the formation of transfer film at contacting surface (Natarajan et al., 2006). Comparing the three weight percentages of SiC, it is seen from the figure that with the increase of SiC weight percentage, generally, the coefficient of friction decreases. It may be justified that transfer layer increases with increase in weight percentage of SiC reinforcement which reduces the friction. The variation of friction coefficient with sliding speed is shown in Figure 6 for different applied normal loads. It can be seen from the plot that the coefficient of friction fluctuates around the certain value.

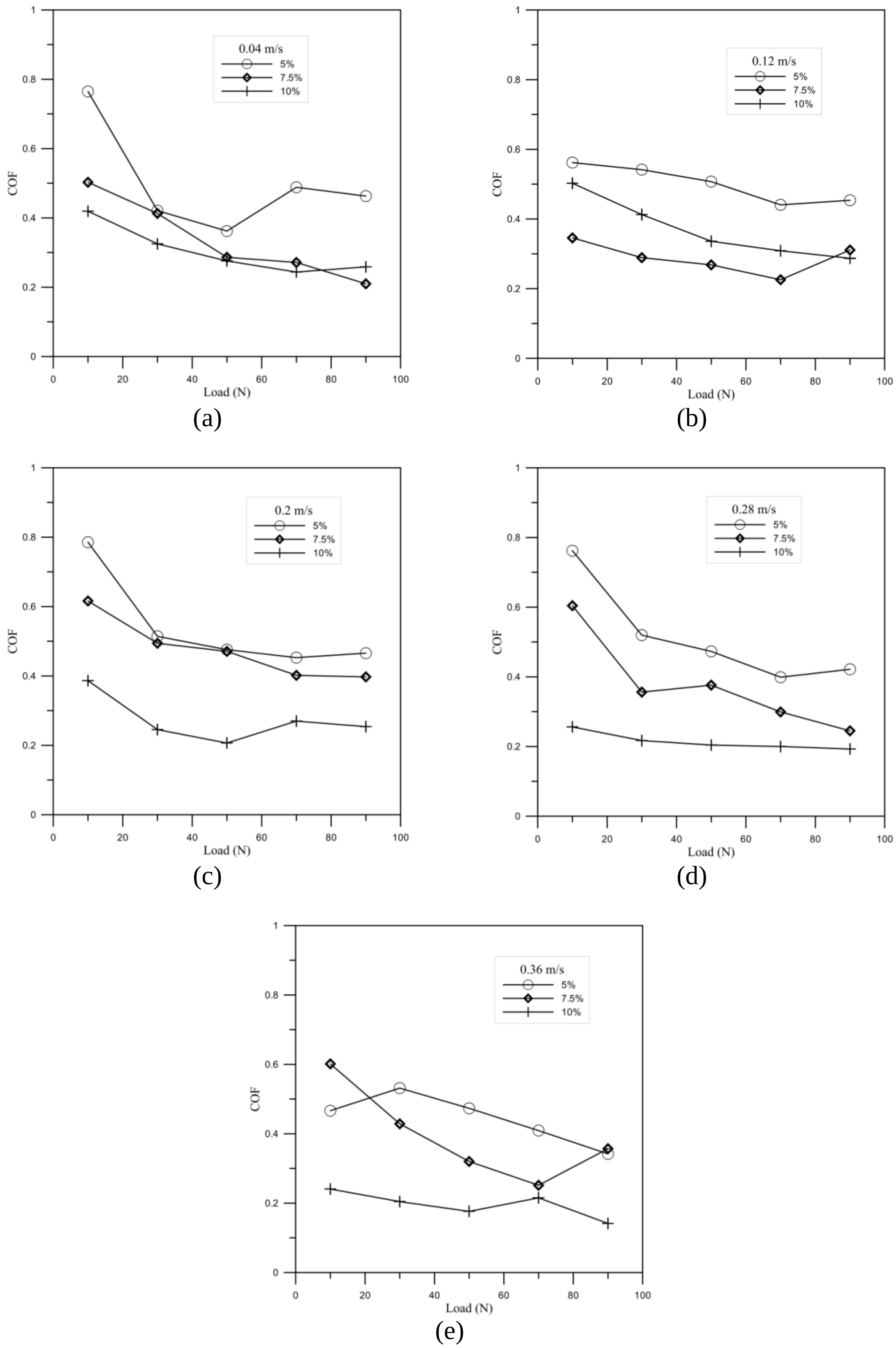


Figure 5: Variation of coefficient of friction as a function of applied load for different sliding speed: (a) 0.04 m/s, (b) 0.12 m/s, (c) 0.2 m/s, (d) 0.28 m/s and (e) 0.36 m/s

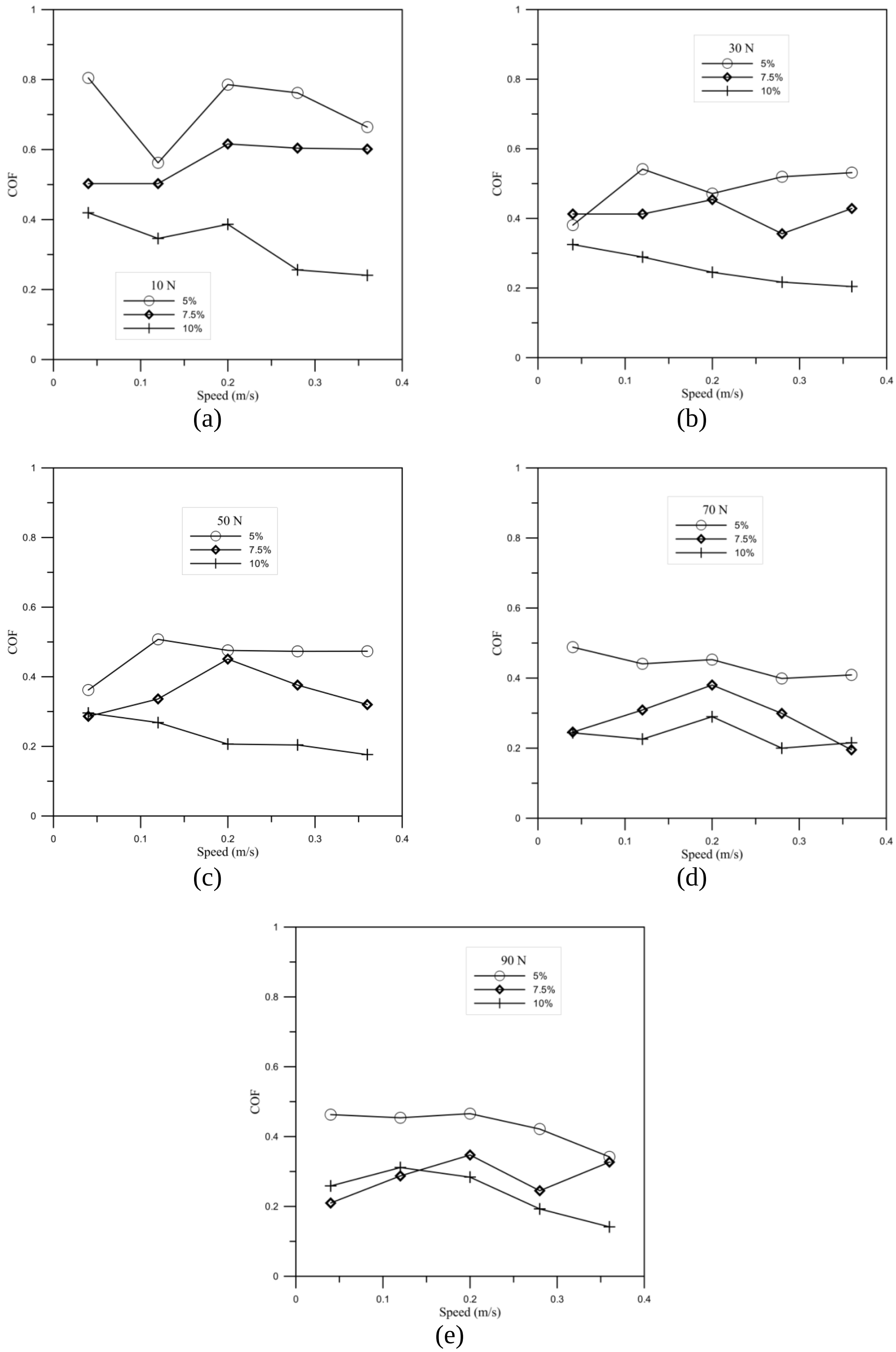


Figure 6: Variation of COF with sliding speed under varying normal load: (a) 10 N, (b) 30 N, (c) 50 N, (d) 70 N and (e) 90 N

3.2 Wear Behavior

Figure 7 shows the variation of wear (weight loss) with applied load under different sliding speed for Al-SiC MMCs under acid environment. It is seen from the figure that weight loss increases with increase in applied load. The fracture of the reinforcement particles takes place in the matrix composite due to the shear occurred by the high applied normal load which reduces the mechanical properties of metal matrix and thus gradually increases the wear rate of Al-SiC (Pradhan et al., 2016c). So, it can be concluded that as the applied load increases the wear increases and also the wear mechanism may change. The variation of wear with sliding distance is shown in Figure 8. As the sliding distance increases, the wear also increases. It is also observed that generally, wear decreases as wt. % of SiC reinforcement increases with respect to both applied load and sliding distance variations. The MMCs with high weight percentage of SiC reinforcement underwent low wear loss. This happens due to enhancement of wear resistance on addition of SiC particles (Bauri and Surappa, 2008; Gul and Acilar, 2004).

3.3 Microstructural Characterization

After the tribological tests, the small thickness of the worn surface of pin sample is prepared for the analysis of microstructure using scanning electron microscope (SEM) and energy dispersive X-ray (EDX). The JEOL JSM-6360 machine is used to take the SEM images of worn surface and EDX analysis is carried out in a system connected with the SEM machine. The SEM images (Figure 9) give the mechanism of wear loss and EDX images (Figure 10) provide the detailed compositional study of three worn surfaces. From the SEM images, it can be concluded that wear occurs mainly due to both mechanical action and corrosive reaction. The parallel layers of wear track indicate the presence of adhesive and abrasive wear.

Figure 10(a) indicates the EDX analysis of Al-5 wt.%SiC MMC material pin where total weight percentage of oxygen is found to be 18.25%. Again, Figure 10(b) and Figure 10(c) give the compositional percentage of Al-7.5wt.%SiC MMC and Al-10 wt. % SiC MMC respectively where oxygen percentages are found to be 24.34% and 30.98% respectively. From Figure 10, an increasing oxide percentage is found as SiC content increases, which reveals that formation of transfer layer increases as SiC content increase in the MMCs. The transfer layer improves the wear resistance, and thus wear- loss decreases with increase in weight percentage of SiC reinforcement (Yang et al., 2015).

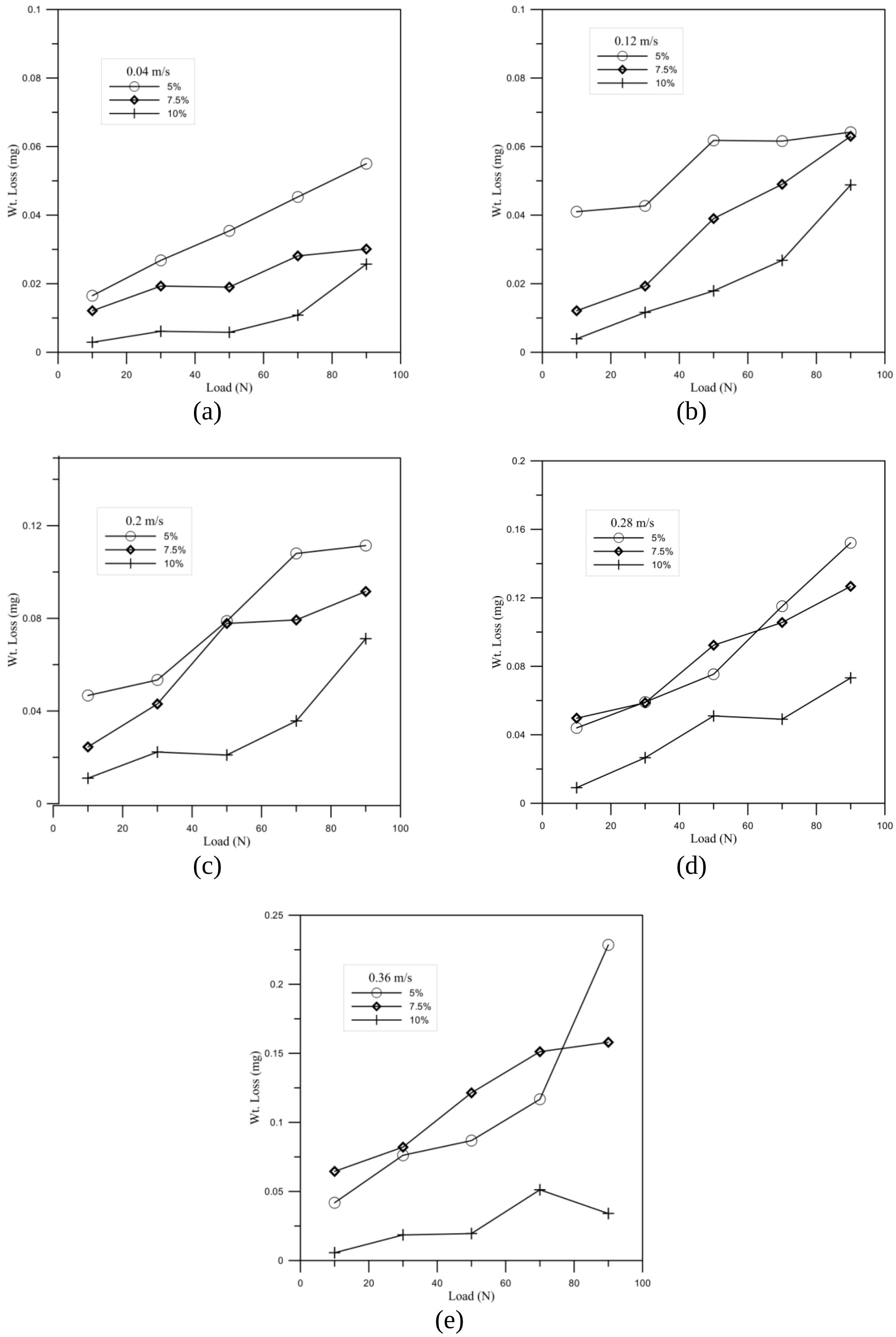


Figure 7: Variation of wear (weight loss) with applied normal load under different sliding speed: (a) 0.04 m/s, (b) 0.12 m/s, (c) 0.2 m/s, (d) 0.28 m/s and (e) 0.36 m/s

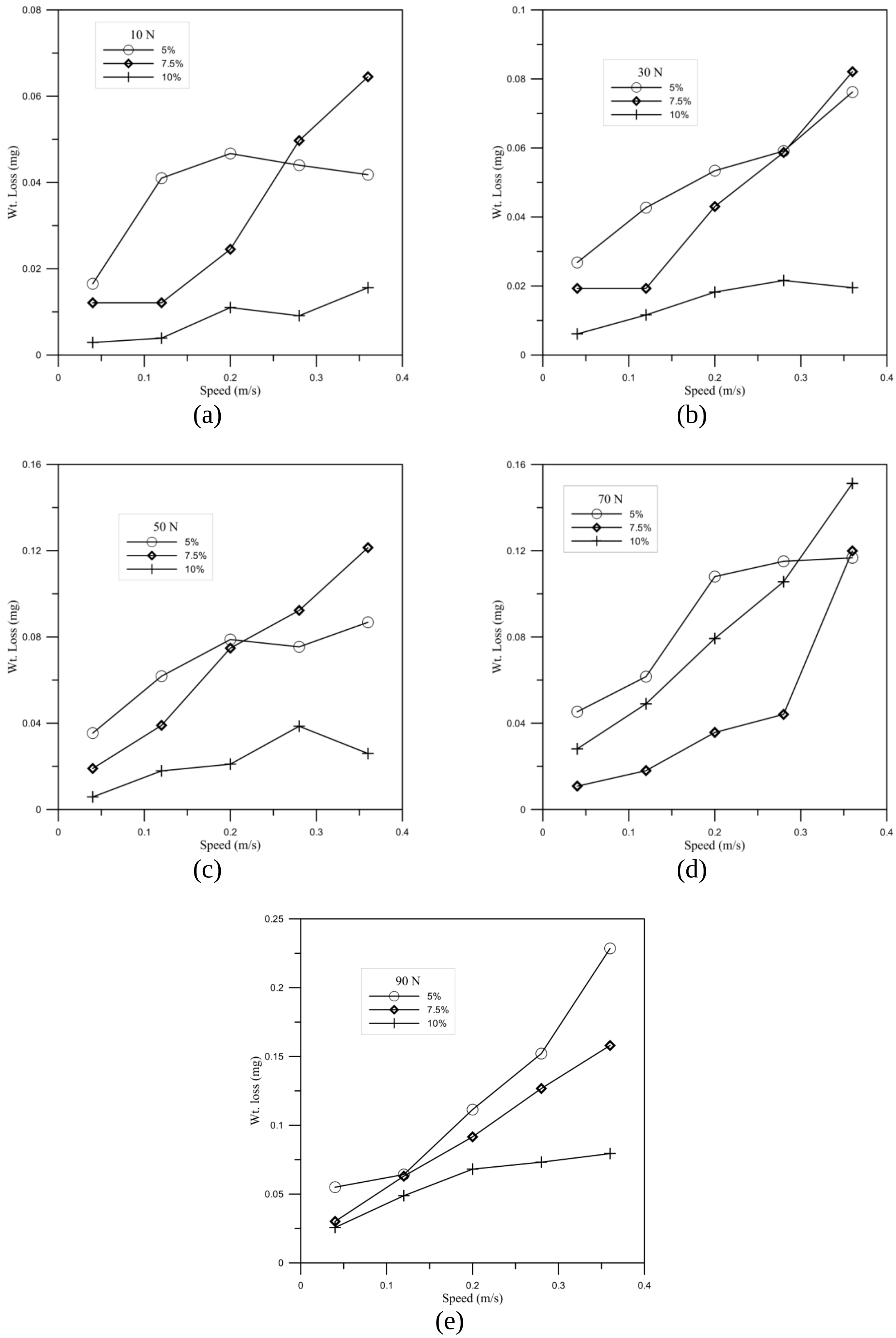
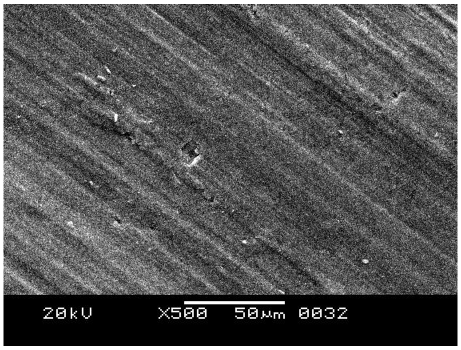
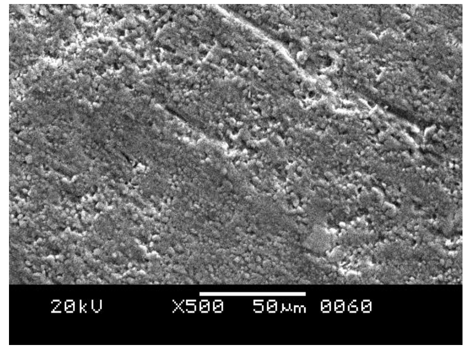


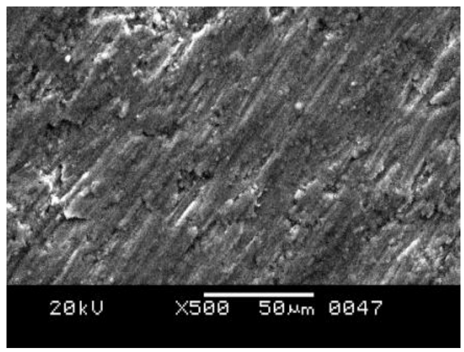
Figure 8: Variation of wear (weight loss) with sliding speed under different environments and applied load: (a) 10 N, (b) 30 N, (c) 50 N, (d) 70 N and (e) 90 N.



(a)

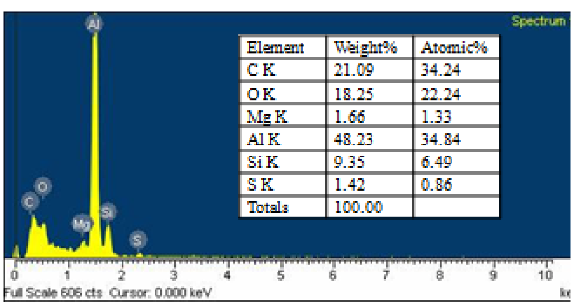


(b)

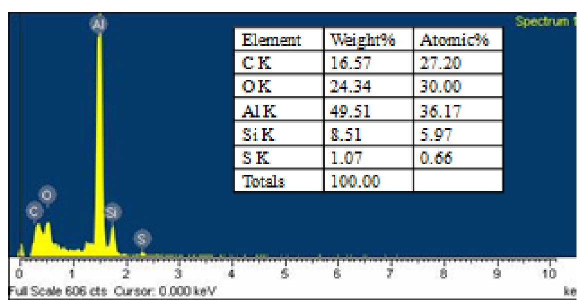


(c)

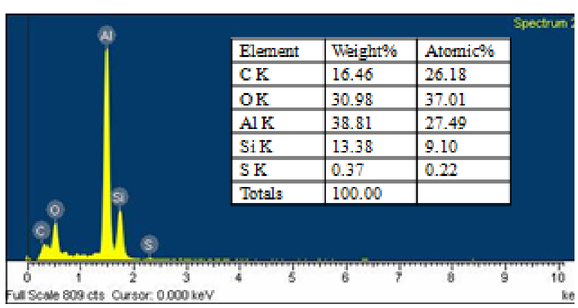
Figure 9: Microstructure of worn pin Al-SiC surfaces at 50 N applied load and 0.2 m/s sliding speed under acid environment: (a) 5 wt %, (b) 7.5 wt % and (c) 10 wt %



(a)



(b)



(c)

Figure 10: EDX images of Al-SiC MMC at 50 N applied normal load and 0.2 m/s sliding speed: (a) 5 wt %, (b) 7.5 wt % and (c) 10 wt %

CONCLUSION

Tribological behaviour of Al based MMCs reinforced with 5 wt.%, 7.5 wt.% and 10 wt.% of SiC content prepared by stir casting method is investigated in a tribotester under acid environment. For conducting the experiment, the applied normal load and sliding speed are varied and coefficient of friction and wear of the Al-SiC MMCs are considered as the responses. It is found that with increase in applied load, the friction coefficient decreases while it slightly fluctuates with variation of sliding speed. Wear of the MMCs material increases with increase in applied load and sliding speed. The wear resistance of the Al-SiC MMCs material increases with increase in weight percentage of SiC content and the coefficient of friction decreases with the increase in weight percentage of SiC reinforcment. From the microstructure study, it reveals that formation of oxide layer enhances the wear resistance and abrasive, adhesive, corrosive wear are the wear mechanisms present in this study.

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