CHAPTER 4

TRIBOLOGICAL BEAHVIOUR OF ZA/ZrB_2 *INSITU* COMPOSITES IN DRY SLIDING CONDITION

4.1 INTRODUCTION

This work has been conducted to understand the suitability of ZA/ZrB_2 composites in tribological applications under dry conditions. Hence, tribological behaviour has been investigated with sliding distance, applied load and volume % of ZrB_2 while keeping the sliding velocity constant. Worn surfaces have been investigated under SEM with EDS, surface profilometer and AFM. Debris analysis has also been done by SEM and EDS. Observed results have been correlated with morphology, hardness and texture studies.

4.2 INFLUENCE OF SLIDING DISTANCE

Tribology of alloy and composites with changing sliding distance has been investigated and presented in Figs. 4.1 and 4.2. This is clearly evident from Fig. 4.1 that with increase in sliding distance, almost linear increase in wear volume take place which indicates steady state wear behaviour. If curves are even extended to zero for composites more or less linear behaviour can be attained which indicates period of running-in wear is very less or due to the less number of experiment at the lower value of sliding distance it is not being observed. But there is visible distinction between composite and base alloy. In base alloy, running-in period is clearly observed. Hence, it can be clearly understood that on introducing hard particles, steady state wear is attained much earlier, which may be due to decrease in adhesive forces on reinforcement of hard particles. These adhesive forces are the main cause of higher static friction. Same behaviour for all composites is observed with distance except for decrease in overall wear with increase in particles volume [Geng et al, 1993]. Another important observation is that for all the loads after 4000 m sliding distance there is slight increase in wear rate with less reinforcement but composites with higher reinforcement show same rate of increase even after 4000 m. Similar trend in wear volume is also observed by the Chourasiya et al. (2020) for metal matrix composites. Figure 4.2 shows variation of coefficient of friction with sliding distance. These curves show some fluctuating behaviour, which is quite likely due to the adhesive forces between two surfaces and presence of hard particles. But with distance rise in surface temperature takes place and oxidation of the surface also takes place. All composites show increase in coefficient of friction with sliding distance which gets quite stabilized after moving certain distance for all the loads (Vineet et al., 2022).

To understand the mechanism of wear, worn surface analysis of composites tested with different parameters was performed under SEM, AFM, surface profilometer and EDS. Figs. 4.3 to 4.5 show the effect of sliding distance at 50 N load for C9.0 composites.

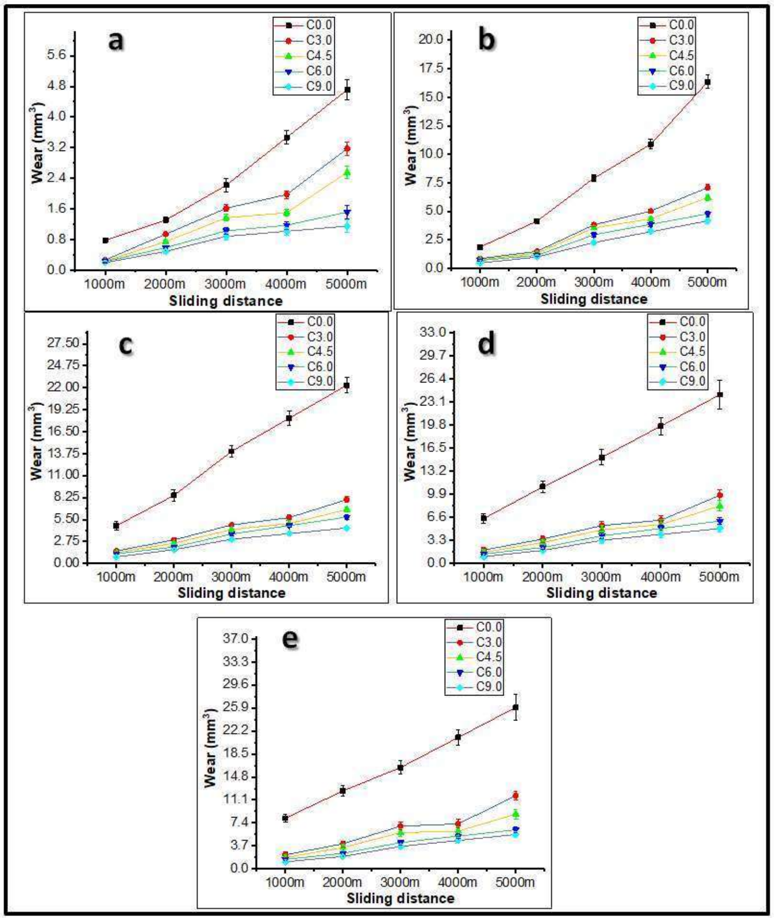

Fig. 4.1 Influence of sliding distance on wear volume at different applied loads (a) 10 N (b) 20 N (c) 30 N (d) 40 N (e) 50 N

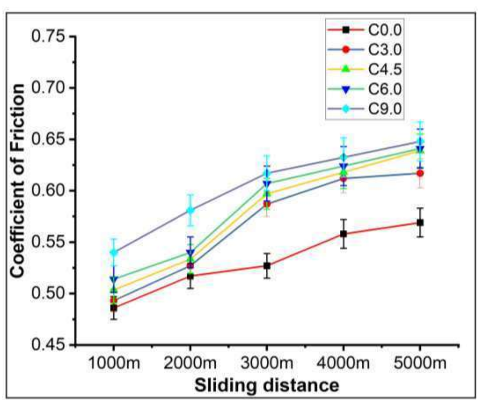

Fig. 4.2 Influence of sliding distance on COF at constant applied load of 50 N

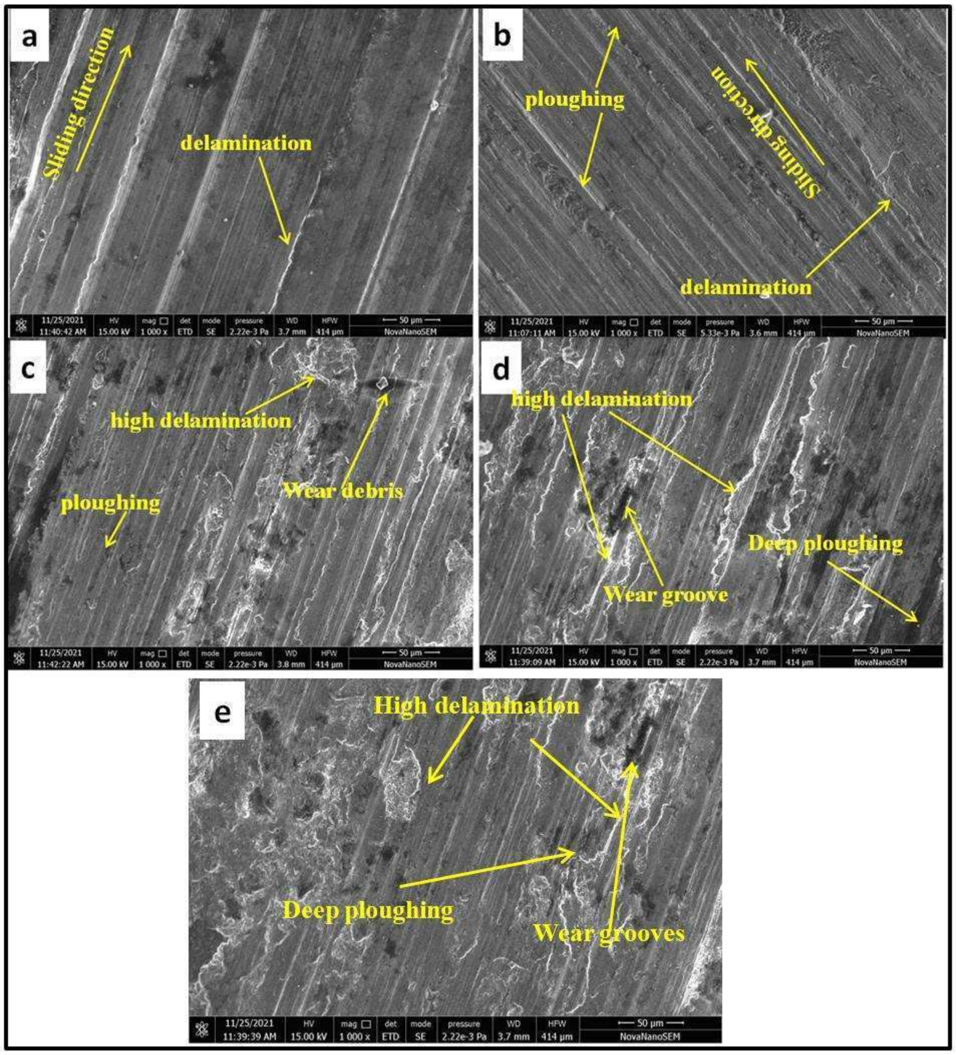

Fig. 4.3 SEM image of worn surface of C9.0 composite at 50 N load and sliding distance of (a) 1000 m (b) 2000 m (c) 3000 m (d) 4000 m (e) 5000 m

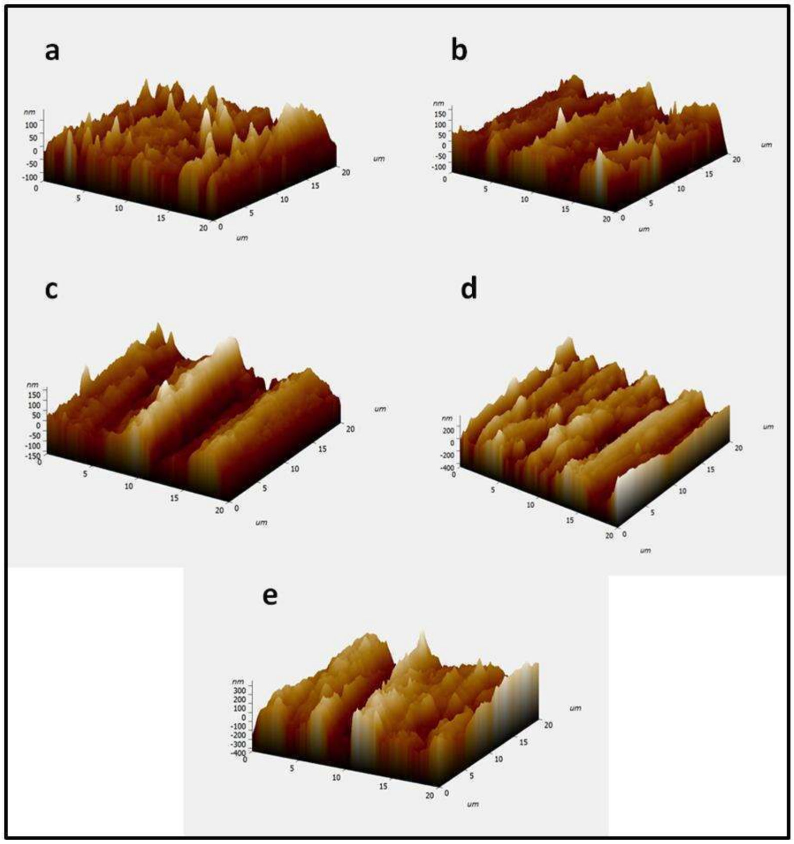

Fig. 4. 4 AFM image of C9.0 composite at 50 N load and sliding distance of (a) 1000 m (b) 2000 m (c) 3000 m (d) 4000 m (e) 5000 m

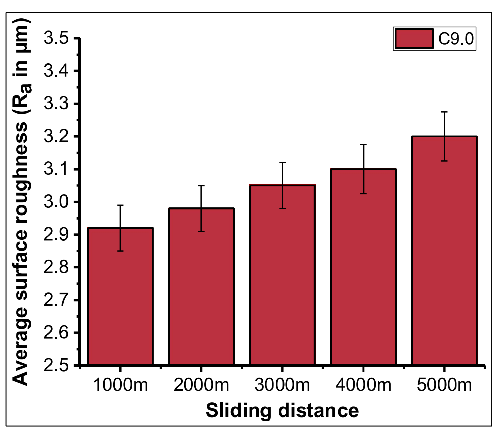

Fig. 4.5 Average surface roughness value (Ra in µm) of C9.0 composite at 50 N load

Figure 4.3 shows the effect of increasing sliding distance from 1000 - 5000 m on the worn surface. This can be inferred that with increase in distance cumulative wear increases, however, after 2000 m of sliding distance severity of damage increases (Fig. 4.3(c to e)) and delamination, deep grooves and ploughing takes place, which results in increase of rate of wear. Figures 4.4 and 4.5 are showing the AFM image of worn surface and average surface roughness value respectively for C9.0 at 50 N applied load and varying sliding distance. Figure 4.4 (a-e) clearly indicates that with rise in sliding distance from 1000 m to 5000 m the average value of peaks and valley enhances from 200 nm to 700 nm and Fig. 4.5 indicate the average value of surface roughness increases from 2.92 ± 0.06 μm to 3.17 ± 0.08 μm. These observations are in line with the observations made in SEM image of worn surface at varying sliding distance and clearly suggest rise in wear with increase in sliding distance [Vineet et al., 2022(b)].

4.3 INFLUENCE OF APPLIED LOAD

Figures 4.6 and 4.7 show the influence of applied load on wear rate and specific wear rate of ZA alloy and ZA/ZrB_2 composites. Figure 4.6 clearly shows an increase in the wear rate with applied load but another phenomenon, which cannot be ignored is a decrease in the rate at which wear rate is increasing or in other words angle of slope is decreased and it is observed for all the distances. It is definitely indicative of severe to mild wear transition and this phenomenon becomes more obvious and pronounced with specific wear rate observing influence of applied load for all the distances in Fig. 4.7. Further, it is also observed that transition in wear rate from severe to mild is shifted towards lower load for all composites after 3000 m of sliding distance but for base alloy it shows a change at 3000 m and 4000 m but final transition from severe to mild takes place after 5000 m only.

ZA alloy is ductile in nature and its surface gets oxidized even at low temperature. When hard particles are introduced in the alloy by *insitu* reaction to prepare composites its hardness increases [cf. section 3.6] [Vineet et al., 209]. Hence, without particles it is likely to exhibit dominance of adhesive wear, which changes to a combination of adhesive and abrasive wear with *insitu* formed particles. Another phenomenon that takes place, side by side takes place depending on working parameters etc. is oxidation of the surface.

When two surfaces are in contact hard asperities of counterface EN31 steel disc will either deform the softer asperities of ZA composite matrix or delaminate/cut. This phenomenon is observed in the initial stages and with increase in applied load this phenomenon aggravates increasing the wear rate [Vineet et al., 2022(b)].

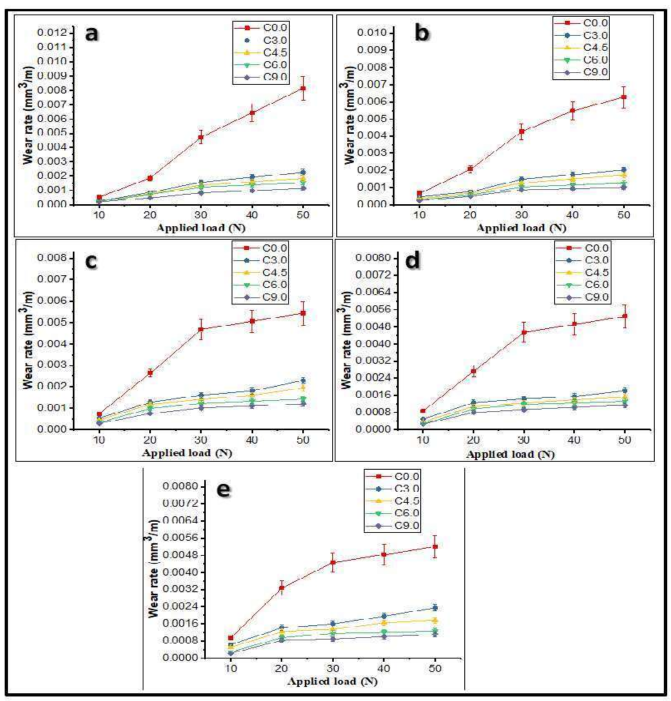

Fig. 4.6 Influence of applied load on wear rate at sliding distance (a) 1000 m (b) 2000 m (c) 3000 m (d) 4000m (e) 5000 m

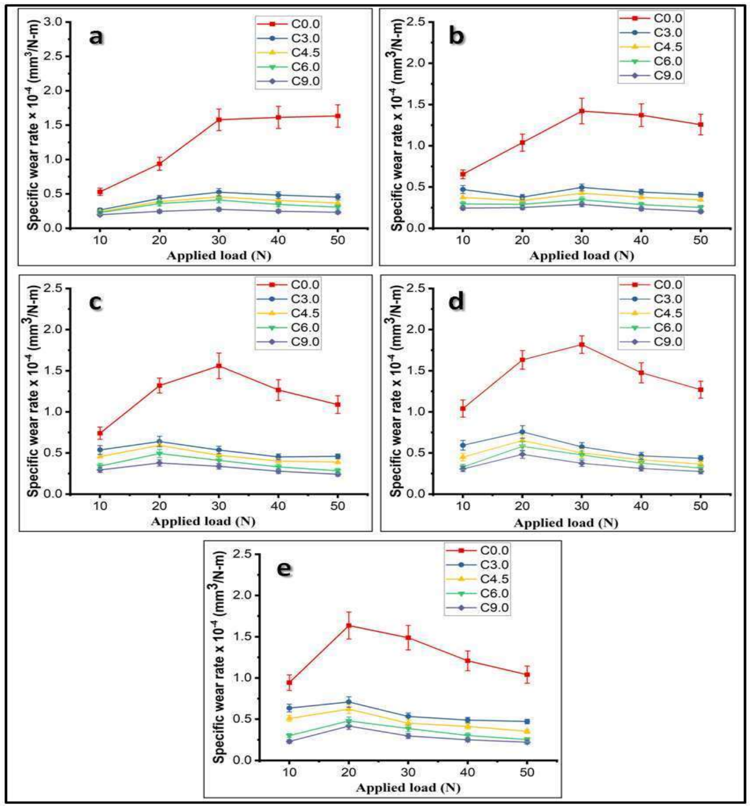

Fig. 4.7 Influence of applied load on specific wear rate at sliding distance (a) 1000 m (b) 2000 m (c) 3000 m (d) 4000 m (e) 5000 m

As the load/pressure continue to increase, rise in surface temperature takes place enhancing the oxidation of surface and metal to metal contact decreases and there is dip in the rate of increase of wear rate. This decrease in wear rate is observed for all the compositions and also for all five distances (Figs. 4.6 & 4.7). Further, it is also well understood that at low load, the wear is low for most aluminium alloys and aluminium base composites. But with increase in load, the rise in temperature becomes prominent, which increases oxide layer thickness. At high loads, formed oxide layer may develop cracks and get detached. This removed oxide layer works as third body and enhances the wear rate. Deformation of soft asperities and matrix of composite by hard asperities also provide in third body wear on high load and increases the wear and the wear mechanism is transformed from mild/oxidative to severe/oxidative-metallic [Narendra et al., 2018]. But in the present case this phenomenon seems to be absent in the present case. May be such higher loads have not been investigated.

Further, shifting of applied load for transition of severe wear to mild wear to lower one with increase in sliding distance is quite interesting. Logically with higher sliding distance, surface is likely to be more damaged (Fig. 4.5), so transition load should have been shifted to higher load but this is not the case with present alloy/composites. This could be due to the larger oxide formation at larger distances providing stability at earlier stage. COF with applied load in Fig. 4.8 shows an increasing trend with applied load but after certain load it starts getting stabilized. It clearly exhibits that with larger distance study, COF gets stabilized at lower load. Larger distance and higher loads both are causing higher oxidation and smooth oxide restricts contact with matrix and COF shows stable nature [Gautam et al., 2015, Parveez et al., 2021].

Figures 4.9 to 4.11 present the worn surface analysis for applied loads from 10 to 50 N at 1000 m sliding distance for C3.0 composites. Figure 4.9 is the SEM images of the worn surfaces, which clearly indicate the increase in deep grooves, delamination and ploughing at higher loads resulting in higher wear rate. These worn surfaces were further analysed under AFM for three-dimensional profile (Fig. 4.10) and analysis of worn surface consists of peaks and valleys, which were further used to determine the unevenness of worn surface as exhibited in Fig. 4.12. It shows the average surface roughness value (Ra in µm) at different applied loads. These figures show that with increase in applied load from 10 N to 50 N the average value of peaks and valley changes from 250 nm to 2000 nm and Ra values from

2.85 ± 0.04 μm to 2.97 ± 0.05 μm (Fig 4.9). This can be inferred as load rises the unevenness of the surface increases as well as wear rate increases, which is in line with wear rate results with applied load. Further, debris generated at different loads was also analysed by EDS. Figure 4.12(a) shows the EDS analysis with micrograph of C3.0 composite debris particles at 20 N, while Fig. 4.12(b) is at 50 N applied load. At 20 N applied load, the EDS spectrum consist of the presence of Zn, Al, Zr, B with the O (Fig. 4.12a). The quantitative analysis under EDS indicates that the amount of O (oxygen) is 19.68 wt.% on worn surface at the 20 N load. But at 50 N load, The EDS spectrum exhibits the presence of (Zn, Al, Zr, B), O and Fe. The quantitative analysis results show that the amount of O and Fe is 16.14 and 13.87 wt.% respectively on the worn surface at the 50 N load. Wear mechanism is dominated by oxidative wear, however, at higher loads counterface also gets worn off as it is evident from iron pick-up in debris.

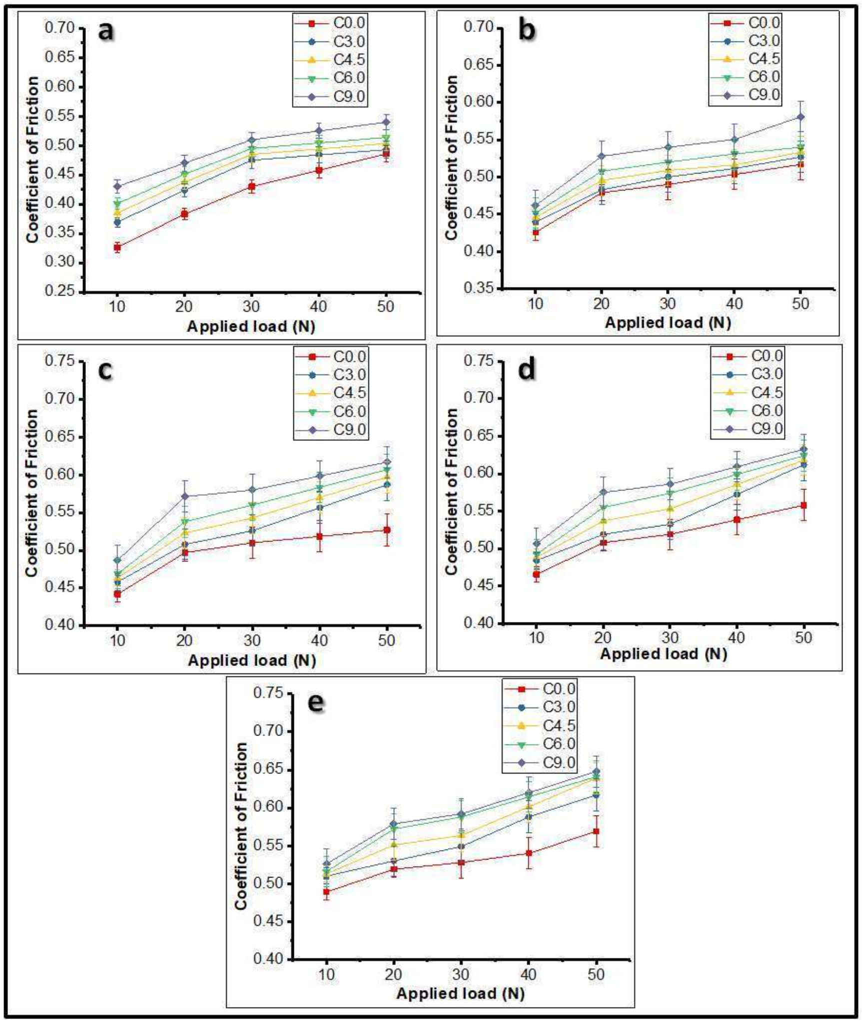

Fig. 4.8 Influence of applied load on COF at sliding distance (a) 1000 m (b) 2000 m (c) 3000 m (d) 4000 m (e) 5000 m

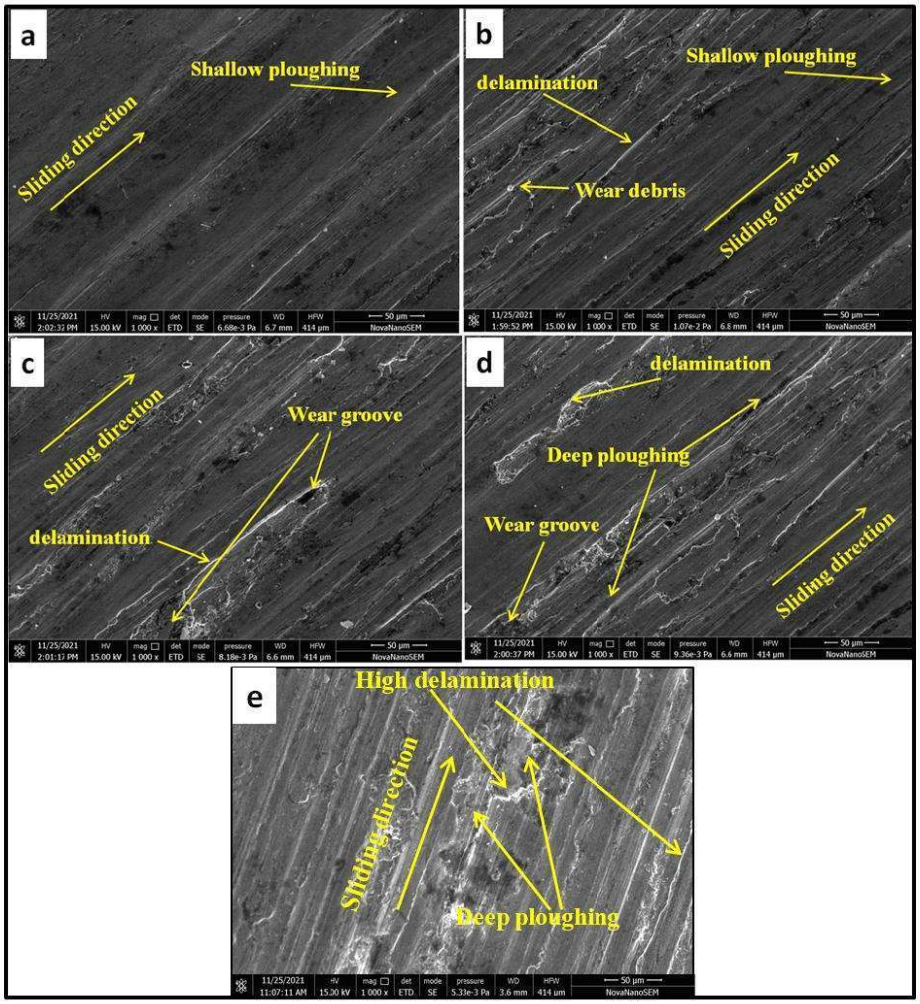

Fig. 4.9 SEM image of worn surface of C3.0 composite at 1000 m of sliding distance at (a) 10 N (b) 20 N (c) 30 N (d) 40 N (e) 50 N

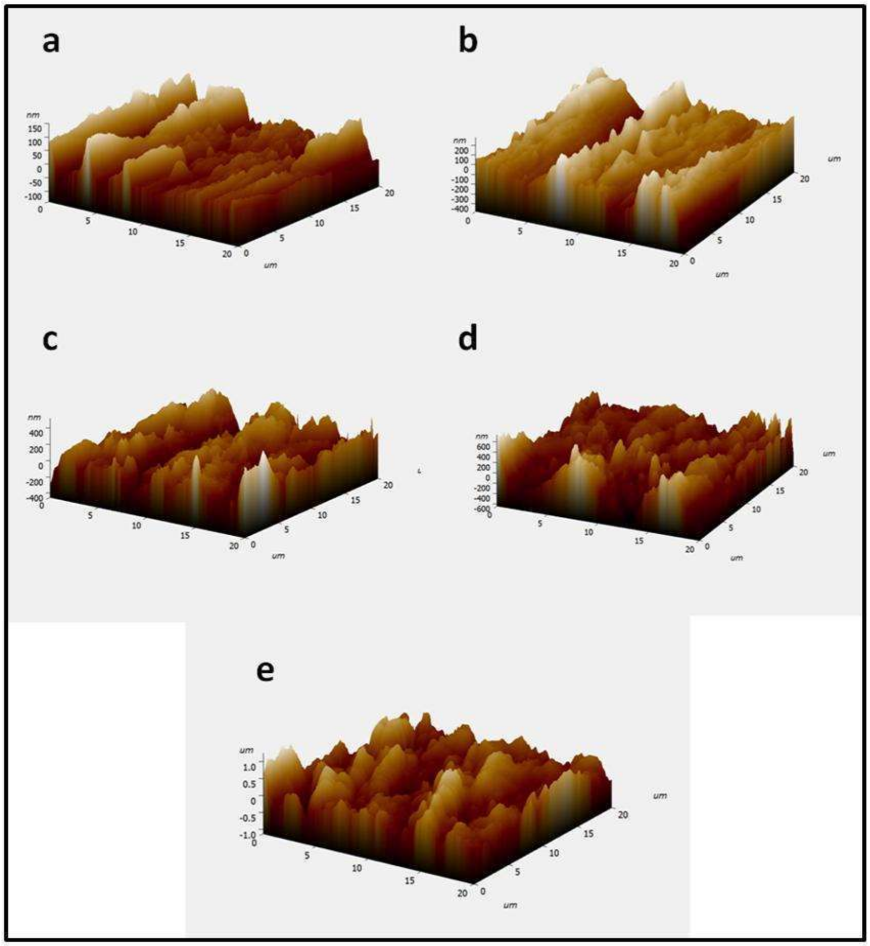

Fig. 4.10 AFM image of C3.0 composite at 1000 m of sliding distance at (a) 10 N (b) 20 N (c) 30 N (d) 40 N (e) 50 N

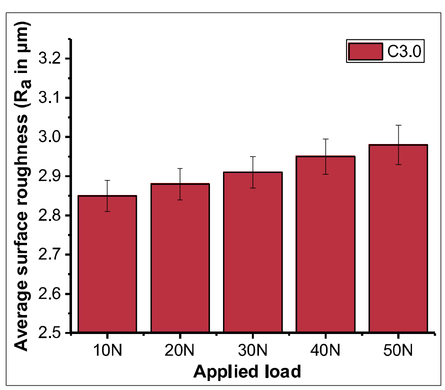

Fig. 4.11 Average surface roughness (Ra in µm) of C3.0 composite at 1000 m of sliding distance

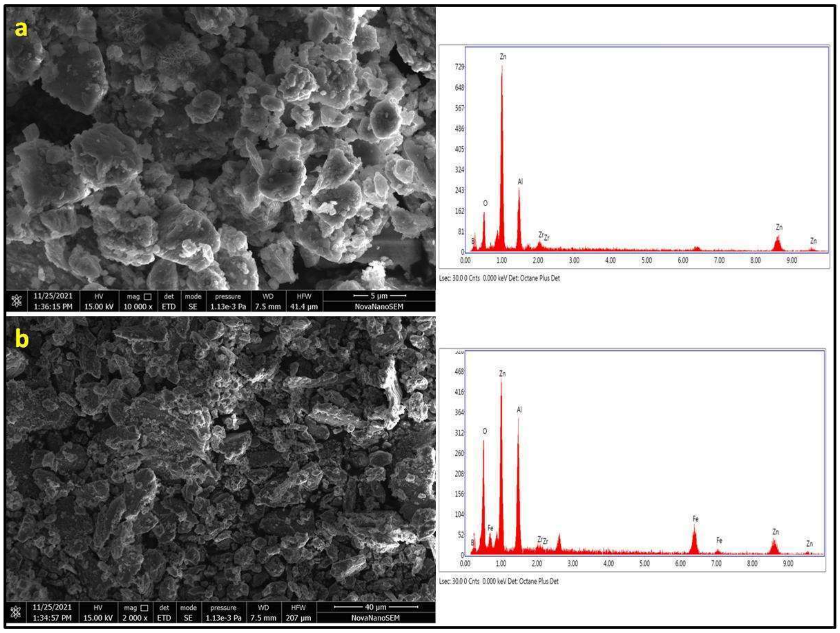

Fig. 4.12 Debris particles of composite at different applied load (a) 20 N and (b) 50 N

4.4 INFLUENCE OF ZrB_2 REINFORCEMENT

The influence of vol.% of ZrB_2 particle on wear, wear coefficient and COF of composites is shown in Fig. 4.13 (a & b) and Fig. 4.14 for 5000 m sliding distance and 50 N load. Wear volume decreases with increase in the amount of ZrB_2 particles in composite; however, lowest wear volume and wear coefficient is observed in the composite C9.0, which consists of 9 vol.% of ZrB_2 particles as depicted in Fig. 4.13(a & b). In contrast, COF shows an increasing trend with ZrB_2 particles content in the composite and the maximum value of COF is observed in same composite (C9.0) as shown in Fig. 4.14. Here, it is important to note that higher composition i.e. with more than 9 vol.% of ZrB_2 was not possible with melting technique due to excessive foaming.

Finer grain size of β phase with formation of ZrB_2 particles as shown in Fig. 3.3 and already discussed in Chapter 3, showed enhancement in the hardness of composites with increasing amount of ZrB_2 particles and also due to refining of matrix phase. The hardness of composite material reduces its susceptible to plowing, which takes place due to the interaction of two surfaces. Hence, improved hardness of matrix and presence of hard particles decreased the wear rate of composites with rise in vol.% of ZrB_2 particles. Additionally, the high tensile strength of the composites indicating the good interfacial bonding of the ZrB_2 particle with matrix also contributes in reducing the wear of composites as reported by Vineet et al. (2019). The presence of these hard ZrB_2 particles increases the capability of matrix to function properly for larger sliding distance and higher loads. Similar kind of tribological characteristics with reinforcement of ZrB_2 particles in the aluminium metal matrix has been observed by material researchers [Kumar et al., 2015].

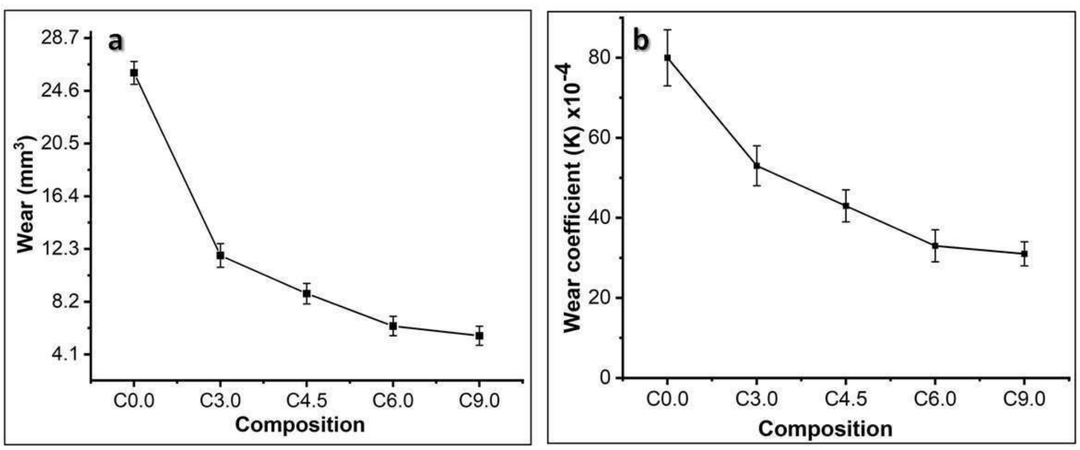

Fig. 4.13 Influence of ZrB_2 content at constant sliding distance of 5000 m and 50 N applied load (a) wear volume (b) wear coefficient

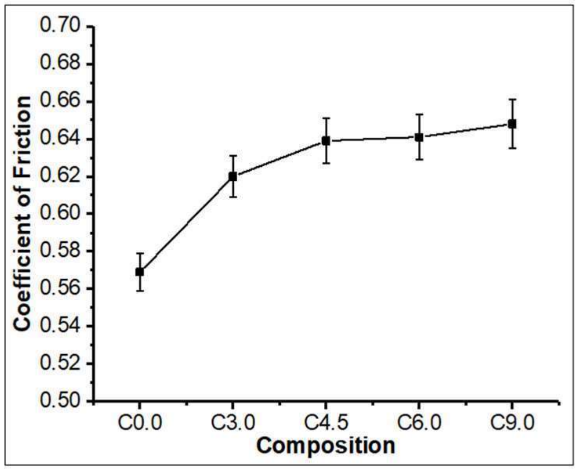

Fig. 4.14 Coefficient of friction for alloy and composites

SEM image, AFM image and average surface roughness value (Ra) of the worn surfaces of alloy and composites at 20 N load and after 2000 m sliding distance are shown in Figs. 4.15 to 4.17. This can be inferred from the Fig. 4.15 that with increase in ZrB_2 vol.% from 0 to 9, the severity of damage of surface decreases. High delamination and deep ploughing along with wear grooves can be clearly seen from the worn surface in Fig. 4.15a, while the severity decreases as can be seen from Fig. 4.15(b-e) and less delamination, ploughing and wear groves result in less wear. AFM image in Fig. 4.16 also confirms the above observation as this can be seen as vol.% of ZrB_2 increases from 0 to 9 the uneven level of surface decreases and the average value of peaks and valleys decreases from 2500 nm to 600 nm owing to existence of hard ZrB_2 particles, which hinders the perforation of hard asperities of steel disc owing to their existence. Presence of ZrB_2 particles also helps in improvement in strengthening through grain refining of matrix phase due to rise in dislocation density, which causes decrease in the severity of damage. Above trends is further confirmed by average surface roughness values in Fig. 4.16 and these results are in line with Fig. 4.13.

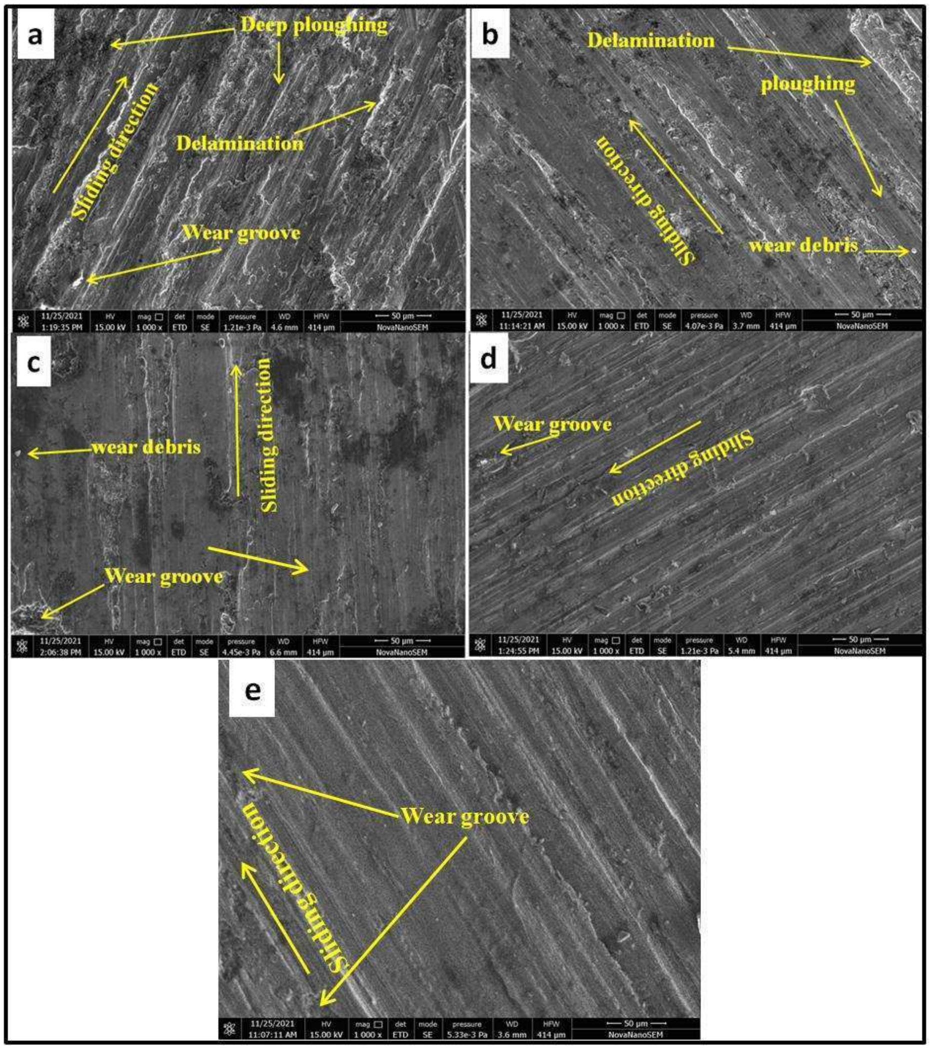

Fig. 4.15 SEM image of worn surface at 20 N load and 2000 m of sliding distance for (a) C0.0 (b) C3.0 (c) C4.5 (d) C6.0 (e) C9.0 composites

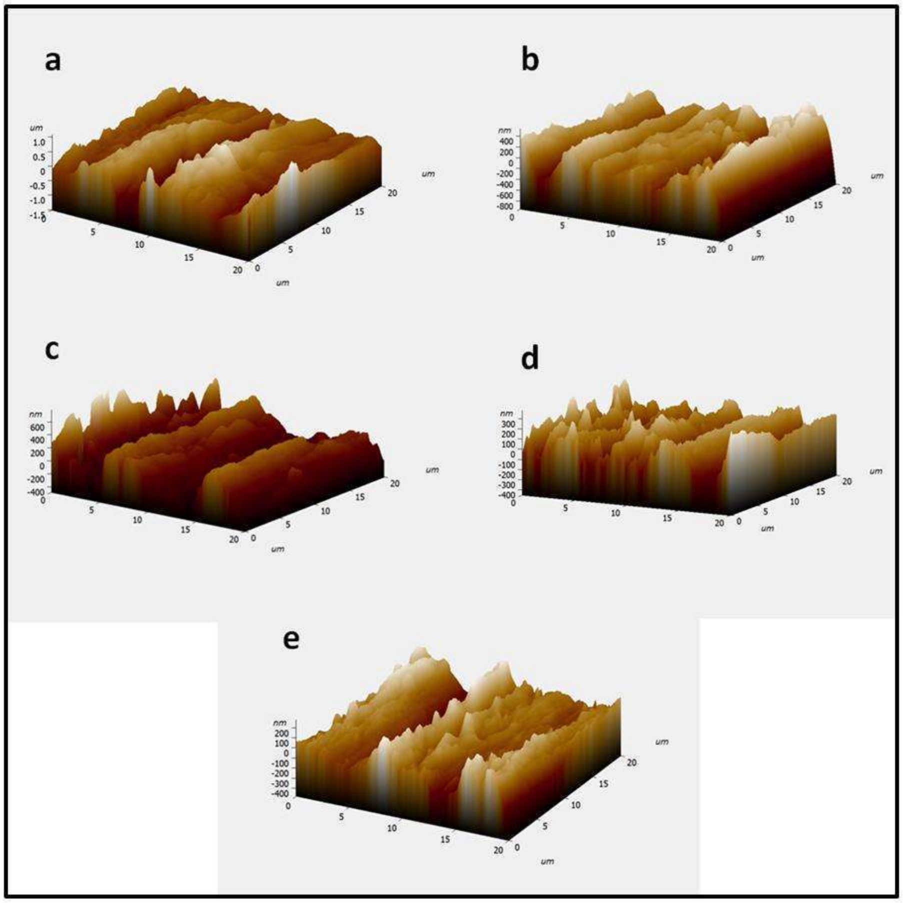

Fig. 4.16 AFM image at 20 N load and 2000 m of sliding distance for (a) C0.0 (b) C3.0 (c) C4.5 (d) C6.0 (e) C9.0 composites

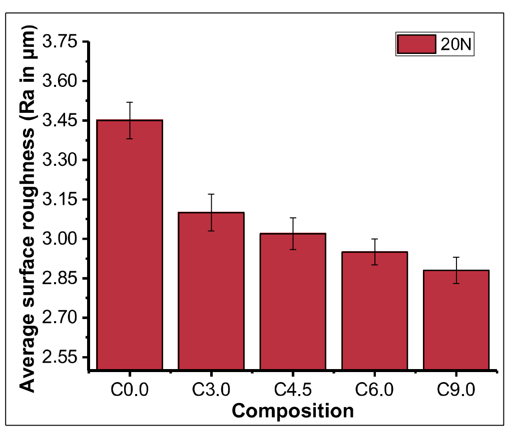

Fig. 4.17 Average surface roughness value (Ra in µm) at 20 N load and 2000 m of sliding distance for alloy and composites

4.5 CONCLUSIONS

Following can be concluded from the work the above work

- Tribological analysis indicates that with enhancement in load and sliding distance wear volume of alloy and composites increases, while it decreases with an increasing vol.% of ZrB_2 particles in the composites.
- The C9.0 composite (consisting of 9 vol.% of ZrB_2 particles) shows approximately 80% less wear volume compared to C0.0 (ZA alloy) at 50 N load and 5000 m sliding distance.
- SEM & AFM images and average surface roughness values clearly suggest that surface damage increases with sliding distance and load but with reinforcement of ZrB_2 particles in ZA alloy surface damage reduces.
- The EDS analysis indicates that generally oxidative mechanism dominates, however, at high loads, counterface wear also prevails due to the presence of hard ZrB_2 particles.
- COF increases with all parameters i.e. sliding distance, applied load and vol.% of ZrB_2.