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Effects of vacuum degree on tribological behavior of TiB_2/Al composites

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Abstract: The effects of vacuum degree on the tribological behavior of TiB_2/Al composites were investigated by a pin-on-disc tribometer under five vacuum degrees of 0.01, 0.03, 0.05, 0.07 and 0.1 MPa, respectively. The results show that the friction coefficient decreases with the increase of vacuum degree, while the wear rates change little. EDS spectra of composites wear surfaces show that Fe element content decreases with the increase of vacuum, which is consistent with the change of friction coefficients.
Key words: vacuum degree; tribological behavior; TiB_2/Al composite

1 Introduction

Improvement in wear resistance by incorporation of hard ceramic particles like TiB_2 [1−6], Al_2O_3 [7], B_4C [8−9] and SiC [9−11] into aluminum-based alloys is well known. Among these reinforcements, TiB_2 has been emerging as a promising candidate for fabricating Al-based composites. The reason is that TiB_2 is stiff, hard [12] and does not react with aluminum to form reaction product at the interface of reinforcement and matrix, and particllarly TiB_2 is wetted by liquid aluminium [13], all of which are beneficial to fabricate composites.

Currently, TiB_2/Al composites are reported mainly about their fabrication methods and mechanical properties. Concerning the effect of TiB_2 particle on tribological properties of materials, two main viewpoints are mentioned: first, it increases the wear resistance of aluminum matrix alloy by using its high hardness [1], which is mostly reported under high load sliding friction and abrasive wear conditions; second, it reduces coefficient of friction and wear rates by reacting with oxygen and water vapor in ambient environment to produce solid lubricant boric acid [14], which is mostly reported under light load and high sliding speed or high temperature wear conditions. Thus, it could be seen that, in order to increase wear resistance and decrease the coefficients of friction, oxygen plays an important role besides suitable speed and load. Based on the above considerations, the present work investigates the effect of vacuum degree on friction and wear properties of TiB_2/Al composites by changing vacuum degree.

2 Experimental

55%TiB_2/2024Al (volume fraction) composites were fabricated by pressure infiltration method. The tribological behavior of the composites was tested under the peak aged (T6) conditions. The details of the process parameters and peak aged conditions of the composites were mentioned in an earlier work.

The dry sliding friction and wear tests were conducted on a pin-on-disc wear testing machine (Model: WTM-2E, Lanzhou, China) according to the ASTM G99-04 standard.

The composites were processed into cylindrical pins with size of d 3 mm×13 mm, then one end of each pin was turned into semispherical shape, and the semispherical surface was polished with grinding paste. The counterface material used was the hardened GCr15 steel (HRC 60). The tests were carried out at different vacuum degree (0.01, 0.03, 0.05, 0.07 and 0.1 MPa), and low vacuum degree was obtained by mechanical vacuum pumps. The sliding speed and sliding distance were maintained 0.5 m/s and 900 m, respectively, for all the

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tests. The tests were carried out at ambient temperature without any lubrication. The wear surfaces of selected samples were characterized using scanning electron microscope (SEM) equipped with energy dispersive spectrometry (EDS).

3 Results and discussion

Figure 1 shows the SEM image of TiB_2/Al composites. It can be seen that the microstructure is dense without obvious voids and inclusions. The relationship between vacuum degree and friction coefficient of the composites is shown in Fig. 2. As seen, the coefficient of friction decreases with the increase of vacuum degree. The coefficient of friction is between 0.7 and 0.85 at vacuum degree of 0.01−0.05 MPa. When the vacuum degree reaches 0.07 MPa, the coefficient of friction decreases to 0.4; and at 0.1 MPa, when the vacuum reaches atmospheric environment, the coefficient of friction is the lowest of 0.36. From Fig. 2, it could also be found that the range of error bar decreases with the increase of vacuum degree.

Figure 3 shows the SEM images of wear surface of TiB_2/Al composites at different vacuum degree and the location of EDS analyses is noted by white box. It can be seen that the morphology of wear surface of TiB_2/Al composite at different vacuum degree is very different.

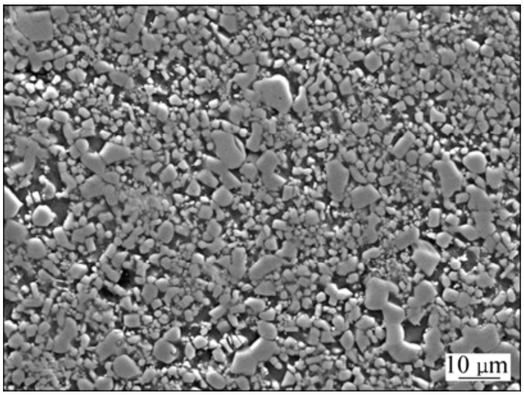

Fig. 1 SEM image of TiB_2/Al composite

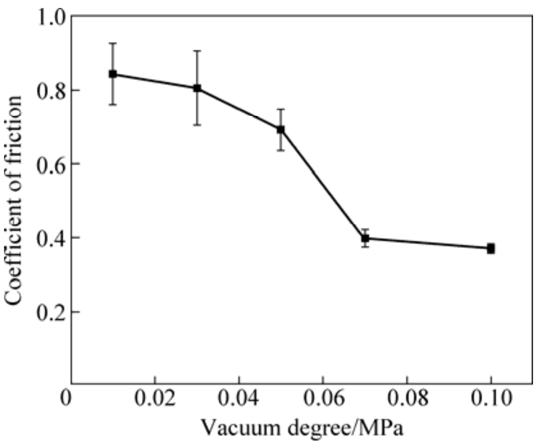

Fig. 2 Effect of vacuum degree on coefficient of friction for TiB_2/Al composites

At vacuum degree of 0.01 MPa, there is large plastic deformation present in the wear surface, and also smear in the wear surface. The EDS spectrum shows that there are lots of Fe in the plastic deformation zone, suggesting wear transfer. In combination with wear morphology, it can be seen that the main wear mechanism under vacuum degree of 0.01 MPa is adhesive wear. When the vacuum degree is increased to 0.03 MPa, the wear surface shows traces of adhesive tear. For the wear pair of TiB_2/Al composite materials and GCr15, adhesion junction tear appears in the softer side of the composite. When the vacuum degree further increases to 0.05 MPa, the wear surface is smooth, and part of the wear surface still has adhesive wear tear. But EDS analysis on the smoother region of wear surface shows that the content of Fe on the wear surface decreases a lot, indicating that with the increase of vacuum degree, Fe element transfer reduces gradually. When the vacuum degree further increases to 0.07 and 0.1 MPa, the wear surface appears smooth and flat, which is different from that under low vacuum degree. The EDS spectra show that the content of Fe on the wear surface is extremely low, with almost no element transfers, indicating that the wear mechanism changes. One of the main characteristics of adhesive wear is the element transfer. In Figs. 3(a)−(c), only the marked areas contact with wear counterpart, the other areas produced by wear tear do not contact with wear counterpart. Therefore, only the change of Fe content with the vacuum degree in the box area is investigated, as shown in Fig. 4.

It can be seen that the content of Fe decreases with the increase of the degree of vacuum. The decrease of Fe indicates the reduction of adhesion between the wear counterpart, which is beneficial to reduce friction. As the content of Fe decreases with increasing vacuum degree, it is believed that this is related to the oxidation of TiB_2. TiB_2 and oxygen react as:

$$TiB_2+5/2O_2 = TiO_2+B_2O_3 \quad (1)$$

It shows that the increase of oxygen partial pressure increases the reaction products, producing more B_2O_3 which reacts with water vapor to form boric acid as:

$$B_2O_3+3H_2O = 2H_3BO_3 \quad (2)$$

Boric acid reduces the friction coefficient, and it is also beneficial to reduce adhesive wear between two surfaces. Therefore, the content of Fe in the sample surface decreases with the increase of vacuum degree.

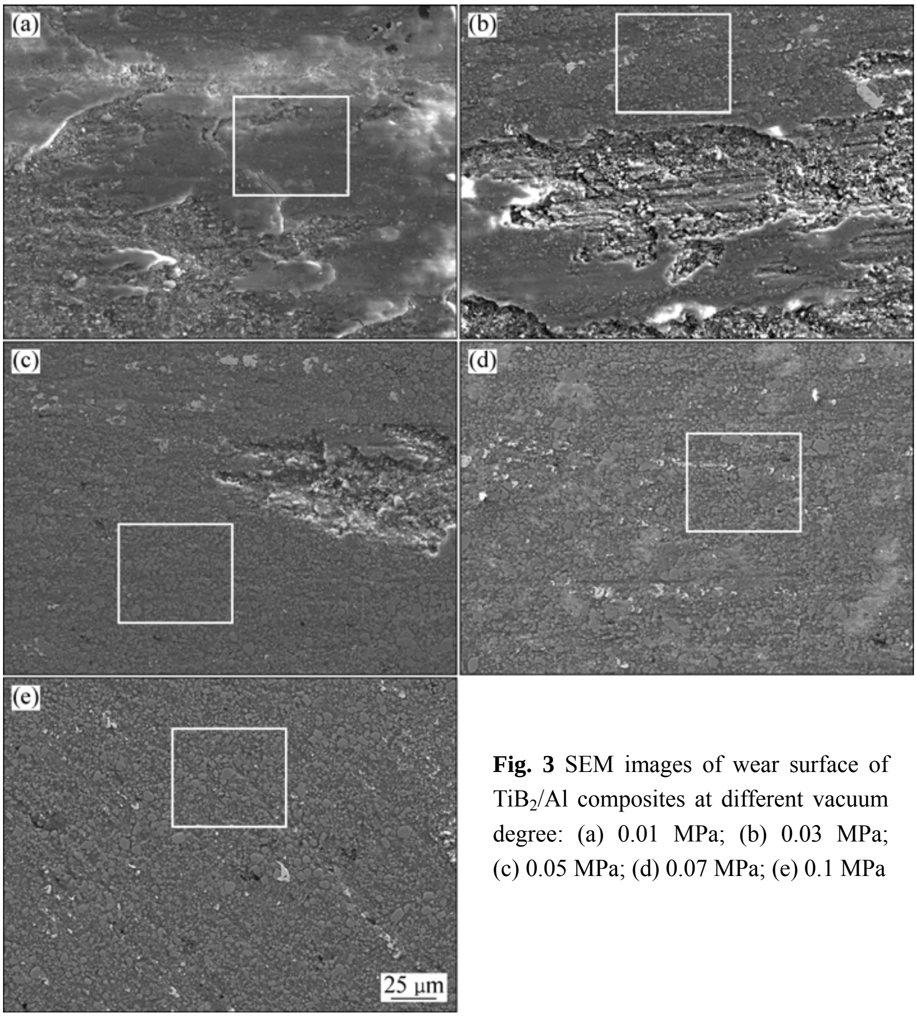

Fig. 3 SEM images of wear surface of TiB_2/Al composites at different vacuum degree: (a) 0.01 MPa; (b) 0.03 MPa; (c) 0.05 MPa; (d) 0.07 MPa; (e) 0.1 MPa

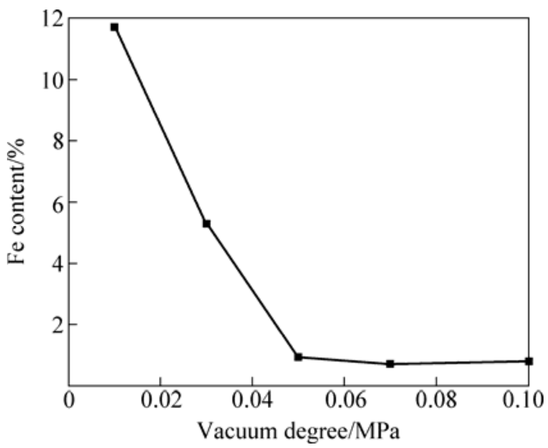

Fig. 4 Variation of Fe content in areas as marked in Fig. 3

4 Conclusions

1) The friction coefficient of 55% TiB_2/Al composites decreases from 0.85 down to 0.36 with the increase of vacuum degree from 0.01 to 0.1 MPa.

2) EDS spectra of wear surfaces of pin specimen show that the content of Fe decreases with the increase of vacuum degree, which is the same as the change of friction coefficient with the vacuum degree. The final oxidation product H_3BO_3 from TiB_2 plays a role as a solid lubricant, inhibiting the adhesion wear of friction pairs and reducing the friction.

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真空度对 TiB_2/Al 复合材料摩擦行为的影响

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摘　要：在不同真空度条件下(0.01、0.03、0.05、0.07 和 0.1 MPa)，采用销盘式摩擦磨损试验机研究气压对 TiB_2/Al 复合材料的摩擦学行为的影响。结果表明：随着气压的增加，摩擦系数呈现下降的趋势，而磨损率变化不大。能谱分析表明，随着真空度的升高，磨损表面的 Fe 含量逐渐下降，与摩擦系数的下降趋势保持一致。

关键词：真空度；摩擦学行为；TiB_2/Al 复合材料

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