Effect of Speed and Load on the Dry Sliding Wear Behaviour of Titanium Carbide Coatings

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Abstract. Titanium coatings are widely used to improve surface hardness and wear resistance of the substrate. Self-propagating high-temperature synthesis (SHS) and Vacuum-Expendable Pattern Casting (V-EPC) were used to develop titanium carbide coatings in this paper. The present work attempts to explore tribology behaviour of titanium carbide coating deposited on steel. Wear tests were carried on a pin-on-disc tester under different loads and sliding speed. The wear mechanism for different loads and sliding speeds are addressed in this paper.

1. Introduction
Due to its excellent strength and toughness, steel are widely used on engineering machinery industry. However, because of low hardness of steel, the application of coatings deposited on the surfaces of steel, which is used to protect surfaces against wear and friction, are very diverse. Titanium carbide has widespread applied owing to its excellent hardness, high melting point, thermal stability and excellent wear resistance. Many techniques have been used to produce the ceramic coating on the steel matrix, such as laser cladding \cite{1}, reactive sintering \cite{2}, plasma spray \cite{3} and so on. Self-propagating high-temperature synthesis (SHS) provides an economical and energy efficient process route for the preparation of various hard ceramic particles that can be subsequently incorporated in a metallic matrix \cite{4}.

The sliding friction and wear behavior of a ceramic coating depend upon the characteristics of the coating such as hardness, thickness, internal stress level and load bearing capacity \cite{5}. Several investigations were carried out on wear mechanism for different coating-substrate under different conditions. These are ploughing \cite{6, 7}, flake formation \cite{8}, micropolishing \cite{6, 7}, cohesive failure or fragmentation \cite{6, 7, 9}, spalling \cite{6, 7, 10}, removal of hard particle phases \cite{11}, and binder extrusion \cite{11}.

In the present study, SHS has been used to manufacture a TiC-reinforced steel matrix composite. Attention was focus on the combined effect of sliding speed and applied load on the friction and wear behavior of TiC coating.
2. Experimental procedures

The Experimental materials were made from commercial powder of titanium (purity: 99.8%, the mesh of powder: 200~300), tungsten (purity: more than 99.7%, the mesh of powder: 200~300), carbon (purity: more than 99.6%, the mesh of powder: 200~300). The reactant powder was mixed in planetary ball mill for 6 hours to ensure homogeneous, then was made into a paste with 2% the polyvinyl alcohol solution. The prepared EPS mold was covered with the paste, of which the thickness was 6~7mm. After being dried for 1~2 days at 35~40 degree, the coated mold was placed in the sand box in order. Then the sand box was filled with quartz sand, reserving the pouring gate and vacuum orifice. The plastic film was used to seal the sand box, and then the sand box was vacuumizing. The negative pressure of the vacuum was 0.03–0.05MPa. The molten base steel (composition was shown in table 1) was fully melted by heating to 1500 degree, and then poured into the sand box. After 2 hour cooling, the sample was moving out. Finally, the sample was tempered at 200 degree.

Table 1. The composition of base steel (wt %).

| C     | Mn  | Si  | Ni  | Cr  | Mo  | Ti  | Fe   |
|-------|-----|-----|-----|-----|-----|-----|------|
| 0.53  | 0.77| 0.45| 0.29| 5.32| 0.26| 0.41| 91.97|

The dry sliding wear tests were carried out using a MMW-1 pin-on-disc apparatus at room temperature. The pin, with the size of 10mm×10 mm, was made by TiC-reinforced steel matrix composite. The friction surface was TiC coating. The counter face disc was made by 200 mesh quartz sand, with 2.2mohs hardness. The sliding surface of the pin had an initial toughness Ra less than 0.30 μm. During the wear test, the disc was fixed and the pin rotated at the radius of 20mm. All tests were performed without lubricated for 1000m distance under loads of 50, 100, 150, 250, 300N and sliding speed of 0.2, 0.3, 0.4m/s. The friction coefficients were continuously measured at a frequency of 1Hz. To ensure repeatability, all tests were repeated for three times and the mean value was reported. The weight of the samples was measured by the Sartorius BSA224S digital balance with an accuracy of 10⁻⁴g. After each test, the sample was washed with acetone then dried and weighed. The difference of weight before and after the test was the wear loss of the sample. After each test, surface morphology of the sample was analyzed by FEI InspectS50 scanning electron microscope. Vickers hardness at load of 0.5kg was carried out on a KB30S Vickers hardness tester.

3. Results and Discussion

3.1. Microhardness

![Figure 1. Micro hardness in a cross-section of TiC-reinforced steel matrix composite.](image-url)
Fig 1 indicates the Vickers hardness along the depth direction of the TiC-reinforced steel matrix composite. The average hardness is approximately 1050HV0.5, which is much higher than that of the substrate. The thickness of TiC coating was about 5mm.

3.2. Effect of load on the wear behavior

Fig 2 illustrates the effect of load on the wear resistance of TiC-reinforced composite. It can be observed that the increase in load from 50N to 300N leads to an increase in wear loss. The increase of load from 50N to 100N leads to an almost 150% increase in total wear. With the load increases from 100N to 200N, the wear loss increases slightly. However, alone with the load continues to increase to 250N, the wear loss is suddenly increased by 50%. Subsequently, as the load increases to 300N, the wear loss remains unaltered. The transition in the wear behavior occurs at a point 100N and 250N.

![Figure 2. Effect of load on the wear loss of TiC-reinforced composite coating.](image)

![Figure 3. Effect of load on the friction coefficient of TiC coating at sliding speed of 0.3m/s.](image)

It can be observed that with the increase in applied load, the wear morphologies gradually change from slight scratches and some spots to distinct plough.

The wear behavior describes above can be attributed to the following reasons. When applied load is 50N, the TiC particles effectively improve the hardness of the substrate and prevent the abrasive particles from embedding into the contact surface, thus effectively prevent the plough cutting. Meanwhile, the binding force between TiC and substrate is higher than shear strength of the interface. Thus, there is almost no TiC particle pull out from the contact surface and there are only slight scratches as shown in fig 4(a). Therefore, the wear loss at 50N load is quiet lower than that of other loads. When the load increases to 100N, the binding force between TiC and substrate becomes lower than shear strength of the interface, which produce spalling and cohesion failure of TiC. As shown in fig 4 (b and c), these spots are the imprint after TiC particle is pulled out. This might explain the 150% increase in wear loss compared with that of 50N. As the load increase from 100N to 200N, more and more TiC particles are pulled out from the surface.

As the applied load increase to 250N, the wear rate increase sharply. The pull-out TiC particles together with abrasive particles from the counter face disc are embedded into the surface of the sample deeply as the load increase. Thus the ploughing effect is obvious at 250N load as shown in fig 4(e).

It is shown in fig 3 that the low coefficient at 50N can be attributed to the low load level, which leads to the low friction at the interface. At this point, ploughing effect is not significant, attributing to the easy slide of TiC coating over the disk. When the load increase to 100N, the TiC particles starts to pull out, leading to an increase in friction coefficient. As the load continues to increase, the increase rate of friction force is relative lower than that of load, which makes the coefficient friction decrease.
3.3. Effect of sliding speed on the wear behavior

Fig5 shows the effect of sliding speed on the wear resistance of TiC-reinforced composite. The tests were carried out at three different speeds of 0.2m/s, 0.3m/s and 0.4m/s. Three different loads of 50N, 150N and 250N were investigated at each speed. Under the condition of 50N load, with the increase of sliding speed from 0.2m/s to 0.4m/s, the weight loss makes no difference. It can be observed that the increase in sliding speed from 0.2m/s to 0.4m/s at load of 150N produces more than 50% increase in wear loss. The wear loss increases approximately 30% percent from 0.2m/s to 0.4m/s under the load of 250N.

Some researchers have found that sliding speed have an overwhelming effect on the surface temperature [13]. Under the condition of 50N load, the increase of sliding speed has little effect on wear loss. Due to the low level of load, the friction of the interface is low, leading to little change on interface temperature along with the increase of sliding speed. It is shown in fig 7(a, d) and fig 4(a) that there is only some mild abrasion on the worn surface. As load increase from 50N to 150N, wear loss increase with the increase of sliding speed. The temperature at the surface of the coating increase with the increase of sliding speed, resulting in the oxidative process. This process will lead to the softening of the coating surface and TiC particles are pulled out from the surface. As shown in fig 4(c) and fig 7(b), these spots are TiC pulled out. It is shown in fig 7(e) that there is obvious ploughing cut under the condition of 150N and 0.4m/s, which is owing to more TiC particles, together with abrasive particles from the counter face disc, accelerate the wear rate of the TiC coating. Since applied load increases to 250N, abrasive wear starts to play a key role at 0.2m/s sliding speed and there is ploughing cut as shown in fig 7(c). It can be observed from fig 4(e) and fig 7(f) that with the increase of sliding speed, the ploughing becomes more wider and deeper.

It is shown in fig 6 that the coefficient of friction is relatively low under 50N. This is the same phenomena observed in the case of 50N load discussed at fig 4. After the load increase to 150N and 250N, the trend of friction coefficient decreases along with the increase of sliding speed. The behavior just describe above can be attributed to easier plastic flow due to the low shear strength at higher temperature. Meanwhile, it is easier for the debris generated is easier to eject from the wear track at higher speed.
4. Conclusion

In this paper, a serious sliding wear tests have been carried out for TiC coating at different sliding speed and load. The following conclusions can be drawn:

1) The TiC coating, with the thickness of 5mm, has an average hardness of 1050HV0.5, which is much higher than that of the substrate.

2) The effect of load on wear loss is significant. At the load of 50N, the TiC particles effectively improve the hardness of the substrate, thus the wear loss is relatively low. At the load from 100N to 200N, the increase of wear loss is mainly due to the pull-out TiC particles. With further increase of load, ploughing effect becomes significant. The friction coefficient decrease with an increase load.

3) It has been found that the sliding speed affects wear loss significantly. The sliding speed has an overwhelming role in local heating and thus determines the surface temperature. With the load increase to 150N, the wear loss is found to increase with increase in sliding speed. Friction coefficient is found to decrease with an increase in sliding speed.

4) The wear mechanism is TiC particle pulled out, oxidative wear and abrasive wear.
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