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Short communication

The relationships between tribological behaviour and heat-transfer capability of Ti6Al4V alloys

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Abstract

The heat-transfer capability affects the tribological properties of Ti6Al4V alloys. In present paper the friction and wear behaviours of Ti6Al4V alloys dry sliding against GCr15 steel were investigated on a high-speed pin-on-disc tribometer. Friction and wear tests were carried out at sliding speeds from 30 to 60 m/s and at contact pressure ranging from 0.33 to 1.33 MPa. In order to change the heat-transfer capability of Ti6Al4V pin, one group of pins were Ti6Al4V alloys, another group of pins made of two parts were Ti6Al4V alloy and copper. The dynamic sliding temperatures of Ti6Al4V alloys were measured using thermocouples. Morphology and composition of the surface and subsurface for Ti6Al4V alloy were examined by means of scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The tests results were used for investigation of the relationship between sliding interface temperature, microstructure, friction coefficient, wear rate and heat-transfer capability. Finally, it is observed that heat-transfer capability enhancement is of great benefit to reducing the sliding interface temperature for Ti6Al4V alloy. Furthermore, advance in heat-transfer capability is favorable for increase in friction coefficient of Ti6Al4V/GCr15 pairs and in resistance to wear of Ti6Al4V. And moreover, the weight of GCr15 disc was changed from increase to loss. This indicates that transition of wear mechanism exists.

Keywords: Heat transfer; Ti6Al4V alloy; Dry sliding; Microstructure; Friction and wear

1. Introduction

Recently Titanium alloys have attracted considerable attention on account of their potential advantages (i.e. having high strength and corrosion resistance) [1,2]. However, Titanium alloy by itself exhibits poor tribological properties due to low heat-transfer capability. Rise in heat-transfer capability may be a feasible method for enhancing tribological properties of Titanium alloy because good heat-transfer capability may reduce the interface temperature. Under dry sliding condition, specially under high-speed, a large quantity of friction heat generated on the contact surface [3–5]. The interface temperature will rise up to a higher value, even up to melting temperature of materials [6,7]. Therefore, influence of friction heat on tribological behaviour has been an attractive topic for many years. Unfortunately, it is very difficult to obtain the sliding surface temperature or temperature field during the sliding by means of experimental methods. It has been reported that wear mechanism has close relationship with interface temperature and temperature gradient in subsurface region [8,9]. The effect of interface temperature on wear behaviour of Ti6Al4V alloys was published earlier [10]. It was found that there is critical temperature for Ti6Al4V alloys at which friction coefficient suddenly decreases, wear rate suddenly increases and transition from mild to severe wear take place. Straffelini and Molinari [11] have also reported that there is a critical temperature at which mode of wear suddenly changes from mild to severe. However, there are not many reports, which relate the wear mechanism to the change in interface temperature for Ti6Al4V alloys with varying heat-transfer capability. In general, the resistance to plastic shearing, microcracking tendency and thermal stability of microconstituents greatly control the mechanical and tribological properties of Titanium alloys.

In the present work, the relationship between sliding interface temperature, microstructure, friction coefficient, wear rate and heat-transfer capability has been investigated.

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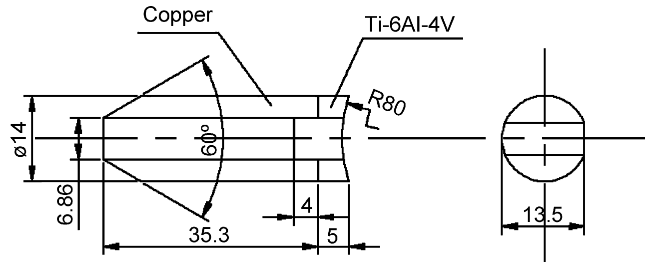

Fig. 1. The structure of pin for Ti6Al4V alloy and copper.

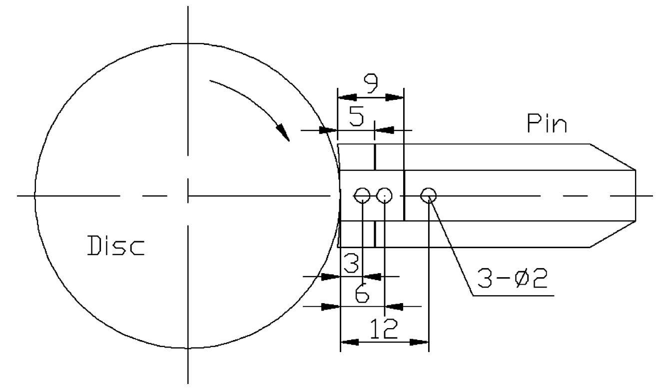

Fig. 2. The locations of three thermocouples.

2. Experimental procedure

2.1. Material

The pin material was Ti6Al4V alloy with average hardness of 40HRC, it was gained by a hot extruded rod through solution treating at 955 °C for 2 h and aging at 540 °C for 4 h. The disc material was GCr15 steel with a hardness of 60 HRC. The pin specimens were in the form of cylinder with a diameter of 14 mm and a height of 40 mm. The disc specimens were in the form of cylinder with an inner diameter of 138 mm, an outer diameter of 160 mm and a thickness of 30 mm. In order to change the heat-transfer capability of Ti6Al4V pin, one group of pins were Ti6Al4V alloys, another group of pins made of two parts were Ti6Al4V alloy and copper (Fig. 1).

2.2. Sliding wear tests

The friction and wear tests were carried out by the high-speed pin-on-disc tribometer (MMS-1G) [12]. The tests were performed at contact pressure of 0.33, 0.67, 1 and 1.33 MPa, and within a sliding velocity ranges from 30 to 60 m/s. The sliding time was about 100 s. During the tests, the friction moment was recorded. The volume losses of pins were determined by measuring the height losses. The mass losses of discs were measured by an analytical balance with a sensitivity of 0.001 g.

2.3. Temperature measurement

Temperature measurements of the pin specimen during the sliding were carried out with three thermocouples. These thermocouples were placed into the holes each of 2 mm diameter at 3, 6 and 12 mm away from sliding surface drilled up at axis of cylindrical pin (Fig. 2). To find out the interface temperature exactly at the sliding surface extrapolation method was used. Based on the distance from the first hole (original distance is 3 mm) to sliding surface after friction process, if the distance was zero, the interface temperature was equal to the temperature of the first hole tested, if the distance was not zero, the interface temperature was calculated by heat-transfer equation.

2.4. Examination of the worn surface

The surface morphologies of worn samples were examined using the scanning electron microscopy (SEM). Energy dispersion spectroscopy (EDS) was carried out to determine the chemical elements present on the surface.

3. Results

3.1. Interface temperature

Typical interface temperature variation during the sliding of Ti6Al4V and Ti6Al4V–copper with sliding time at 30 m/s sliding velocity and 1 MPa contact pressure was shown in Fig. 3. Figure showed that there were three regimes of temperature variation with sliding time in the entire range of sliding velocities and contact pressures used in the work. The first regime corresponded to initial steep rise in temperature during the run in period, the second one corresponded to the steady state sliding showed constancy in temperature and the third one corresponded to final steep drop in temperature during the stop in period. Furthermore, the interface temperatures of Ti6Al4V pins were higher than those of Ti6Al4V–copper pins.

Variation in interface temperature with PV (P is contact pressure and V is sliding velocity) for Ti6Al4V and Ti6Al4V–copper was shown in Fig. 4a. It was observed that increase in PV increased the interface temperature. At the same time, in the low PV range the temperature difference between Ti6Al4V and Ti6Al4V–copper increased with PV increasing. Above certain PV (about 40 MPa m/s) drop slowly in temperature difference

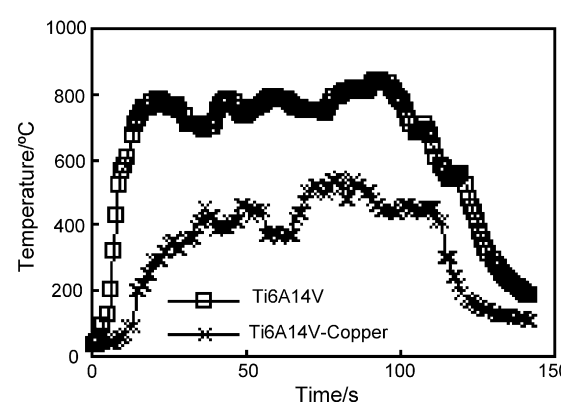

Fig. 3. Interface temperature vs. sliding time relationships for Ti6Al4V and Ti6Al4V–copper.