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Space tribological properties of metal matrix space lubricant coating prepared on titanium surface

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ABSTRACT

In order to improve space tribological properties of pure Ti substrate, Ti_3Al/Ag metal matrix lubricant coating has been synthesized successfully on pure Ti substrate by laser cladding using Al and Ag powders as the precursor. The prepared Ti_3Al/Ag metal matrix coating is mainly comprised of Ti_3Al and Ag phases. Space tribology properties of the prepared Ti_3Al/Ag metal matrix coating and pure Ti substrate were systematically evaluated in a simulated space environment such as high vacuum (VC), atomic oxygen (AO) and ultraviolet (UV) irradiation in comparison with those in an air environment through the space tribological test system. It has been found that in the simulated space environment Ti_3Al/Ag metal matrix coating has good wear resistance and lower friction coefficient than the pure Ti substrate with relative lubricity.

1. Introduction

Service life and stability of the moving mechanical assemblies for aerospace applications are dependent on many factors, such as maintenance free, low friction and low wear operation of lubricants and coatings of contacting surfaces [1–3]. Low earth orbit (LEO) is the space 200–700 km above the earth's surface where the satellites and space stations are running. The LEO space environment is harsh, with ultrahigh vacuum (VC), atomic oxygen (AO) and ultraviolet (UV) irradiation, a wide range of temperature gap etc. [3–6]. These space environmental conditions' effect on most lubrication materials is very severe and complex. Researchers have found that the synergistic interactions of the LEO environments make some traditional lubrication materials invalid in space, e.g. polymer and some other solid lubrication materials may degrade or decompose in a space environment [6,7].

Titanium and its alloys are extensively used into many industrial applications, such as marine and chemical industries, power generation, biomedical devices, sports and leisure transportation, especially in aeronautical and aerospace, because of their high strength-to-weight ratio [8–10]. A larger number of works have been reported on the tribological properties of titanium and its alloys in an air environment and found that titanium and its alloys show low hardness, high friction coefficient and high wear rate (low wear resistance) [11–13]. But to the best of our knowledge, there have been seldom articles describing the space tribological properties of titanium and its alloys, in particular, prepared metal matrix lubricant coating on their surface to improve their space tribological properties. There have been only few studies reported on the tribological properties of titanium and its alloys in vacuum environment [14–17]. Yetim et al. [14] investigated the wear performances of titanium oxide films, produced by anodic oxidation on commercially pure titanium surface in vacuum conditions. They indicated that the wear resistance of CP-Ti significantly enhanced with anodization in all wear tests. Hard-anodized samples exhibited better tribological properties than soft-anodized samples. Yazdanian et al. [15] reported that titanium and its alloys (Ti–6Al–4V) exhibited severe plastic deformation and adhesive transfer characterized by a "stick–slip" type of worn surface morphology. Liu et al. [16] have researched the microstructural changes in the surface layer of Ti–6Al–4V alloy after sliding wear in vacuum. The experimental results showed that a severely deformed layer with a grain size of 50–100 nm and thickness of about 70 μm was formed underneath the worn surface. Jha et al. [17] studied the failure of titanium alloy (Ti6Al4V) fastener used in aerospace application. They found that the microstructure variations are found along the shank axis and the microstructure deteriorates the properties of material and hence the failure.

The purpose of present work is to understand the effects of the space environment on the tribological behavior of titanium. Furthermore, in order to improve its space tribological properties, Ti_3Al/Ag metal matrix space lubricant coating was first fabricated on pure Ti surface.

2. Experimental procedures

2.1. Material details

Polished pure Ti (TA2) disks (31 mm in diameter, 10 mm in thickness) were used as the substrates. Prior to coating preparation, the

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substrates were abraded with SiO_2 grit. Aluminum powder (grit size 74–150 μm; 99% purity) and its mixture with 50 wt.% silver powder (grit size less than 75 μm; 99% purity) were used as the starting materials. Before laser cladding, the mixed powders were pre-placed onto the surface of the substrate without any binding materials at a thickness of approximately 0.5 mm.

2.2. Laser cladding procedure

A 10 kW transverse flow continuous wave CO_2 laser processing system connected to a computer for numerical controlling was performed for laser cladding. Laser processing was conducted in argon shielding gas through the two nozzles under the specimens at a pressure of 0.2 MPa. The other laser processing parameters were selected such as beam diameter of 3 mm, laser power of 4 kW, beam traverse speed of 600 mm/min, and overlapped tracks of 50%.

2.3. Composition and microstructure analysis approach

After laser treatment, the prepared coating was selected and polished for the following tests. The samples for SEM (JEOL JSM-5600LV) observation were prepared using standard mechanical polishing procedures in association with etching in $HF + HNO_3 + H_2O$ (volume ratio of 2:1:47) mixed acidic solution at room temperature. The phase composition was identified by a Philips D/max 2400 X-ray diffractometer (XRD, 40 kV, 100 mA, Cu-$K\alpha$ radiation; scanning within $2\theta = 20$–$80°$). A Tecnai-G^2-F30 transmission electron microscope (TEM) operating at 300 kV was performed to obtain HRTEM images. The hardness profile along the depth direction of the coating zone was determined using an MH-5 Vickers microhardness tester, at a load of 1.96 N and dwell time of 5 s, and hardness values were obtained from the average of 5 individual measurements.

2.4. Space tribology experiments

Space tribology experiments were conducted in a LEO space environment simulation facility (for a schematic illustration of the space tribological test system see Fig. 1) in Lanzhou Institute of Chemical Physics, Chinese Academy of Science. The samples for atomic oxygen irradiation experiments were conducted in a ground-based AO simulation system. AO beam with an impingement kinetic energy of 5.0 eV, which was the same with the direct impact energy of AO to material surfaces in actual LEO orbit [18]. Typical flux of atomic oxygen was determined to be 5.0×10^{15} atoms/cm^2 s, and the samples were irradiated to a period of 240 min. UV irradiation experiments were conducted in a ground-based simulation system. The pressure in the test chamber was high vacuum in the order of 10^{-4} Pa, and the UV wavelength range was 115–400 nm. A typical UV energy flux at the sample position was determined to be 6 suns with an impingement kinetic energy of 5.5 eV, and the exposure period was controlled as 240 min, being equivalent to 24 sun hours [19]. After atomic irradiation and UV irradiation the friction and wear behavior of the samples were evaluated by the space tribological test system with ball-on-disk method, commercially available AISI52100 steel balls (hardness ~700 HV, diameter 3.175 mm) were used as the upper specimens, and samples as the lower specimens. At a load of 5 N, sliding diameter of 12 mm, sliding speed of 0.1884 m/s, and for a period of 30 min, total sliding distance is 339.12 m. The pressure in the wear tester's chamber was in the order of 10^{-4} Pa. The vacuum and air environment tribology experiments were also evaluated by the same space tribological test system with the high vacuum in the order of 10^{-4} Pa and atmospheric environment (the other wear conditions the same to those described above), respectively. The friction coefficient was continuously recorded by the computer connected to the space tribological test system. After the friction and wear tests, the wear volume loss was measured by a MicroXAM three dimensional (3D) non-contact surface mapping profiler (ADE Corporation, Massachusetts, USA). The worn surfaces of friction pairs were analyzed using SEM and surface mapping profiler. The element map distribution of the counterpart AISI52100 steel balls was also analyzed by EDS.

3. Results and discussion

3.1. Composition and microstructure of the laser cladding coating

Fig. 2 presents the XRD patterns of the laser cladding coating. It can be seen that the prepared coating is mainly composed of Ti_3Al and Ag phases. During the laser cladding process, Al powder was completely reacted to the melt Ti and in-situ synthesized to Ti_3Al intermetallic compound, which is attributed to the high energy density of the CO_2 laser beam.

Fig. 3 shows the cross-sectional morphology and corresponding Ti, Ag, and Al element distribution map of the Ti_3Al/Ag coating's cross-section. It can be seen that the prepared Ti_3Al/Ag coating is metallurgically bonded to substrate with a thickness of about 1.2 mm. It should be noted that Ti, Ag, and Al elements are dispersed uniformly in the

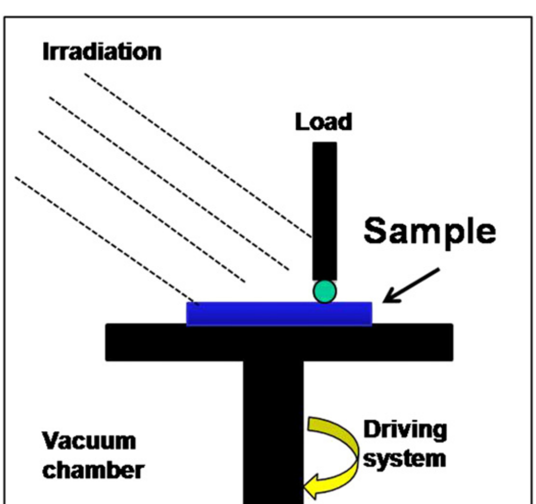

Fig. 1. Schematic illustration of the space tribological test system.

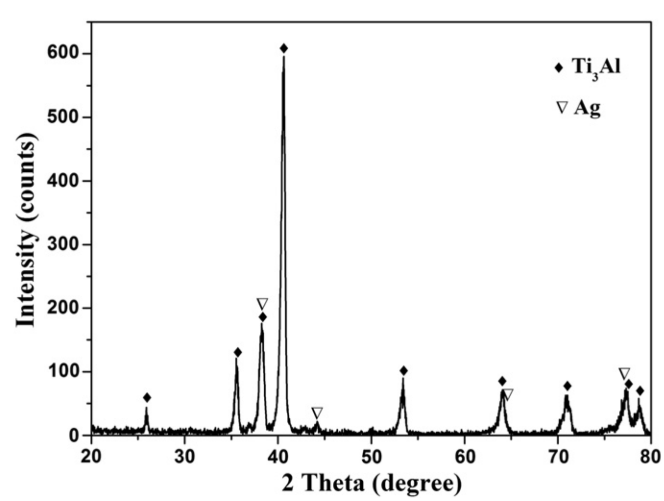

Fig. 2. XRD patterns of the laser cladding coating.