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ARTICLE

Tribological Behavior of 1Cr18Ni9Ti Steel under Hydrogen Peroxide Solution against Different Ceramic Counterparts

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Abstract: We investigated the effect of counterface of ZrO_2, Si_3N_4 and SiC ceramics on the tribological behavior of 1Cr18Ni9Ti steel in 90% hydrogen peroxide solution. The results show that the tribological properties of 1Cr18Ni9Ti steel are strongly dependent on the counterfaces. The adhesion behavior affects the tribocouple of 1Cr18Ni9Ti/ZrO_2, leading to a high coefficient of friction (COF) fluctuating from 0.17 to 0.27 and the highest wear loss of 1Cr18Ni9Ti steel. The oxidation and hydrolysis protect the worn surface of 1Cr18Ni9Ti/SiC, inducing a low COF 0.035 and the lowest wear loss of 1Cr18Ni9Ti steel. Both the adhesion behavior and the reactions play important roles in the wear behavior of 1Cr18Ni9Ti/Si_3N_4, leading to a complex COF and intermediate wear loss of 1Cr18Ni9Ti steel. As for the counterparts, ZrO_2 ceramic shows the most severe wear, SiC ceramic shows relatively low wear volume, and Si_3N_4 ceramic presents the lowest wear volume.

Key words: hydrogen peroxide; tribological property; counterpart; tribochemistry; adhesion

High concentration hydrogen peroxide (HCP), including hydrogen peroxide concentrations ranging from 70% to 98% is receiving renewed interest as a monopropellant and the oxidizer for bipropellant systems [1]. However, the strong oxidizing property of H_2O_2 determines the incompatibility of most alloys and excessive wear of tribo-pairs [2,3]. Pure Al and 1Cr18Ni9Ti stainless steel are the rarely compatible materials of H_2O_2[4]. Compared with the soft pure Al, 1Cr18Ni9Ti stainless steel with good mechanical strength, processing property and corrosion resistance, is potential to preserve nice wear-resistance and be moving parts in H_2O_2 solution[5,6]. Wear, as a complex phenomenon during the surface interaction, is affected by the structures of both materials in the tribo-pair[7,8]. Studying the wear mechanism of different materials coupled with 1Cr18Ni9Ti stainless to design the tribo-pairs with nice tribological property in HCP, is important for the new propulsion systems.

C. Q. Yuan *et al* found that the 1Cr18Ni9Ti steel/Si_3N_4 ceramic rubbing pair could preserve nice wear-resistance[3]. In addition, it was reported that SiC ceramic also could preserve low COF (coefficient of friction) and wear loss in HCP [9]. With nice compatibility in H_2O_2 solution [5] and good wear-resistance [10,11], SiC and Si_3N_4 ceramics are potential to be the good counterpart of 1Cr18Ni9Ti steel in the HCP propellant systems. However, very few papers focused on the difference between the wear mechanism of Si_3N_4 and SiC ceramics in HCP.

Aiming at understanding the aforementioned points, we investigated the tribological properties of 1Cr18Ni9Ti stainless steel sliding against ZrO_2, Si_3N_4 and SiC ceramics in 90% hydrogen peroxide solution. The wear mechanisms were studied by the worn surfaces of both 1Cr18Ni9Ti stainless and corresponding ceramics.

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1 Experiment

The XRD pattern and chemical composition (wt%) of 1Cr18Ni9Ti steel are presented in Fig.1. The tribological tests were conducted on a SST-ST pin-on-disc tribometer (Wazau Germany) in 90% hydrogen peroxide solution at average room temperature of (298±2) K. In order to insure required face-to-face mating and perpendicularity between the pin and disc, the ingots were fabricated into pin specimens of *Φ*8 mm×15 mm, and then they were carefully polished on 2000# abrasive paper before test. The ZrO_2 ceramic was selected to be the yttrium stabilized zirconium dioxide (YSZ) with tetragonal structure. The physical and mechanical properties of the ceramic materials are shown in Table 1. The surface roughness (*R*a) of 1Cr18Ni9Ti stainless steel and ZrO_2, SiC, Si_3N_4 ceramic discs were polished to 0.2~0.25 μm. The tests were carried out at an applied load of 35 N, sliding speed of 300 r/min (0.690 m/s), and testing time of 30 min.

The wear calculations of discs and pins were evaluated by wear volume and mass loss, respectively. The radius of the wear track was 22.5 mm. As for the counterpart discs, the cross-section profile of worn surface was measured using white light confocal microscope (CM, Micromeasure2 STLE). The wear volume, $V=AL$, was defined as the cross-section area of wear track (A) multiplied by the circumference of the worn track (L). Four locations were measured in each wear track to determine A. With regards to the pins of the 1Cr18Ni9Ti steel, the mass before and after the test was both measured for calculating the wear loss. To make sure the reproducibility of the experimental results, all the tribological tests were carried out at least three times. Morphologies of the worn surfaces of the alloys and ceramics were analyzed by scanning electron microscopy (SEM JSM-6510LV) equipped with energy dispersive spectrometry (EDS).

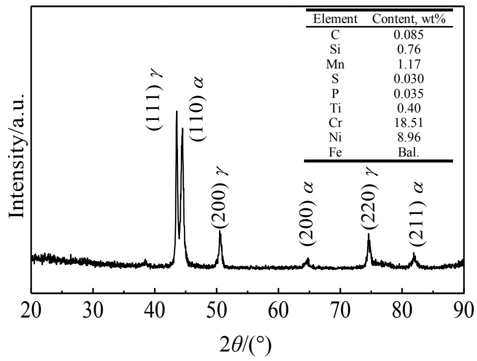

Fig.1 XRD pattern and chemical composition of 1Cr18Ni9Ti steel

Table 1 Physical and mechanical properties of the ceramic

Ceramic	Density/ $g\cdot cm^{-3}$	Hardness, HR_{45N}	Young's modulus /GPa	Fracture toughness /$MPa\cdot m^{1/2}$	Thermal conductively/ $W\cdot(m\cdot K)^{-1}$
ZrO_2	5.8	84	225	7.13	2.5
SiC	3.1	93	441	4.65	58.6
Si_3N_4	3.2	87	294	4.71	12.6

2 Results and Discussion

Fig.2 shows the coefficient of friction (COF) curves of the 1Cr18Ni9Ti steel sliding against different counterparts at applied load of 35 N and sliding speed of 0.690 m/s with sliding time of 30 min. The COF of the 1Cr18Ni9Ti steel/ZrO_2 ceramic pair keeps the stabilization with about a high value fluctuating between 0.17 and 0.27 during the test process. For the 1Cr18Ni9Ti steel/SiC ceramic pair, the COF curve shows a gradual decreasing trend within 250 s at the initiatory stage, and then presents an excitingly low value of about 0.035 with the increase of time. In contrast to the smooth characteristics against ZrO_2 and SiC ceramics, the COF curve of 1Cr18Ni9Ti steel rubbing against Si_3N_4 ceramic is complex. In order to clearly describe the experimental results, the complex COF curve of Si_3N_4 ceramic is decomposed into two regimes in the present work. α regime keeps the high value with distinct fluctuation similar to ZrO_2 ceramic. β regime is a complex process where the COF firstly decreases to the low value similar to SiC ceramic, and then increases sharply to the high value. In the COF curve of 1Cr18Ni9Ti steel/Si_3N_4 ceramic pair, α and β regimes present alternately. With the continuation of sliding process, the duration of α regime decreases gradually. Namely, α regimes displayed in the test maintain at about 600, 400 and 50 s, successively. The different friction behavior indicates that the counterpart plays an important role in the tribological behavior of 1Cr18Ni9Ti steel in 90% hydrogen peroxide solution.

Fig.3 illustrates the wear loss of the 1Cr18Ni9Ti steel pins and the wear volume of the three different ceramic discs. Both the wear loss of pin and the wear volume of disc in the 1Cr18Ni9Ti steel/ZrO_2 ceramic pair are obviously higher than those in other pairs. With low total wear loss, the tribo-pairs with SiC and Si_3N_4 ceramics exhibit different wear properties of steel and ceramic. The wear loss of 1Cr18Ni9Ti steel rubbing against SiC ceramic, is the lowest, which is

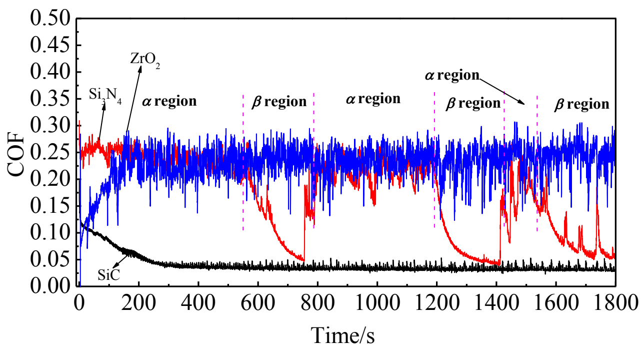

Fig.2 COF curves of the 1Cr18Ni9Ti steel sliding against ZrO_2, Si_3N_4 and SiC ceramics at 35 N and 0.690 m/s with sliding time of 30 min