Effect of nano-size nickel particles on wear resistance and high temperature oxidation resistance of ultrafine ceramic coating

GU Yi(N —), XIA Chang-qing(~{~'~i), LI Jia(~ ~), WU An-ru(~ll)
(School of Materials Science and Engineering, Central South University, Changsha 410083, China)

Abstract: In order to improve the wear resistance and high temperature oxidation resistance of titanium and titanium alloy, the high temperature ultra fine ceramic coating containing nano-size nickel particles was prepared by flow coat method on the surface of industrially pure titanium TB1-0. The effects of nano-size nickel particles on the wear resistance and high temperature oxidation resistance of coating substrate system were investigated through oxidation kinetics experiment and wear resistance test. The morphologies of the specimens were examined by means of optical microscopy, scanning electron microscopy and X-ray diffraction. The results show that the high temperature ultra fine ceramic coating has notable protection effect on industrially pure titanium TB1-0 from oxidation. The oxidation and wear resistance properties of the coating can be effectively improved by adding nano-size nickel particles. The oxidative mass gain of the specimen decreases from 11.33 mg • cm⁻² to 5.25 mg • cm⁻² and the friction coefficient decreases from 1.1 to 0.6 by adding nano-size nickel particles, and the coating containing 10% (mass fraction) nano-size nickel shows the optimum properties.

Key words: nano-size nickel particle; coating; oxidation resistance; wear resistance

1 INTRODUCTION

Improvements in aero gas turbine engine and artillery recoil absorber performance in terms of power, efficiency and mass necessitate the use of high specific-strength and low-density materials, which results in the development of a wide range of titanium alloys in the compressor section of modern gas turbines and artillery recoil absorber. Titanium alloys, in general, easily absorb oxygen, leading to oxidation and alpha phase formation when exposed to high temperature (>500 °C) in air, which limits the high temperature capability of alloys due to their mechanical properties. In order to make use of titanium alloys more effectively at higher temperature, the ingress of oxygen should be reduced, if not prevented completely. The results on bare IMI 834 alloy at different temperatures revealed that the thickness of the oxide scale and the depth of the alpha phase are proportional to the exposed temperature[3]. Another important observation was that alpha phase formation was significantly enhanced at or above 800 °C, which stresses the need for protective coatings to avoid oxide scale growth. Surface modification techniques were examined as a means of limiting oxygen ingress by many researchers[2-4]. However, the inherent low ductilities of the ceramic coatings and the instability of metallic coating systems at high temperatures are areas of great concern restricting their application.

Composite nano-coatings have extensive application prospects in modifying the surface of the materials for their characters of high strength, tenacity and hardness[9-17]. In this paper a modified ceramic coating was obtained by adding nano-size nickel particles into ultra-fine ceramic coating, which maintains both the ductility of the metallic coatings and the stability of the ceramic coatings at high temperature. The performance of the coating on the surface of pure titanium was evaluated by wearing capacity and generating mass gain data as a function of time and subsequently, optical microscopy, scanning electron microscopy and X-ray diffraction were employed to study the microstructure and protective properties of the coating at elevated temperatures, and the distribution of nano-size nickel particles in the coating was also investigated.

2 EXPERIMENTAL

The ultra-fine ceramic coating used contained 50% (mass fraction) solids in which the ratio with size below 1.0 μm exceeded 80%. The average size of nano-nickel particles was about 80 nm. The viscosity of the coating slurry was adjusted with distilled water. The coatings were prepared by adding 10% and 5% nano-nickel particles respectively, and then mixed and dispersed[2,16]. The substrate
was industrially pure titanium TB1-0 ground by a 400-grit diamond sand paper, and the surface of which was treated with acid and alkali in turn. The coating specimens were prepared in the following ways: coating with flow coat method, drying in air, keeping in thermostated container at 50 °C for 1 h for further drying, and then sintering in a high-temperature furnace at 1 050 °C for 5 min.

2.1 Oxidation kinetics test

The coated specimens containing 0, 5%, 10% (mass fraction) nano-nickel particles, respectively, together with the uncoated specimen were used for oxidation experiments in a high temperature diffusing furnace. The oxidation temperature was 900 °C. The mass of these specimens were measured every 20 h with a TG 328A balance. The composition and microstructure were analyzed by optical microscopy (OM, POLYVER-MET), scanning electron microscopy (SEM, JSM-5600LV) and X-ray diffraction (XRD, XD-98).

2.2 Wear resistance test

The wear resistance tests of the coating specimens containing variable contents of nano-nickel particles were performed on a block-on-wheel dry sliding wear tester (Fig. 1). The coating specimens with dimensions of 20 mm X 10 mm X 10 mm, were set on a rotating wheel of chromium-plated GCr15 steel with a radius of 20 mm. The load was 50 N and the wearing time was 2 min.

3 RESULTS AND DISCUSSION

3.1 Results and analysis of oxidation experiments

Fig. 2 shows the results of oxidation kinetics of 4 specimens, indicating that the oxidative mass gains of the specimen without coating increases rapidly at the first 20 h, and then slows down, which indicates that an oxide layer is formed rapidly at early stage. The oxidative mass gain appears to slow up when oxidation is continued because of the protection of the oxides for the substrate. The oxidative mass gain of the specimen decrease from 11.33 mg cm⁻² to 5.25 mg cm⁻² by adding nano-size nickel particles. From Fig. 2 it can be seen that the oxidation resistance performance of the specimens with coating is obviously superior to that of the specimen without coating, and the oxidation resistance performance of the coating specimens containing nano-nickel is superior to that of the coating specimen without nano-nickel. Furthermore, the oxidation resistance performance of the coating is enhanced by increasing the content of nano-nickel particles, which can be explained as follows: the toughness of the coating increases with the addition of nano-nickel particles, and the number of micro-cracks caused by thermal-stress during oxidation at high temperature decreases. Much research work indicates that the increase of toughness is mainly due to crack bridge-link mechanism [14]. When the cracks spread in ceramic-based composite, the tough metal sliced by cracks is pulled up to break (Fig. 3). The plastic yield of the metals takes place accompanied with energy consuming in crack-spreading, resulting in raising the toughness. The effects of crack bridge-link of the dispersing nickel particles in the coating are enhanced with increasing the nano-nickel particles, which makes the micro-cracks hard to generate and expand, and decreases the diffusion paths through