The character of fracture of iron based thermal coating during fretting

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Abstract. The character of destruction of thermal coatings during fretting has been investigated. An iron based plasma coating has been tested with oscillation amplitude from 30 to 200 microns. The tests were conducted in air. It has been determined that the main factor influencing the rate of the wear of the coating during fretting corrosion is the size of the coating area involved into the wear process. The coating exhibits high wear resistance when the amplitude of the oscillation is commensurate with the size of the sprayed particles. During destruction of the coating the leading role belongs to fatigue-oxidation processes. The wear of the coating acquires a catastrophic character when coating macro defects – pores and interlayer boundaries – are involved into the wear process.

1. Introduction

The stress-strain state of the system under friction representing a composition with a coating is defined by two interfaces: ‘counterface – coating’ and ‘coating – substrate’. During wear of the composition with a thermal coating it is necessary to consider the interfaces presence in the coating which are formed by layering monolayers of a sprayed material on each other [1, 2]. The main bulk of solid oxide inclusions and pore space is situated at interlaminar boundaries. It leads to arising of stress concentrators on internal interfaces. The structural features of the thermal coating appear during arising of all kinds of wear including fretting [3-5]. Fretting is a kind of corrosion-mechanical wear of contacting bodies at small amplitudes of relative vibratory motions of rubbing surfaces. Staging is typical for the development of destruction processes during fretting. Wear is a result of the process of setting and fatigue failure in the first stage of fretting. In the second stage the surface destruction is due to the fatigue-oxidation processes. The processes of fatigue and corrosion failure are solidary in the third stage. Each stage of the process feature is defined by the nature of contacting materials, their structure and physical and mechanical properties. The fracture mode of iron based plasma coatings and a role of structural components of the coating in this process are considered during coating wear in conditions of fretting.

2. Materials and methods

Thermal coatings obtained by the method of plasma spraying were investigated [2]. The coating of the iron-based alloy doped with 2.0 mas. % C, 8.2 mas. % Si, 5.1 mas. % Al was sprayed on the substrate of the preliminary sandblasted carbon steel. The coating thickness was about 2 mm, the coating had a heterogeneous structure consisting of particles with non-identical internal structure form and properties [6]. The average value of coating microhardness was 5800 MPa.

Tribological tests of investigated coatings for fretting resistance were carried out in conditions of air vibratory displacement. A "plane-plane" test circuit with the motion amplitude of 30 μm was used [7]. The alloy steel was a material of the counterface. The material was pre-quenched martensite tempered to sorbite. The counterface microhardness was 4440 Pa. To evaluate the role of macrostructure elements of the coating involved in the process of wear during fretting, the tests in the vibratory displacement range of 30, 60, 100 μm and the load equal to 25 MPa, as well as in the ranges of 100, 150, 200 μm and the load of 50 MPa were carried out. The test duration was $6 \cdot 10^5$ cycles. Total linear wear was being continuously recorded during tests. A friction coefficient was calculated in the area of the steady friction torque. Then, in order to determine the final amount of linear wear of the coating, a friction track of the specimen with the coating was registered by means of a strip chart recorder. Thus, the main criteria for evaluation of tribological properties were linear wear of a tribopair and coating. The wear character was evaluated by the metallographic analysis of friction tracks fragments of the coating and counterface with the characteristic tribo-failure.

3. Results and discussion

When the material has a heterogeneous structure consisting of individual particles, the main factor affecting the intensity of the coating wear under fretting is the size of the coating area involved in the wear process. The minimum of oscillation amplitude established in the experiment is a small part of the longitudinal size of sprayed particles [6]. Hence, the interaction and the contact of individual claws of a counterface micro pimple arise to the elements of the coating microstructure. The structure with the large assurance coefficient is formed inside the sprayed particles during the process of plasma spraying. The main phase of solid solution hardening and the secondary phases of hardening by fine particles promote high deformation and fracture resistance of the coating particles [6]. Macrostructural elements of the coating can serve as a main source of failure during the oscillation amplitude increase. These elements represent pores and boundaries between particles and interlaminar interfaces [6].

The analysis of obtained results showed that an increase in vibratory displacement amplitude enhances the wear of the coating and the tribopair. The growth of vibratory displacement amplitude from 30 to 100 μm under the load of 25 MPa leads to twice as much of wear increase of both coating and tribopair (Figure 1).

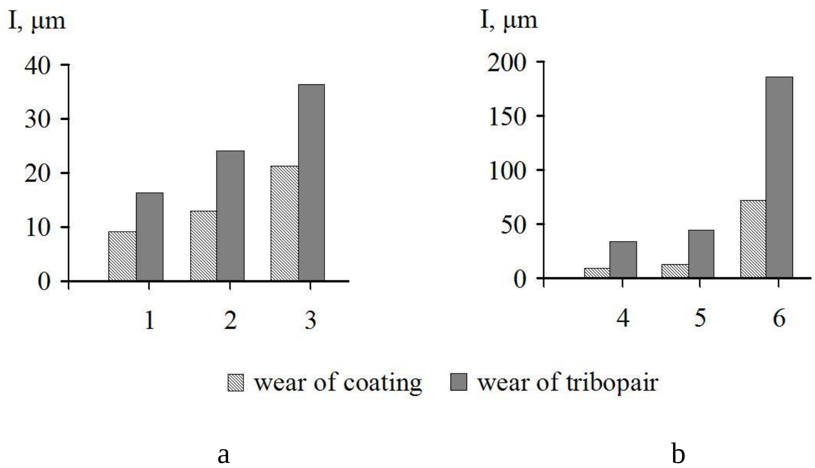

Figure 1. Wear values (I) of tribopairs and coatings under the test load of 25 MPa (a) and 50 MPa (b) and vibratory displacement amplitude: 1 – 30 μm; 2 – 60 μm; 3, 4 – 100 μm; 5 – 150 μm; 6 – 200 μm.

The load increase from 25 MPa to 50 MPa with vibratory displacement amplitude of 100 μm has practically not affected the wear. The wear of coating and tribopair increases during vibratory displacement amplitude increase up to 150 μm (Figure 1). The wear increase is due to the intensification of processes of setting and abrasion of wear particles on the friction surface. A wear pattern which is typical for fatigue-oxidation processes is observed during tests with vibratory displacements amplitude of 100 μm. Caverns and small amount of adhered wear particles are observed in the area of the friction track. (Figure 2a, b). A fatigue-oxidation wear mechanism is confirmed by optical metallography of the coating cross section after wear. As a result of fatigue-oxidation processes during fretting, the thickness of oxidized layers in the coating can be tens of micrometers. The other important outcome of the worn coatings structure analysis is the that roughening of coating fragments is of a wave nature. The size of these fragments is comparable to the motion amplitude [7].

Along with the fatigue-oxidation damages, the traces of abrasive damages with the increase in vibratory displacement amplitude up to 150 μm are clearly visible (Figure 2c, d). The friction coefficient increases with increasing vibratory displacement amplitude. Friction coefficient has values 0.35, 0.4, 0.5 and 0.55 when vibratory displacement amplitude equals 30, 60, 100 and 150 μm, respectively. The friction coefficient increase is due to the fact that wear yield from the friction zone is facilitated under large amplitude values. Thus the conditions for the direct contact of friction surfaces in the large area are created. In turn, the contact area increase leads to the increase of friction force and, hence, the friction coefficient.

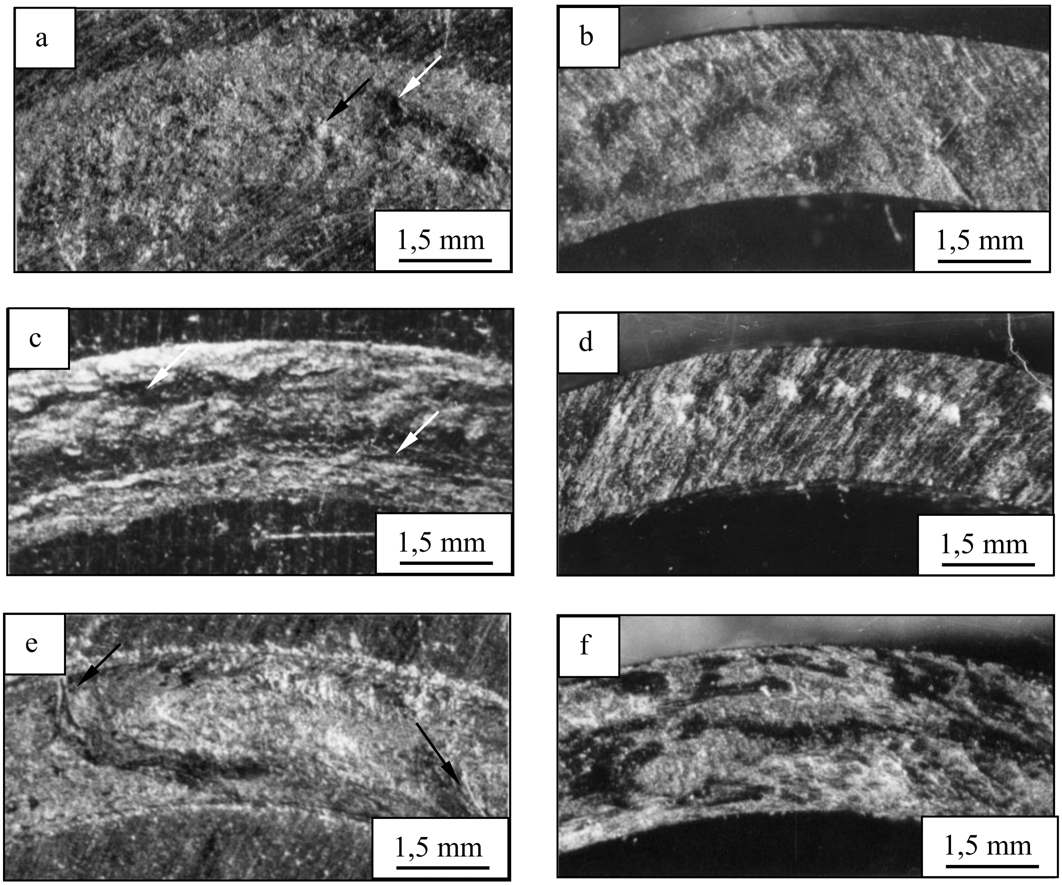

Figure 2. Fragments of coated friction tracks (a, c, e) and counterface (b, d, f). An experiment with amplitude vibratory displacement: a, b – 100 μm; c, d – 150 μm; e, f – 200 μm. Arrow marks on the photo show the following: white – cavity; black – adhered wear particles (a) should be abrasive damage (c), burrs (d).

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The coating wear increases up to 70 μm and the tribopair wear increases up to 180 μm with increasing vibratory displacement amplitude up to 200 μm. A friction coefficient becomes 0.95. In this case the coating fragments are involved in the setting process. These fragments exceed the size of individual sprayed particles. The process of interaction of the coating material with the counter body proceeds to macro. Catastrophic wear of the coating illustrates the nature of the tribo damage of the friction surface (Figure 2e, f). Multiple teasers, cut away places and mutual material transfers are observed on the surface of the coating and its associated counterface.

The catastrophic wear of coating can be described as follows. Stress oscillations, enhanced in the places of contact of the counterface with the coating surface, occur at the first stage of fretting. As a result, crack extension occurs in pores at the interfaces between the particles. Formed fragments are fragile crumbles from the coating surface, and large vibratory displacement amplitude intensifies wear yield of the friction zone. The defect structure accumulation in the coating barrier layer occurs at the second stage of fretting. Then the formation and the rotational movement of large fragments and their separation in the form of wear particles occur. In this case few monolayers of the coating are involved in the wear process. Such intensive wear leads to the total coating wear.

It is not recommended to work with vibratory displacement amplitude of more than 150 μm. Therefore, these parameters exceeding significantly the fragments of the coating macrostructure are involved in the wear process. The size of these fragments is comparable with the size of several sprayed particles and interparticle defects. That leads to catastrophic wear.

4. Conclusions

The main role in the iron-based coating destruction during fretting has fatigue-oxidation processes. The main factor influencing the coating wear intensity is the size of the coating area involved in the wear process. The coating shows high wear resistance which is comparable to and exceeds the wear resistance of the counterface material when vibratory displacement amplitude is less than 150 μm, which is comparable to the sprayed particles size. Coating macrodefects (pores and interlayer boundaries) are involved in the process of wear when vibratory displacement amplitude increases up to more than 150 μm. In this case the coating wear becomes catastrophic.

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