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Effect of Molybdenum on Formation of Nanostructured Film at Friction of Titanium Material Ti–Cr–Mo–TiC

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The addition of molybdenum into the titanium material Ti–Cr–TiC significantly changes the composition and properties of nanostructured film, which is fabricated due to the friction on air and under high temperatures. Predominant contents of brittle oxide TiO_2 (rutile) within the films in the process of friction determines the high wear of materials. There is no titanium oxide TiO_2 within the newly fabricated film of titanium material containing molybdenum, whereas hydroxides and molybdenum oxides prevail in terms of quantity, and ensure high protective and lubricate properties of film.

Добавление молибдена в титановый материал Ti–Cr–TiC значительно изменяет состав и свойства наноструктурной плёнки, которая образуется в результате трения на воздухе при высоких температурах. Высокое содержание хрупкого оксида TiO_2 (рутила) в плёнках в процессе трения определяет высокий износ материалов. Оксида TiO_2 нет в свежеприготовленных плёнках титанового материала, содержащего молибден, в то время как гидроксиды и оксиды молибдена преобладают в количественном выражении и обеспечивают высокие защитные и смазочные свойства плёнки.

Додавання молібдену у титановий матеріял Ti–Cr–TiC значно змінює склад і властивості наноструктурної плівки, яка утворюється внаслідок тертя на повітрі за високих температур. Високий вміст крихкого оксиду TiO_2 (рутилу) в плівках у процесі тертя визначає високий знос матеріялів. Оксиду TiO_2 немає у щойноприготованих плівках титанового матеріялу, що містить молібден, у той час як гідроксиди й оксиди молібдену переважають у кількісній мірі і забезпечують високі захисні та змащувальні властивості плівки.

Key words: titanium material, molybdenum, high-temperature friction, nanostructured film.

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1. INTRODUCTION

The mechanism of wear of titanium material Ti–Cr–TiC was already studied before [1, 2]. The influence of chromium as an alloying element on the mechanism of wear of titanium material Ti–Cr–TiC was previously examined. It is shown that nanostructured films are being generated in the process of wear of the material on air and under the room temperature, and act as the solid-film lubricants. These films consist of chromium and titanium oxides, hydroxides, nitrides, and hydrides. The additional alloying of titanium material allowed a significant raise of its strength and wear resistance within the temperature range of 250–750°C [3].

This paper is aimed at the examination of influence of molybdenum on nanostructured film formation at the high-temperature friction of titanium material Ti–Cr–Mo–TiC on air.

The investigation was carried out on such compositions as Ti, Ti–Cr–TiC, Ti–Cr–Mo–TiC, which were obtained by the pressing and the subsequent sintering in vacuum of 0.13 Pa from powder mixture of electrolytic titanium of the fraction 180 + 40 μm, Cr_3C_2 and Mo of the fraction 10 μm. The porosity of sintered materials was 10–12%. It was sought to obtain a partial dissolution of molybdenum in titanium base within the Ti–Cr–Mo–TiC material. The presence of free molybdenum was supposed to ensure its full participation in oxide films formation process. The molybdenum trioxide formation is known to occur at the temperature of 250°C and to intensify at 500°C [4].

The wear-resistance of sintered materials Ti, Ti–Cr–TiC, Ti–Cr–Mo–TiC is studied. The friction test is carried out according to the scheme of 3 specimens: disc on air under the temperature of 550°C, loading of 3.0 MPa, test time of 1 h and slip velocity of 1.0 m/sec. Disc was produced from nitrated titanium alloy VT-14. The area of samples section is 0.35 cm^2. The wear-resistance of friction pair is estimated according to intensity of samples and disc wear, which is measured accurately to 25.

The structure of friction surface was studied by section perpendicularly to the surface of titanium material friction as well as to the surface of samples oxidized on air under the temperature of 550°C during 1.0 h. The studying process is carried out on X-ray unit URS-50I under the iron radiation.

2. RESULTS AND DISCUSSION

The structure of Ti–Cr–Mo–TiC material is a titanium base, alloyed with chromium and molybdenum, which contains uniformly distributed inclusions of titanium carbide and not fully dissolved inclusions of

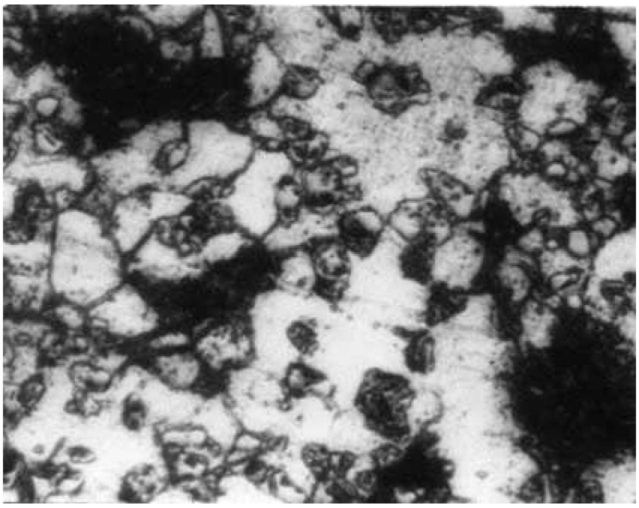


Fig. 1. Structure of Ti–Cr–Mo–TiC material (×500).

TABLE. Wear and friction coefficient of titanium materials under the temperature of 550°C and sliding rate of 1.0 m/sec.

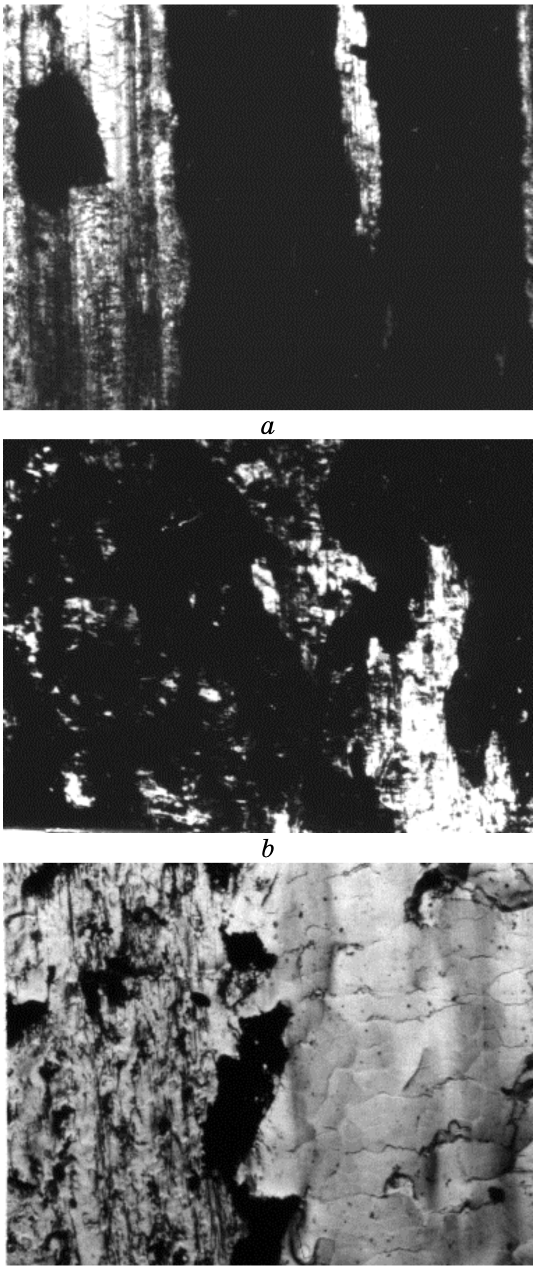
Material composition	Wear intensity, μm/km	Friction coefficient
Ti	1360	0.23
Ti–Cr–TiC	700	0.25
Ti–Cr–Mo–TiC	20	0.26

molybdenum (Fig. 1).

The wear testing (see Table) shows high wear intensity of the friction pair titanium–nitrated titanium, which amounts to 1360 μm/km.

However, there is no pair adhesion as at the friction under the room temperature. The wear of Ti–Cr–TiC material is twice as lower as of titanium, but still high enough and amounts to 700 μm/km. The addition of molybdenum reduced the wear of the pair to 20 μm/km. The friction coefficient remains irrespective of the composition of titanium material and equals to 0.23–0.26. Visual inspection of friction surfaces has showed that there are tears along the friction direction in samples from Ti and Ti–Cr–TiC. That is an evidence of significant plastic flow of surface layer of materials within the friction area. No tears were seen on the samples of materials, which contain molybdenum, due to the influence of this plastic flow on formation of Ti–Cr–Mo solid solution. It was already mentioned in [2] that molybdenum essentially increases the strength of titanium base of material at the specified temperature of 550°C. As a result, the plastic strain of friction surface layer also decreases.

The metallographic study (Fig. 2) reveals the formation of white



a

b

c

Fig. 2. Surface of material friction: Ti (*a*), Ti–Cr–TiC (*b*), Ti–Cr–Mo–TiC (*c*) (×63).

films on the surface of friction. The softening of surface layer reflects the character of its destruction. The destruction of the film by tracks (Fig. 2, *a*, *b*) is seen at significant plastic strain (Ti, Ti–Cr–TiC). If no plastic flow is evident, the film is destructed as a spot (Ti–Cr–Mo–TiC) and probability of its damage is significantly reduced (Fig. 2, *c*).

Phase composition of the film on the surface of friction differs from that on oxidized surface of material. Simple oxides such as titanium, chromium and molybdenum nitrides are generated on the surface of specimens oxidized on air, while mostly oxides of complex composition (hydroxides) are being formed on the surface of friction. The film on the friction surface of titanium consisted of oxides TiO_2 (rutile), Ti_3O_5, Ti_9O_{17}, and nitrides TiN that ensured the sliding of friction pair without adhesion but with the disastrous wear. As opposed to friction under the room temperature, the high-temperature friction of titanium ensured more intensive oxidation and subsequent recovery of destructed oxide films. The main constituent of film of Ti–Cr–TiC material is oxide TiO_2 (rutile) as in case of pure titanium. This material has a little bit lower but still high wear. Chromium oxides Cr_5O_{12}, CrO_2 and compounds like spinel Cr_3Ti_3O were also constituents of film. In comparison with titanium, these constituents contributed to reduction of wear of the Ti–Cr–TiC material. There is no TiO_2 oxide on the friction surface of Ti–Cr–Mo–TiC specimen, and newly generated film contains the following compounds (in order of intensity reduction of the lines on X-ray pattern): $Mo_5O_8(OH)_8$, $Mo_5O_7(OH)_8$, Mo_9O_{26}, Cr_3O_4, and Mo_2N, Cr_3Ti_3O.

Hydroxides and molybdenum oxides prevailed in terms of quantity. Titanium is to some extent engaged in formation of wear-resistant film, which contains mainly oxidation products of such alloying elements as molybdenum and chromium. It also acts as the constituent of complex compound like spinel Cr_3Ti_3O. Brittle oxide was the main constituent of the film on the surface of Ti–Cr–Mo–TiC sample oxidized on air, but no evidence of it was found within the film generated at friction of this material.

The reduction of level of titanium part and increase of activity of alloying elements in the process of films formation at friction is accompanied by the reduction of wear intensity of titanium material and subsequent improvement of lubricate and protective properties of newly generated films.

3. CONCLUSIONS

The presence of molybdenum in the titanium material Ti–Cr–Mo–TiC contributes to the formation of solid films with high lubricate and protective properties under the conditions of high temperatures. These films contain mainly hydroxides and molybdenum oxides.

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