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Arc erosion behavior of La-doping titanium-zirconium-molybdenum alloy

Ping Hu [a, b, *], Bo-liang Hu [a], Kuai-She Wang [a], Fan Yang [a], Rui Song [a], Zhi-Tao Yu [c], Qiang Wang [a], Wei-Cheng Cao [b], Dong-Xin Liu [b], Geng An [b], Lei Guo [c], Hailiang Yu [d]

[a] *School of Metallurgy Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China*
[b] *Jinduicheng Molybdenum Co., Ltd., Xi'an 710068, China*
[c] *Ruifulai Tungsten & Molybdenum Co., Ltd, Xi'an 721914, China*
[d] *School of Mechanical, Materials and Mechatronics Engineering, University of Wollongong, NSW 2522, Australia*

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ABSTRACT

La-doping titanium-zirconium-molybdenum alloys have good arc erosion resistance performances, but there is no research about the changes during the arc erosion. Arc erosion characteristics of La-doping titanium-zirconium-molybdenum alloys after 5000 operations under direct current 20 V, 15 A and resistive load conditions were investigated using a JF04C test system. The results indicated that the probability distribution and change trend of arc energy and arc time during 5000 operations were similar and the relationship between arc time and arc energy followed exponential function. The change of arc energy with test number was consistent to electrical resistance. Oxide particles, crater and cracks defects were discovered on the surface of La-doping titanium-zirconium-molybdenum alloy. The electrical resistance change is mainly concerned with the surface.

1. Introduction

Titanium-zirconium-molybdenum (TZM) and La-doping molybdenum (La-Mo) alloy are the two of most widely molybdenum alloys. Rare earth doped in molybdenum alloy could improve the strength of molybdenum alloy. La-doping titanium-zirconium-molybdenum (La-TZM) alloys have excellent performances such as high temperature strength, adequate thermal conductivity, low contact resistance and good arc erosion resistance. Molybdenum alloy was widely used in the electronics industry, aerospace and energy industry [1–4].

With the development of rocket missile technology, space technology, aviation technology, nuclear power technology and other cutting-edge technology, the material requires higher operation temperature (above 1500 °C) and good performance of oxidation resistance and ablation properties [5]. The refractory molybdenum alloy has high melting point (2620 °C) and high temperature mechanical properties, and the density is lower than that of other refractory metals, such as tungsten alloy, so it meets the field of cutting-edge technology [4]. When TZM molybdenum alloy was used as cathode in electronic tube electronic, its temperature was extremely high due to the electron emission and ion bombardment, and it often exceeds the melting point of cathode material, therefore, the cathode was ablated seriously and was damaged easily.

Qian et al. [6] showed that the addition of La_2O_3 was useful to improve the properties of CuW alloys and the CuW-La_2O_3 composites which had excellent arc erosion resistance. Many literature reported that rare earth would improve the comprehensive properties of silver alloys, such as Ag-Ce, Ag-Y and Ag-La [7,8]. When 0.1%–0.5% Ce was added to Ag-Cu electrical contact materials, the corrosion resistance of arc and welding resistance ability was improved greatly.

For molybdenum and molybdenum alloy, it was easy to be oxidized at high temperature [9]. Yang et al. [10] proved that doping lanthanum could improve the oxidation resistance of TZM alloy. However, the arc erosion of molybdenum alloy was not studied when it was applied in electronic electrical industry. In this study, La $(NO_3)_3$ was doped into molybdenum matrix by liquid–solid doping method, followed by the fabrication of La-TZM alloys composites by sintering. The arc erosion mechanism of La-TZM alloy was discussed based on the morphology analysis of the worn surface.

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* Corresponding author. School of Metallurgy Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China.
E-mail address: huping1985@126.com (P. Hu).

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Table 1
Design composition of the La-TZM alloy (ω/%).

Ti	Zr	$C_{18}H_{36}O_2$	$La(NO_3)_3$	Mo
0.5	0.1	0.25	1	Bal

2. Experimental

2.1. Preparation of La-TZM alloy

Molybdenum powder (99.95%, 2.0–3.5 μm), TiH_2 powder (96%, ≤10 μm), ZrH_2 powder (96%, ≤10 μm), La $(NO_3)_3$ (analytical reagent) and $(C_{18}H_{36}O_2)$ respectively, were used as the starting materials. The chemical composition is shown in Table 1.

The flow diagram of manufacture processes is presented in Fig. 1. The molybdenum powder was subsequently mixed with TiH_2 and ZrH_2 powders for 2 h. The organic carbon was firstly dissolved in alcohol, and then added to the mixed powders. This mixture was dried in a vacuum furnace at 70 °C for 4 h. The alloy powders were milled for 2 h at the rotational speed of 240 rpm and the ratio of ball feed was 2:1. After the treatment, the mixed powders were compressed with 150 MPa, followed by sintering at 1950 °C for 4 h in hydrogen atmosphere [11].

2.2. Experimental conditions and characterization

Electrical contacts were tested by JF04C electrical contact materials testing system with breaking measurement mode. The experimental conditions are shown in Table 2. The load current was set at DC 20 V 15 A. The size of the test sample was φ3 mm × 15 mm.

The form of contacts is shown in Fig. 2. Contacts are divided into the top movable contact and the below static contact. As shown in Fig. 2a, at the beginning, the contacts are closed, and then the contacts begin to separate and produce arc in Fig. 2b. At last, the contacts close and the arc disappears in Fig. 2c.

The sintering density of La-TZM alloy was measured by the displacement method. The electrical resistivity was tested by a DC low-voltage conductivity instrument (TH2513A, China). The hardness of La-TZM alloy sintered compact was tested with digital Vickers hardness tester (WILSON 401MVD, China). Electronic universal tensile machine (WDW300, China) was used for the tensile strength and elongation. The mass losses were measured using an electrical scale. By using the scale, mass changes of more than 0.1 mg can be measured accurately. (CP2245, China). The microstructure was characterized by both an optical microscope (POLYVAR-MET) and a scanning electron microscope (JSM-6460LV) equipped with an energy dispersive energy diffraction spectroscope (EDS). X-ray Diffractometer (Bruker D8 advance, Germany) was used to test the phase on the surface of the material substance formed after ablation.

3. Results

3.1. Electrical and mechanical properties of the samples

Electrical and mechanical properties are represented in Table 3. The density and Vickers hardness are increased by 1.7% and 36.3%, respectively. Tensile strength and elongation increased by 16.7% and 23.8%. The electrical resistivity of La-TZM alloy decreases 34.6%, compared to TZM alloy. This observation can be explained as La_2O_3 has a poor electrical conductivity in comparison with Mo. Moreover, addition of La_2O_3 can inevitably cause lattice distortion. According to the free electron theory [12], dislocation and point defects destroy the ideal crystal lattice, resulting in the increased scattering of free electron in these sites. On the other hand, La_2O_3 addition can improve the spatial distribution of Mo, and this microstructural change helps to improve the electrical conductivity. These combined effects result in the less decreased electrical resistivity [6].

Table 2
Experimental conditions.

Contact material	La-TZM
Circuit condition	20 V–15 A
Number of operations	5000
Switching mode	DC
Contact force, N	10
Surrounding gas	Air
Test interval, ms	100
Closing drive voltage, V	2.5
Turn driving voltage, V	−2.4

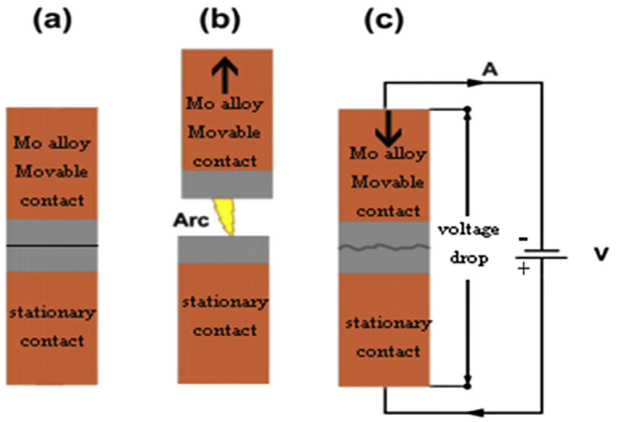

Fig. 2. The form of contacts model: (a. contact closed, b. contact separated form electric arc, c. contact closed again).

As shown in Fig. 3a and b, the size of La_2O_3 particles is different in the molybdenum substrate. The large particle size is about 1.5 μm (Fig. 3b), but the small particles is only about 0.1 μm (Fig. 3a). The second phase particles exists at both the grain boundary and the grain interiors. Tungsten alloys added with rare earth oxides have excellent resistance to arc burning and good arc stability [13,14]. The La_2O_3 in the surface has a good ability of electron emission and the La_2O_3 particle fracture will absorb energy, so La doping can reduce the arc energy.

3.2. Electrical contact physical phenomena

The changes of arc energy, arc time, closed pressure and contact

Fig. 1. La-TZM alloy sintered material preparation process flow.