Study on Electrochemical Effect in Electrochemical Grinding of Tungsten Alloy

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Keywords: electrochemical grinding, tungsten alloy, electrochemical effect

Abstract. Tungsten and its alloys are used in various fields owing to their excellent physical, mechanical and chemical properties. However, they are difficult to be machined due to their high hardness and brittleness. Electrochemical grinding (ECG) is a promising process to machine the hard and brittle metals with the assistance of electrochemical reaction in the grinding. In this paper, the electrochemical effect of tungsten alloys in two different electrolytes, $NaNO_3$ solution and Na_2CO_3 solution, are investigated. The results show that $NaNO_3$ solution has a good passivation effect on the tungsten alloy. However, the passive film obtained from $NaNO_3$ solution is too thin to be grinded precisely. The Na_2CO_3 solution produces a porous corrosion layer with large enough thickness, which can guarantee the electrochemical action and mechanical abrasion reach a balanced state in ECG. Therefore, Na_2CO_3 solution is more suitable for the ECG of the tungsten alloy.

1. Introduction

Tungsten has excellent physical, mechanical and chemical properties, such as high melting point (3650K), high thermal conductivity, low thermal expansion, low steam pressure, good electric conductivity, strong electron emission ability, etc. Due to these excellent properties, tungsten and its alloys are used in the fields of nuclear industry, integrated circuits, precision measuring equipment, hot electron emission and some acidic and high temperature environments [1.2.3]. However, the brittleness of tungsten and tungsten alloy makes them difficult to process [4.5]. As a result, the application of tungsten and its alloys in a wider field is restricted.

Electrochemical grinding is a composite processing method, which combines mechanical process with electrochemical effect [6]. Because of the electrochemical action, ECG can be used to process brittle materials with high hardness. Compared to the traditional grinding, ECG has many advantages, such as low induced stress, large cutting depth, and increased wheel life, etc. [7]. However, the balance between mechanical and electrochemical actions in the ECG progress has a great effect on the surface quality and form accuracy [8]. If the electrochemical action is much stronger than the mechanical action, the surface roughness will deteriorate. Conversely, if the electrochemical action is too weak, it will cause the increase of grinding force and residual stress. Therefore, the electrochemical action in the process of tungsten alloy ECG is investigated in this paper to provide a reference for the subsequent processing.

Usually, the properties of electrolytes are basically understood by the anodic polarization curve experiment.[9] In order to find out the specific electrochemical actions of this two kinds of electrolyte, $NaNO_3$ solution and Na_2CO_3 solution, on the tungsten alloy, the experiment of anodic treatment was carried out.

2. Experiment

The material components of the workpieces used in this paper analyzed by X-Ray Fluorescence (XRF) are shown in Table 1.

Table 1 Composition of the workpieces

Analyte	**W**	**Ni**	**Fe**
Propotion[wt.%]	96.67	1.97	1.36

2.1 Potentiodynamic polarization curve experiment

Potentiodynamic polarization curve is a very important research method for the study of electrochemical action of metal anodes. Based on the anodic polarization curve, we can study the polarization rule of metal anode, determine the polarization characteristics of metal, and study the effect of different electrical parameters and electrolyte on the anodic polarization process.

The electrochemical test system adopts three-electrode system to test the polarization curve. It is made up of working electrode, auxiliary electrode and reference electrode. The working electrode is the workpiece of tungsten nickel iron alloy, which is cut into 15cm×15cm×5cm by Wire Electrical Discharge Machining (WEDM). In the pretreatment process, the workpiece is lapped and polished by emery papers and diamond spray successively to be surface-finished, then soaked in anhydrous ethanol and washed by ultrasonic cleaning machine to remove the residual oil. The area exposed to the electrolyte is 1 cm^2. The auxiliary electrode is a platinum gauze with the size of 20 mm×20 mm. The reference electrode is a saturated calomel electrode (SCE). Two kinds of electrolyte, 20 wt.% $NaNO_3$ solution and 20 wt.% Na_2CO_3 solution, was tested respectively.

The electrochemical workstation is the PARSTAT 2273 of Princeton. The temperature of the experiment is 25 ℃, and the scanning rate is 1 mV/s.

2.2 Anodic treatment experiment

The experimental system for anodic treatment is shown in Fig.1. The electrochemical reaction cell is designed to imitate the electrochemical process in ECG processing. The experimental parameters are shown in Table 2.

The surface morphology of the workpiece after polarization treatment is observed by Scanning electron microscope (SEM, FEI QUANTA450). The surface elements composition is measured by the incidental Energy Dispersive Spectrometer (EDS). The thickness of the passivation film after anodic treatment in the $NaNO_3$ solution is measured by the ellipsometry (Woollam M-2000DI). The thickness of the corrosion layer after anodic treatment in the Na_2CO_3 solution is observed by the optical microscope (OLYMPUS MX40).

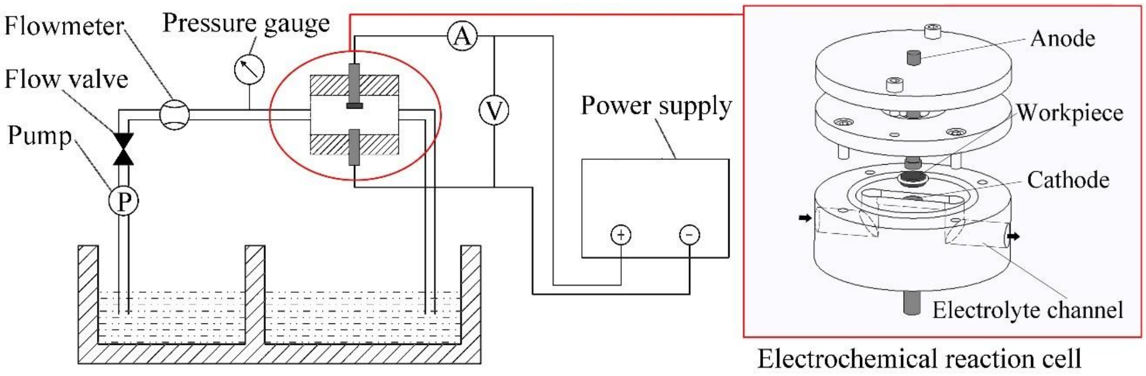


Fig. 1 Anodic treatment experimental system

Table 2 Experimental parameters

Parameters	Value
Temperature	25 [℃]
Voltage	10 [V]
Inter-electrode gap	0.8 [mm]
Duration	90 [s]
Electrolyte	20 wt.% $NaNO_3$ solution
	20 wt.% Na_2CO_3 solution

3. Results and discussion

The polarization curves of the tungsten alloy in these two kinds of electrolytes are shown in Fig. 2.

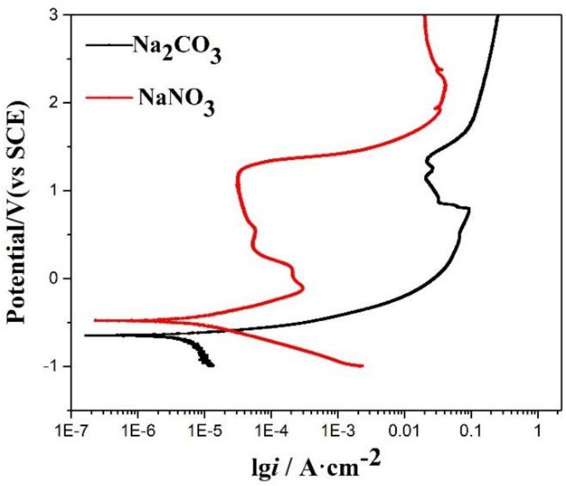
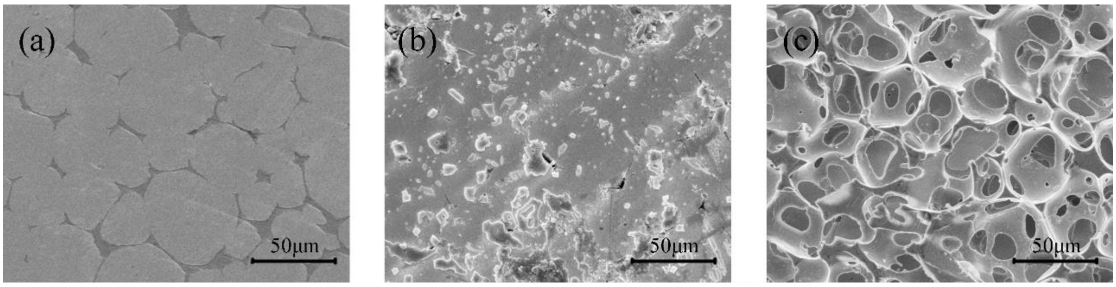


Fig. 2 Potentiodynamic polarization curves of the tungsten alloy

From polarization curves, the passivation potential interval of the tungsten alloy in the $NaNO_3$ solution is 0.3 V ~ 1.2 V. Meanwhile, the current density in the passivation interval is very small. The passivation potential interval of the tungsten alloy in the Na_2CO_3 solution is 0.9 V ~ 1.4 V, which is much shorter than that in the $NaNO_3$ solution. Furthermore, its passivation current density is higher than that in the $NaNO_3$ solution. The curves shows that for this kind of tungsten alloy the passivation effect of $NaNO_3$ solution is much more significant than that of Na_2CO_3 solution.

The surface morphology of the workpieces before and after polarization treatment is shown in Fig. 3. The surface element composition before and after polarization treatment is shown in Table 3.



(a) Initial surface (b) Treated in the $NaNO_3$ solution (c) Treated in the Na_2CO_3 solution

Fig. 3 SEM photos of the workpieces surface before and after anodic treatment

Table 3 The surface element composition

Elements	**W[wt.%]**	**Ni[wt.%]**	**Fe[wt.%]**	**O[wt.%]**
Initial surface	93.99	3.17	1.41	1.43
Treated in $NaNO_3$ solution	82.83	0.20	0.88	16.09
Treated in Na_2CO_3 solution	27.60	47.40	19.72	5.28

Fig. 3 (b) shows that a layer of film is formed on the surface of the workpiece after passivation in the $NaNO_3$ solution. The proportion of oxygen on the surface increased significantly. Comparatively, from the Fig. 3 (c), the porous structure is generated on the surface after the polarization treatment in the Na_2CO_3 solution. In addition, the proportion of tungsten on the surface decreases significantly.

This experiment results are in well agreement with the polarization curves. For tungsten alloys, the $NaNO_3$ solution has good passivation performance, which makes the surface of the anode be passivated. It forms a layer of compact passive film with the main component of tungsten oxide. On the contrary, the Na_2CO_3 solution is a kind of electrolyte with quite intense activation. It causes the dissolution of tungsten and makes a porous reaction layer on the surface of the anode.

The thickness of the passive film after passivation in the $NaNO_3$ solution is approximately 50nm. This thickness is far smaller than the minimum cutting depth of the machine tools. Therefore, it is difficult to adjust the balance between the electrochemical action and the mechanical action. On the contrary, the corrosion layer formed in the Na_2CO_3 solution has enough thickness, which is approximately 20 μm, as shown in Fig. 4. From the theoretical point of view, if the cutting depth equals to the thickness of the reaction layer, the balance between the electrochemical action and the mechanical action is considered to be realized.

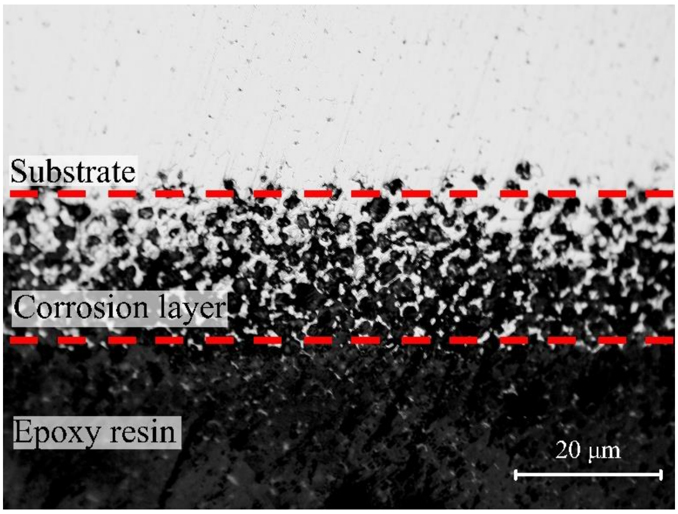


Fig. 4 The cross section photo of the corrosion layer formed in the Na_2CO_3 solution

4.Conclusion

(1) For tungsten alloy, the $NaNO_3$ solution is a kind of passivating electrolyte, and the Na_2CO_3 solution is a kind of activating electrolyte.

(2) In the $NaNO_3$ solution, a layer of compact passive film is formed on the surface. In the Na_2CO_3 solution, the tungsten alloy is corroded, and a porous corrosion layer structure is formed on the surface of the workpiece.

(3) The thickness of the passive film is too thin to be applied on the assistance of grinding. The thickness of the corrosion layer is enough for ECG. As a result, the Na_2CO_3 solution is more suitable for the ECG of the tungsten alloy.

Acknowledgement

This research is supported by Science Challenge Project (No. JCKY2016212A506-0201), National Key Basic Research and Development Program, (No. 2015CB057304) and Science Fund for Creative Research Groups of NSFC, (No. 51621064). We extend sincere thanks to all project staff and researchers.

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