https://doi.org/10.33261/jaaru.2019.26.1.019 *Association of Arab Universities Journal of Engineering Sciences (2019) 26(1): 145–149*

Association of Arab Universities Journal of Engineering Sciences
مجلة اتحاد الجامعات العربية للدراسات والبحوث الهندسية

The Tribological and Chemical Properties of Ni-W Alloy Electrodeposition

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Published online: 31 March 2019

Abstract—The Electrodeposition process has been used to substrate Ni-W alloy on low carbon steel by using ammonical citrate bath. The influence of deposition condition by variation of current density (0.04-0.2 A/cm2) and solution temperature (60-70 °C), on the mechanical and chemical properties such as (microhardness, wear resistance, residual stress and chemical resistance) was studied. Results show that the current efficiency has the major influence on the tungsten content in the alloys which reflected to the properties of the deposits.

Keywords— Ni-W alloy, Tungsten content, Wear resistance, Microhardness, Corrosion resistance and residual stress.

1. Introduction

The improvement of wear resistance and hardness is an important goal for surface enhancement technologies, the attention on nickel tungsten alloy electroplating has been increased in recent years due to their mechanical properties and corrosion resistance. [1][4]Tungsten cannot be electrodeposited from aqueous solution of tungsten containing compounds, and however, it can be codeposited with iron group metals it is called induced deposition. Only iron, cobalt and nickel are the induced metals that can be codeposited with tungsten. [2] In recent years, the micro-devices require more materials with excellent physical and mechanical properties with the rapid development of micro electro mechanical systems (MEMS) technologies. [3 [

The objective of this work is to investigate the effect of current density and solution temperature on the electrodeposition process used to substrate Ni-W alloy on low carbon steel sheet.

2. Experimental work

Nickel-Tungsten alloys were electrodeposit from aqueous solution containing: nickel sulfate, sodium tungstate as a source of nickel and tungsten respectively, sodium citrate as a complexing agents, ammonium chloride as a complexing agents and to improve the faradic efficiency. The concentration of Ni-W alloys bath constituents are given in table (1). The pH was measured by digital pH meter and adjusted to a value of (8.0 ±0.2) through addition of H2SO4 and NaOH.

Table 1: The Ni-W alloy bath concentration.

Margin	Margin size
Nickel Sulfate ($NiSO_4.6H_2O$)	0.65 M
Sodium Tungstate ($NaWO_4.2H_2O$)	0.145 M
Sodium Citrate ($Na_3C_6O_7H_5.2H_2O$)	0.5 M
Ammonium Chloride (NH_4Cl)	0.5 M

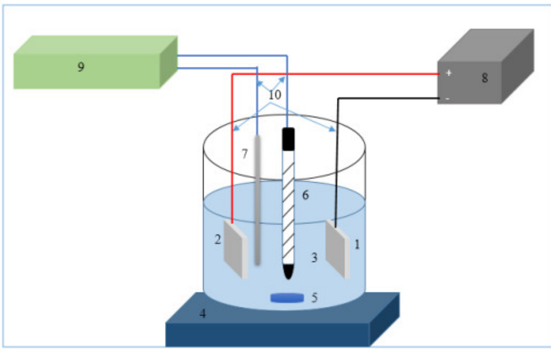

Figure 1: Schematic diagram of electrodeposition bath; (1) cathode, (2) anode, (3) bath solution, (4) magnetic

stirrer, (5) magnetic bar, (6) heater, (7) thermocouple, (8) power supply, (9)heat controller, (10) connecting wires.

A sheet of low carbon steel with dimensions 5 cm^2 and thickness 0.2 cm was used as cathode. Deposition was carried out at current density (0.04, 0.08, 0.12, 0.16 and 0.2) Amp/cm^2 and Temperature (60, 70) °C. The deposition thickness was fixed at 50µm. The anode-to-cathode distance was approximately 5 cm as shown in Fig (1).

The microhardness of the deposits was measured by using a (LARYEE microhardness tester) with load 100 (g) for 15 (sec) while the wear resistance of the deposit was measured by (Ball-on-disk) mechanism shown in Fig (2) with load (150g) for (1.30min). The residual (internal) stress is measured by bent strip method Fig (3). The corrosion test is adopted by Tafel extrapolation method.

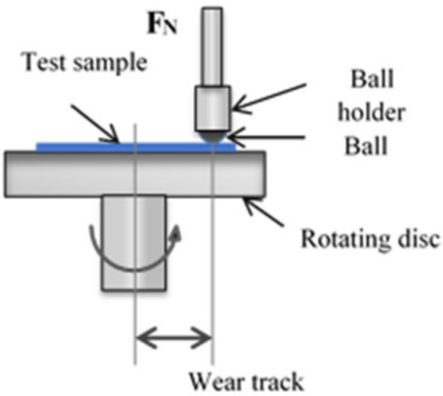

Figure 2: Sketch of (ball-on-disk) wear test.

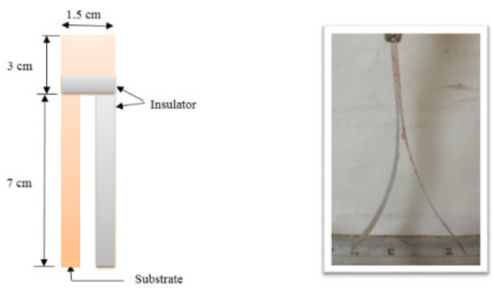

Figure 3: The bent strip method test.

3. Results and Discussion

3.1 *Microhardness Test*

The microhardness of Ni-W alloys deposit were ranging between (600-1000) MPa, which is considered three times higher than the conventional Ni deposit (250-300) MPa. This improvement of the microhardness was related to the tungsten and its percentage in the alloy that seen clearly in Fig (4). The microhardness increased with the increasing of tungsten content with ignoring the variation of current density as shown in the figure. The increasing in the microhardness was related to the decreasing of crystal size, which is related to the tungsten content in the alloy. Also the variation of deposition temperature showed that 60° C was better in result compared with 70° C due to percentage of Tungsten in the alloy.

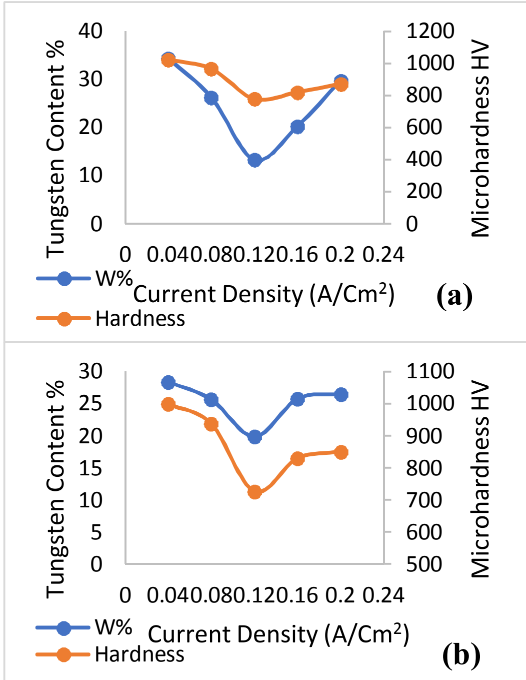

Figure 4: The relation between the tungsten content and the hardness value for Ni-W alloys at different temperature; (a) 60 °C, (b) 70 °C.

3.2 *Wear Resistance Test*

The wear rates for Ni and Ni-W alloys deposit is tested at room temperature using ball-on-disk mechanism. The wear rate is calculated according to the following relationship:

$$W.R = \frac{\Delta w}{S_D} \quad \text{(g/cm)} \tag{1}$$

$$S_D = 2\pi rnt \tag{2}$$

$$\Delta w = w_1 - w_2 \tag{3}$$

Where,

W.R is sliding wear rate (g/min).

w_1 is weight of sample before testing (g).

w_2 is weight of sample after testing (g).

S_D is sliding distance (cm).

r is wear track radius(cm).

n is number of cycle (cycle/min).

t is test time (min).

Results show that wear rates of Ni-W alloy deposit was lower than Ni deposit and that related to the Tungsten percentage in the alloys deposit as shown in Figs (5),(6).

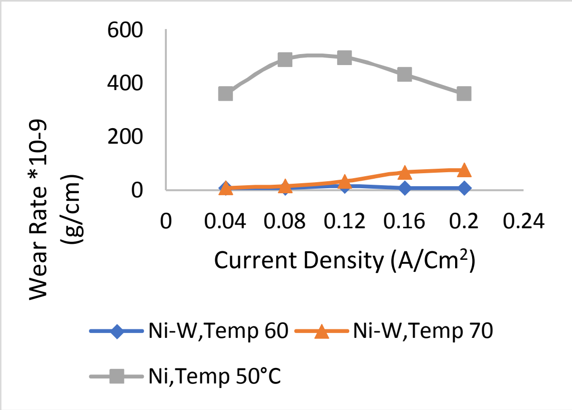

Figure 5: The variation of wear rate with current density for pure Ni, Ni-W alloys.

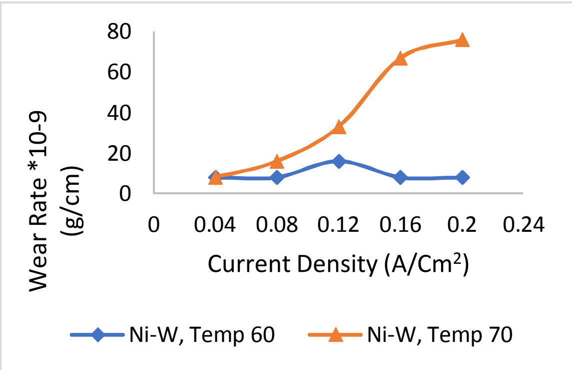

Figure 6: The variation of wear rate with current density for Ni-W alloys.

The low wear rate at low current density range is attributed to the high tungsten content. While at high current density range although an increase in tungsten content, the wear rate is increased and is related to the increasing of residual stress. Also the wear rate of coating are in conjunction to the microhardness as could be seen in Fig (7).

3.3 *Residual (Internal) Stresses*

The residual stresses of the Ni-W alloys deposit were tested using bent strip method by applying Stoney's equation [5] [6].

$$\sigma = \frac{E_\circ d^2}{6l^2(1-\nu_\circ)}\frac{df}{dt} \qquad (4)$$

Where,

d, t: thickness of the substrate and the deposit, respectively.

l, f: the length of the legs and the spread distance between the legs.

E_o: Young's modulus of the substrate E_{Cu}: 130 GPa.

ν_o: Poisson ratio of the substrate, ν_{cu}=0.350.

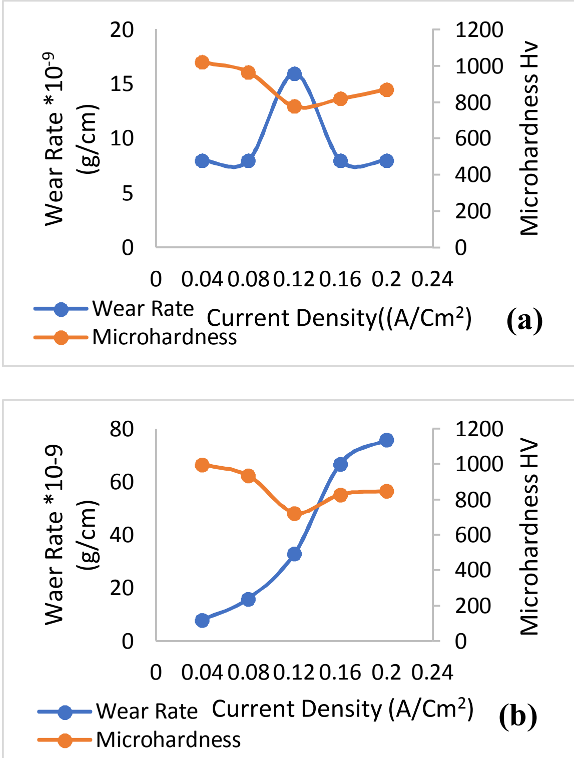

Figure 7: The relation between the wear rate and microhardness for Ni-W alloys at different bath temperature; (a) 60° C, (b) 70° C.

The relation between the residual stress of Ni-W alloys deposit and the current density used in the research at different temperature are displayed in Fig (8). According to the experimental result, the residual stress seems to increase with increasing the current density also it decreases with increasing bath temperature.

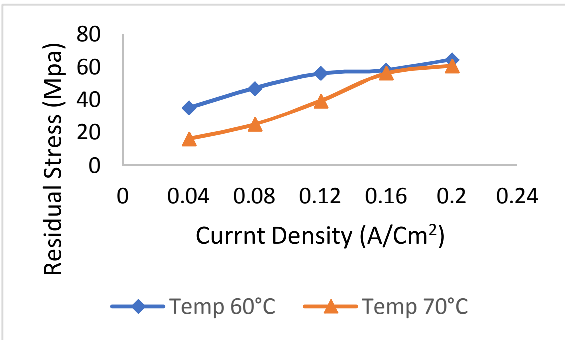

Figure 8: The effect of current density and solution temperature on the residual stress.

Fig (9) showed clearly the proportional relation between wear rate and residual stress of Ni-W alloy deposit with current density

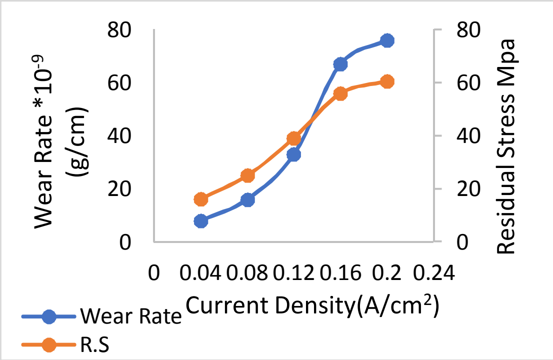

Figure 9: The relation between the wear rate and the residual stress at bath temperature of 70° C.

3.4 *Corrosion Resistance Test*

The corrosion rates for Ni and Ni-W alloys deposit are tested by computer controlled potentiostat/ galvanostat (DY2323, made by Digi-ivy, Inc.), used for the voltammetry measurement. The effect of adding tungsten to the nickel solution to form Ni-W alloy deposit on corrosion resistance was totally observed in fig (10).

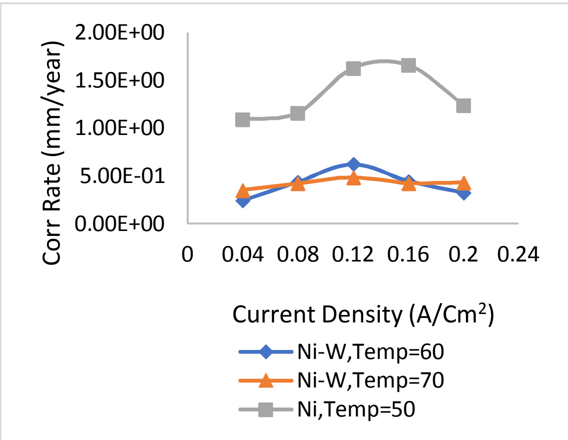

Figure 10: The relation of corrosion rates with the current density for pure Ni and Ni-W alloys.

It can be seen from the comparison the corrosion rate of Ni-W alloys lowers than pure Ni and that due to the presence of Tungsten and it contents on the corrosion behavior of the deposit and that confirmed by Esther. [7].

4. Conclusion

Based on the experimental results presented in this work, it is possible to draw the following conclusions:

1. The sample with current density 0.04 Amp/cm^2 and 60°C bath temperature was the best according to tungsten content.
2. The tungsten content can be controlled by controlling deposition parameters to be suitable for certain application.
3. An increase in tungsten content enhance the mechanical properties of the deposited coating.

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الخصائص الأحتكاكية والكيميائية لسبائك **Ni-W** المرسبة بواسطة الترسيب الكهربائي

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نشر في: 31 آذار 2019

الخلاصة – أستخدمت طريقة الترسيب الكهربائي لتحضير سبائك من النيكل- تنغستن على قاعدة من الحديد واطئ الكاربون بأستخدام أحواض تحتوي على الأمونيا والسترايت. حيث تم دراسة تأثير متغيرات عملية الطلاء من حيث كثافة التيار Amp/cm^2 (0.2-0.04) ودرجة حرارة المحلول°C (60- 70) على الخصائص الميكانيكية والكيميائية مثل (الصلادة المايكروية، مقاومة البلى، الاجهاد الداخلي و المقاومة الكيميائية. أظهرت النتائج أن كفاءة التيار لها التأثير الأكبر على محتوى التنغستن في السبيكة والذي أنعكس على خصائص المترسب.

الكلمات الرئيسية –.