Effect of Current Density and Bath Temperature to The Corrosion and Wear Behaviour of Tungsten Carbide - Nickel Electrodeposition Coating

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Abstract. The composite (ceramic-metal) coating has become a desired coating due to its higher wear and corrosion behaviour compares to metal coating only. This study focuses on the effect of the deposition parameter which is the current density and bath temperature on the corrosion and wear behaviour of the coating. As the current density and temperature will affect the movement of the electron during deposition, it is important to evaluate its effect on the coating thickness and its wear and corrosion performance. The mild steel was used as the substrate and nickel-tungsten carbide (Ni-WC) as the coating. Watts’s bath was used as an electrolyte with the addition of 25 g/l WC. 0.2 A/cm² and 0.5 A/cm² has been chosen as the current density while 30 °C and 50 °C as their temperature. The coating was characterised using a scanning electron microscope (SEM) and x-ray diffractometer (XRD). Immersion test and weight loss test was used to evaluate the corrosion and wear behaviour respectively. The 3 g/l silicon carbide was used as abrasive materials in the wear testing. Vickers micro-hardness tester was used for hardness property evaluation. It is found that higher current density and higher bath temperature results in lower corrosion and wear rate which shows higher resistance.

1. Introduction

Composite electrodeposition is where the fine particles of metallic, non-metallic materials or polymers were co-deposition within the coating to improve material properties like wear resistance, lubrication or corrosion resistance. The metal matrix composite coating layer has led to technology interest in the production of new composite materials with improving and well-controlled properties via substituting micro and nano-sized particles [1]. Embedding the ceramic materials into the nickel coating has been found to increase its wear [2-5] and corrosion resistance [4,5]. Due to its great wettability & solubility in binder metals, WC has been trendy among other carbides. Besides, it also has high strength, high toughness and plasticity which would contribute to the improvement of the coating properties [6].

It was found in the Ni-WC coating that dense coating structure on the deposits is because of high current density while low current density resulting in low deposition rate [7,8]. Growth mechanisms, nucleation and layer thickening are steps in the electrodeposition process. In comparison to the growth process, the nucleation is increased by high current density. This proved that current density is contributed to producing a uniform coated specimen in the electrodeposition process [9,10].
Optimizing the condition of electrodeposition of nickel coating also can be disputed especially in the effect of bath temperature. This is because the bath temperature stands as a crucial factor in the development of the grain size of the coatings [11,12]. The particular process of diffusion may affect electrodeposition. It is can be referred to as the diffusion of metal ions in the electrolyte which involves the evolution of atoms on the electrode surface and the mobility of grain refiners. As reported, it depends on the bath temperature as well as the structure of the deposits has been affected. The properties of the coatings such as deposition rate, quality of the deposits might be harmed if being charged more than 5 °C from the optimum temperature [13].

Thus, this study will evaluate the effects of current density and bath temperature during deposition on the morphology, hardness and wear behaviour of the Ni-WC coating.

2. Methodology
The mild steel was used as the cathode and the graphite rod as the anode. The mild steel was grind and polish before the electrodeposition process. The electrodeposition process of Ni–WC was performed using an electrolytic solution containing 200 g/L nickel sulphate (NiSO$_4$.6H$_2$O), 20 g/L nickel chloride (NiCl$_2$.6H$_2$O), and 20 g/L boric acids (H$_3$BO$_3$). The pH of the solution is 4. After the bath attained the specified temperature (30 °C or 50 °C), the WC powder with a concentration of 25g/l was added to the bath. The bath was stir during the deposition process for 60 minutes by using a magnetic stirrer. The current density used are 0.3 A/cm$^2$ and 0.5 A/cm$^2$. Table 1 shows the samples designation. The sample was characterised using SU1510 Hitachi scanning electron microscope (SEM) and D8 Advance X-ray diffractometer (XRD).

| Sample  | Bath temperature (°C) | Current density (A/cm$^2$) |
|---------|------------------------|----------------------------|
| 30S0.3A | 30                     | 0.3                        |
| 30S0.5A | 30                     | 0.5                        |
| 50S0.3A | 50                     | 0.3                        |
| 50S0.5A | 50                     | 0.5                        |

2.1 Coating testing
The hardness of the coating was evaluated using Vickers’s micro-hardness (Shimadzu, Japan) tester with 100g indentation load for 10 s. The weight-loss method was used for evaluating the wear behaviour of the coating. For wear behaviour analysis, a modified automated grinder was used with 3 g/l silicon carbide as the slurry. 5 N load was applied during the test. The weight loss was measure every 100 m distance until 300 m. The slope of weight loss against the distance graph was used as the wear rate. The corrosion test was conducted using an immersion test with 0.5 M of sulphuric acid as the electrolyte. The sample was monitor every three days.

3. Results and Discussion
Figure 1 shows the surface morphology of the coatings. With higher current density (Figure 1b and 1d), the turtle-like structure of the surface is smoother than the lower current density (figure 1a and 1c). It is difficult to distinguish the interface between the Ni matrix and WC particle due to the small size of the carbide [14]. The thickness of the coating is in the range of 67 μm to 133 μm, which increases by increasing temperature and current density.
Figure 1. Surface morphologies of the coating (a) 30S0.3A (b) 30S0.5A (c) 50S0.3A (d) 50S0.5A

Figure 2 shows the x-ray spectrum for the coating deposited at 50 °C with different current density. The nickel (ICDD = 00-004-0850) and tungsten carbide (ICDD = 01-081-8964) was detected in the coating. Similar phases were also detected for coating at 30 °C.

Figure 2. X-ray Spectrum for samples coated at 50 °C

Figure 3 shows the microhardness value of the coating. It can be seen that increasing the temperature and current density [15] will increase the hardness of the coating. However, the increase in current density shows the highest percentage of value which is up to ± 23 % compares to an increasing temperature which is only ± 2 % increases.
The weight loss of the coating for different distance is shown in figure 4. It is clearly seen that all coatings are following Archard’s Law which stated that the worn materials are proportional with the sliding distance [16]. The wear rate was taken as the gradient of the best fit of this plot.

Table 2 shows the wear rate results. It shows that the wear rate reduces with increasing of current density and temperature which is consistence with previous finding [15]. Increasing the current density reducing the wear rate by about 30% while increasing the temperature only decrease by about 8% of the wear rate. This shows that changing the current density will result in larger changes in the coating property compares to the temperature.
Table 2. Wear rate of coating with different current density and temperature.

| Coated sample | Wear rate, mg/m |
|---------------|-----------------|
| 30S0.3A       | 0.371           |
| 30S0.5A       | 0.244           |
| 50S0.3A       | 0.338           |
| 50S0.5A       | 0.240           |

Figure 5 shows the corrosion rate with different bath temperature and current density. Increasing the bath temperature and current density reducing the corrosion rate shows an improvement of the corrosion resistance. Similar results were found by a researcher that bath temperature increases the corrosion resistance of the coating [12].

4. Conclusion

The Ni-WC coating has been successfully deposited with different bath temperature and current density. It can be concluded that the hardness, wear-resistance and corrosion resistance of the coating increase with increasing current density and bath temperature. It is also found that the percentage of increases value for hardness, wear resistance and corrosion resistance is higher with increases in current density compared to temperature. This shows that current density has a higher influence on the coating properties compares to the temperature.

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