

Evaluation of Corrosion and Wear Behaviour of Nickel Tungsten Carbide Electrodeposited with Different Tungsten Carbide Concentration and Current Density

Zakiah Kamdi^{1*}, Nur Azam Badarulzaman¹, Muhammad Adeeb Reezan Sukkeri²,
Muhammad Syafiq Hassan², Mohamed Nasrul Mohamed Hatta¹ and Ainun Rahmahwati
Ainuddin¹

¹ Nanostructure and Surface Modification (NANOSURF),
Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia.
² Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia.

Received 30 September 2017; accepted 2 March 2018; available online 1 August 2018

DOI: <https://10.30880/jst.2018.10.02.006>

Abstract: Cermets (ceramic-metal) materials have been popular for wear and corrosion application due to their ability to withstand both conditions. In current work, cermets tungsten carbide-nickel (WC-Ni) composite coating has been deposited using direct current (DC) electrodeposition in Watt's bath on mild steel. The current density were varied at 0.08 Acm^{-2} , 0.14 Acm^{-2} and 0.20 Acm^{-2} while others parameter i.e. bath temperature and stirring rate were remain constant. Three carbide concentrations were used that are 15 g/l, 20 g/l and 25g/l. This work is focusing on determining the effect of current density and carbide concentration to the wear and corrosion behaviour of WC-Ni cermet coating. The surface morphology, microstructure and elemental composition were analysed using scanning electron microscope (SEM) with energy dispersive spectroscopy (EDS). The wear and corrosion behaviour were evaluated using weight loss methods and three electrode electrochemical tests respectively. The abrasive wear was done against 800 grit silicon carbide paper. While for corrosion test, two types of electrolytes that were used are 0.5 M sulphuric acid and 3g/l sodium chloride at room temperature. The micro-hardness of the coating was analysed using Vickers micro-hardness tester with 100g load. It is found that, the wear resistance increases with increasing of carbide content and current density. The corrosion resistance was also increase with increasing of carbide content. For current density, it is slightly decrease of corrosion resistance after deposition at 0.20 Acm^{-2} due to uneven distribution of carbide. The hardness of the cermet coatings were increase with increasing of carbide content and current density. It can be concluded that with 25g/l carbide and at 0.14 Acm^{-2} current density shows the optimum combination to achieve high wear and corrosion resistance.

Keyword: Electrodeposition; WC-Ni; Tungsten carbide; Coating.

1. Introduction

Cermet-based coatings are being popular to reduce erosion-corrosion rate in oil and gas industries. In this industry, the environment which contains corrosive media combining with solid particle such as found in offshore piping, production systems and machinery is where this coatings is applicable [1]. The tungsten carbide (WC) based cemented carbides itself is widely used for dies, tools, and wear resistant parts in multiple applications [2,3]. Among other carbides, WC has been popular due to its good wettability & solubility in binder metals as well as high strength, high toughness and plasticity [4].

Electrodeposition is one of the most used techniques for obtaining composite coatings, mixture of metallic and non-metallic materials. The metal is function as a matrix which hold the non-metallic dispersed together as well as developing good adhesion to the metal surface of the substrate [5]. Several researchers have been working on searching optimal parameter i.e. current density, bath temperature and Saccharin content in order to obtain suitable particle size and gain good properties of electrodeposited coating [6-9]. Vaezi et al. have found that in Ni-SiC coating, increasing the carbide content and decreasing the current density will increase the wear and corrosion resistance compares to nickel coating [10]. Another researcher also found that the Ni-WC

coating has higher friction [5] and corrosion resistance compares to nickel coating alone [5,11]. Controlling the electrodeposition parameter such as current density, stirring rate and TiO_2 particle concentration has been found to influence the TiO_2 content in the coating, which results in higher wear and corrosion resistance [12]. The TiO_2 itself has showing high corrosion resistance behaviour after treatment [13].

Thus, it is important of controlling the electrodeposition parameter in order to produce coating with high mechanical properties, as well as high wear and corrosion resistance. It has been shows in another study that controlling the synthesis parameters will result in better performance [14-17]. In this study, the current density and WC concentration was varied to evaluate its relation to the coating wear and corrosion behaviour.

2. Materials and Methods

Ni-WC coating were electrodeposited with different current density (0.08 A/cm^2 , 0.14 A/cm^2 and 0.20 A/cm^2) and different WC concentration which are 15 g/l , 20 g/l and 25 g/l has been used in this study. Table 1 shows the electrolyte composition. The stirring rate and deposition time were fixed at 160 rpm and 40 minutes respectively. Fig. 1 shows the schematic diagram of the experiment.

Table 1 Electrolyte composition.

Item	Amount
Nickel Sulphate	200 g/l
Nickel Chloride	20 g/l
Boric Acid	20 g/l
pH	3
Current density	$0.08 - 0.20 \text{ A/cm}^2$
Tungsten carbide	15 – 25 g/l

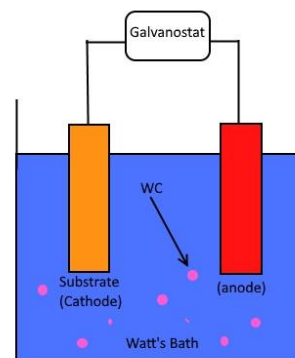


Fig. 1 Schematic diagram of deposition arrangement

The coating were characterised using Scanning Electron Microscope (SEM) JEOL JSM-6380LA, Japan. The hardness of the samples was evaluated using Vickers microhardness tester HMV-2 Shimadzu, Japan with 100 g load. Table 2 show the samples with different current density and WC concentration.

Table 2 Samples with different current density and WC concentration.

Samples	Current density (A/cm^2)	WC concentration (g/l)
15WC0.08	0.08	15
20WC0.08	0.08	20
25WC0.08	0.08	25
15WC0.14	0.14	15
20WC0.14	0.14	20
25WC0.14	0.14	25
15WC0.20	0.20	15
20WC0.20	0.20	20
25WC0.20	0.20	25

2.1 Abrasive wear test

The wear test was done using mass loss methods. Modified grinder machine was used with 5 N loads at three different distances which are 50 m , 100 m and 150 m . The 800 grit sand paper was used as abrasive materials. The balance is use to measure the mass before and after the selected distance, to calculate the mass loss. The mass loss at each distance is plot in a graph. The wear rate is calculated as the gradient of mass loss against distance graph.

2.2 Corrosion test

The corrosion test was carried out according to the ASTM standards G5:1994 and G6:1986 or BS EN ISO 17475:2008 using Autolab potentiostats. A three electrode cell arrangement was used with silver/silver chloride (Ag/AgCl) as the reference electrode, carbon as counter electrode and sample as the working electrode. The electrolyte used is 0.5 M sulphuric acids. During the test, the Tafel curve is plotted. The IVman software was used to analyse the results and determine the corrosion rate.

3. Results and Discussion

3.1 SEM surface morphology of electrodeposited coatings

Surface morphology of all coatings has been studied by SEM. Fig. 2 shows the surface morphology of coating with different current density and WC concentration as label in the figure. The appearance of WC is apparently seen in coating with higher WC concentration with higher current density. Due to small size of the carbide, it is difficult to distinguish the interface between Ni matrix and WC particle as similarly seen by Benea et al. [5]. The higher WC concentration shows more homogeneity in WC distribution compares to lower WC concentration, possibly due to higher content of carbide on surface.

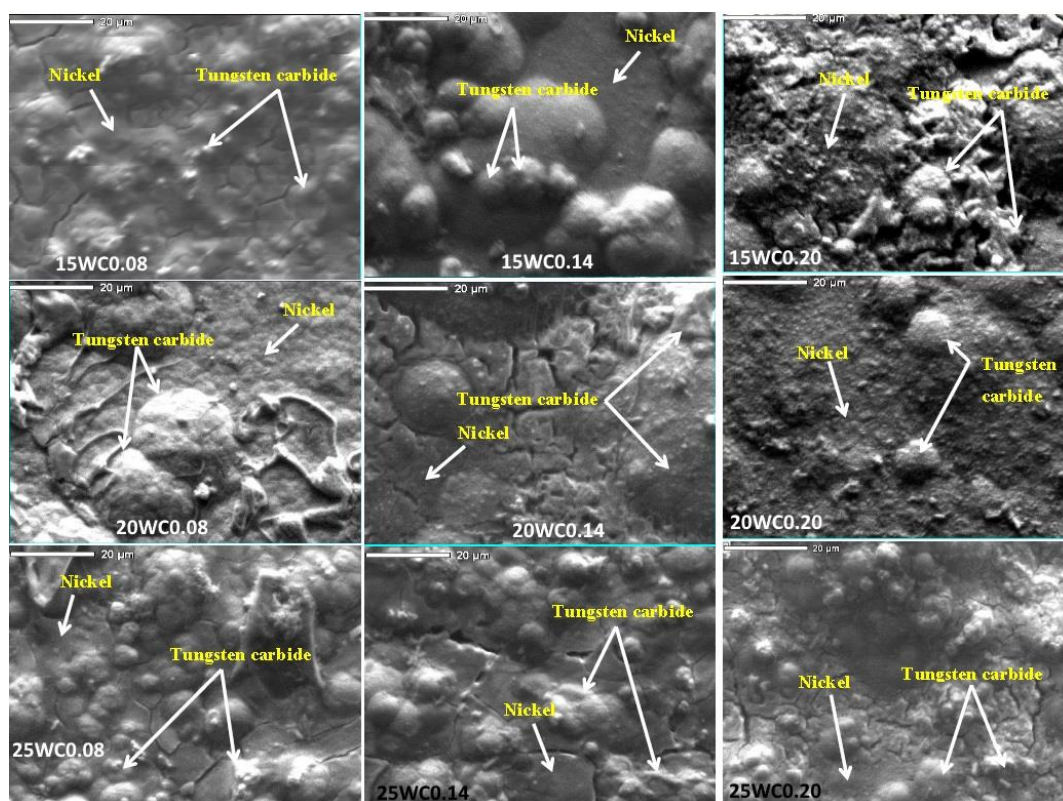


Fig. 2 Surface morphology of electrodeposited coatings with different current density and WC concentration

3.2 Chemical composition

The elemental compositions of the coatings were characterised using energy dispersive X-ray spectroscopy (EDS) attach to the SEM. Fig. 3 shows example of the EDS results. The W and Ni are detected in the coating. It is also found that the W content increases with increasing of WC concentration.

3.3 Micro-hardness analysis

The hardness data is shown in Fig. 4. It is clearly seen that the hardness increase with increasing of carbide concentration and current density.

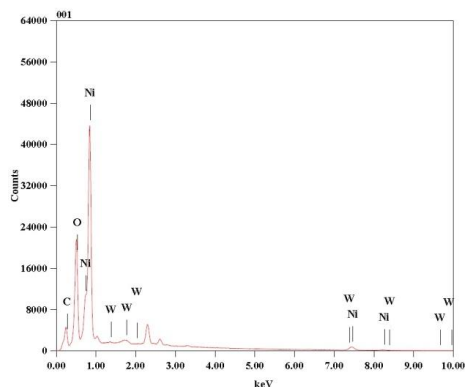


Fig. 3 Example of EDS result of the coating

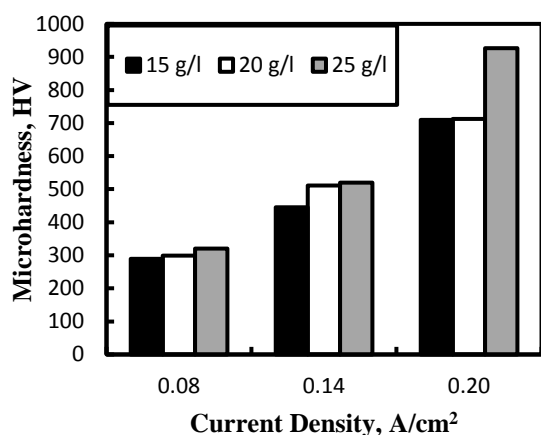


Fig. 4 Micro-hardness of samples with 100g load

With similar carbide concentration at 25 g/l, the hardness increase three times by increasing the current density from 0.08 A/cm² to 0.20 A/cm². With slightly lower carbide concentration (15g/l and 20 g/l), the hardness increases two times for both carbide concentrations. This is consistency with previous work [18] that increasing the carbide content increases the coating hardness.

3.4 Abrasive wear behaviour

Fig. 5 shows the wear rate following wear at 50, 100 and 150 m distance. It is shows that for every current density, the wear rate decreases with increasing of carbide content which is consistency with previous finding which showing that increasing the carbide content will decreases the wear rate [19]. With similar WC content, as the current density reach 0.14 A/cm², the wear rate decrease, then increase again at 0.20 A/cm².

Fig. 6 shows the coating with 25 g/l WC for all current density before and after wear test. After wear test the cracks and debris is visible on the coating surface which is also

seen by previous researcher [20]. The grooving of the sliding track is clearly seen on the carbide surface indicating the abrasive wear.

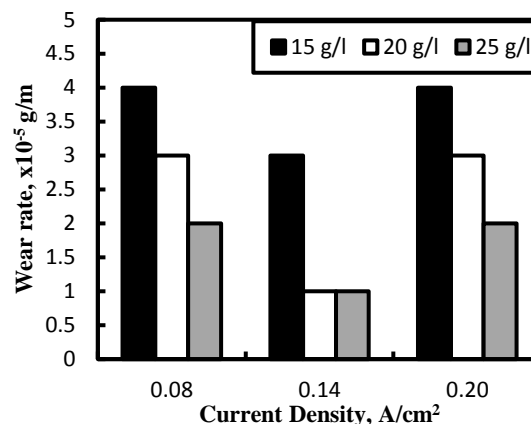


Fig. 5 Wear rate of samples with 800 grit SiC abrasive paper

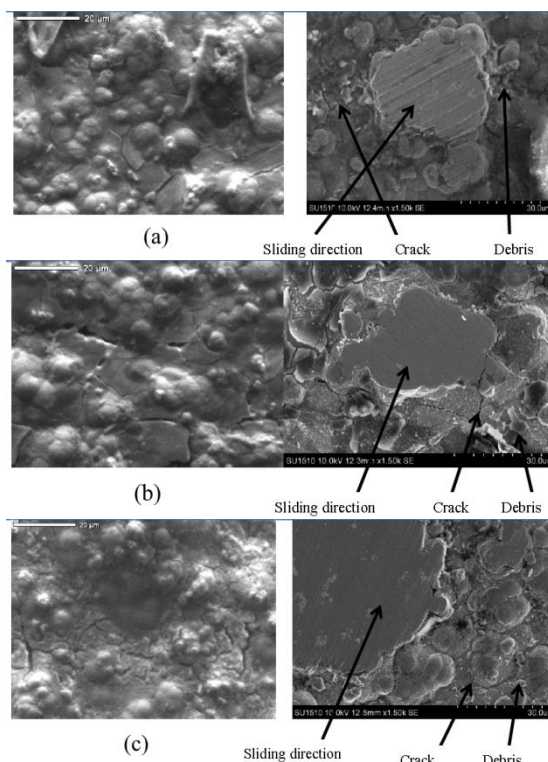


Fig. 6 (a) The 25WC0.08 surface (b) 25WC0.14 surface (c) 25WC0.20 surface before (left) and after (right) wear test for 150m with 800 grit SiC paper

3.5 Corrosion behaviour

Fig. 7 shows corrosion rate of all coatings. It is clearly seen that the corrosion rate decrease with increasing of WC

concentration [10]. For current density, the corrosion rate decrease from 0.08 A/cm² to 0.14 A/cm², then slightly increase with current density 0.20 A/cm².

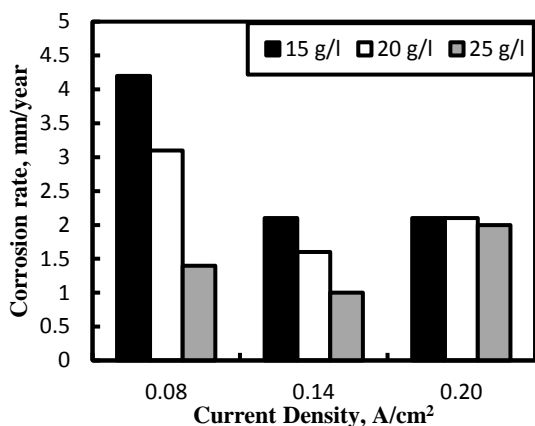


Fig. 7 Wear rate of samples following corrosion in 0.5 M H₂SO₄

4. Conclusion

The WC-Ni coating has been successfully electrodeposited and evaluated. The carbide distribution is high in homogeneity in higher carbide content coating. Thus, this results in higher wear and corrosion resistance of the coating showing by the decreasing of wear and corrosion rate with increasing of WC concentration. The hardness of the coatings is increases with the increasing of carbide content and current density. For wear and corrosion behaviour, the changes of current density do not show any significant correlation. This shows that the carbide content has shows higher contribution on the wear and corrosion behaviour compares to the changes of current density.

References

- [1] El Rayes, M.M., Abdo, H.S., and Khalil, K.A., (2013) "Erosion-Corrosion of Cermet Coating", in *International Journal of Electrochemical Science* Vol. 8 No. 1 pp. 117-1.
- [2] Balla, V.K., Bose, S., and Bandyopadhyay, A., (2010) "Microstructure and Wear Properties of Laser Deposited WC-12%Co Composites", in *Materials Science and Engineering: A* Vol. 527 No. 24 pp. 6677-6682.
- [3] Gu, L., Huang, J., Tang, Y., Xie, C., and Gao, S., (2015) "Influence of Different Post Treatments on Microstructure and Properties of WC-Co Cemented Carbides", in *Journal of Alloys and Compounds* Vol. 620 pp. 116-119.
- [4] Berger, L.-M., (2014), Coating by Thermal Spray, in *Comprehensive Hard Materials*, V.K. Sarin, D. Mari, and L. Llenes, Editors., Elsevier: Kidlington, Oxford, UK.
- [5] Benea, L., Başa, S.-B., Dănilă, E., Caron, N., Raquet, O., Ponthiaux, P., and Celis, J.-P., (2015) "Fretting and Wear Behaviors of Ni/Nano-WC Composite Coatings in Dry and Wet Conditions", *Materials & Design* (1980-2015) Vol. 65 pp. 550-558.
- [6] Rashidi, A.M. and Amadeh, A., (2010) "Effect of Electroplating Parameters on Microstructure of Nanocrystalline Nickel Coatings", in *Journal of Materials Science & Technology* Vol. 26 No. 1 pp. 82-86.
- [7] Bakonyi, I., Tóth-Kádár, E., Tarnóczi, T., Varga, L.K., Cziráki, Á., Geröcs, I., and Fogarassy, B., (1993) "Structure and Properties of Fine-Grained Electrodeposited Nickel", in *Nanostructured Materials* Vol. 3 No. 1 pp. 155-161.
- [8] Bakonyi, I., Tóth-Kádár, E., Pogány, L., Cziráki, Á., Geröcs, I., Varga-Josepovits, K., Arnold, B., and Wetzig, K., (1996) "Preparation and Characterization of d.c.-plated Nanocrystalline Nickel Electrodeposits", in *Surface and Coatings Technology* Vol. 78 No. 1 pp. 124-136.
- [9] Ebrahimi, F., Bourne, G.R., Kelly, M.S., and Matthews, T.E., (1999) "Mechanical Properties of Nanocrystalline Nickel Produced by Electrodeposition", in *Nanostructured Materials* Vol. 11 No. 3 pp. 343-350.
- [10] Vaezi, M.R., Sadrnezhad, S.K., and Nikzad, L., (2008) "Electrodeposition of Ni-SiC Nano-Composite Coatings and Evaluation of Wear and Corrosion Resistance and Electroplating Characteristics", in *Colloids and Surfaces A: Physicochemical and*

- Engineering Aspects* Vol. 315 No. 1 pp. 176-182.
- [11] Rabani, N.A.M. and Kamdi, Z. (2016), "Corrosion Behaviour of High Velocity Oxygen Fuel Spray Process and Electrodeposited Coating in Aqueous Environment", in *ARPJ Journal of Engineering and Applied Sciences* Vol. 11 No. 12 pp. 7638-7644.
- [12] Bagheri, P., Farzam, M., Mousavi, A.B., and Hosseini, M., (2010) "Ni-TiO₂ Nanocomposite Coating with High Resistance to Corrosion and Wear", in *Surface and Coatings Technology* Vol. 204 No. 23 pp. 3804-3810.
- [13] Ainuddin, A.R. and Aziz, N.A., (2016) "Thermal Post-Treatment of TiO₂ Films Via Sol-gel for Enhanced Corrosion Resistance", in *ARPJ Journal of Engineering and Applied Sciences* Vol. 11 No. 14 pp. 8698-8703.
- [14] Sreekantan, S. and Ibrahim, S., (2014) "Fe-TiO₂ Nanoparticles by Hydrothermal Treatment with Photocatalytic Activity Enhancement", in *Advanced Materials Research* Vol. 1024 pp. 39-43.
- [15] Ibrahim, S.A. and Ahmid, M.N., (2017) "Influence of Calcination Temperature towards Fe-TiO₂ for Visible-Driven Photocatalyst", in *Materials Science Forum* Vol. 888 No. pp. 435-440.
- [16] Hussin, R., Hou, X.H., and Choy, K.L., (2012) "Growth of ZnO Thin Films on Silicon Substrates by Atomic Layer Deposition", in *Defect and Diffusion Forum* Vol. 329 No. pp. 159-164.
- [17] Hussin, R., Kwang, L.C., and Hou, X., (2015) "Deposited TiO₂ Thin Films by Atomic Layer Deposition (ALD) for Optical Properties", in *ARPJ Journal of Engineering and Applied Sciences* pp. 7259-7533.
- [18] Guo, B., Qiu, Y., And Li, H., (2017) "Application of Artificial Neural Network for Preparation Process of Ni-SiC Composite Coatings on Ti-Alloy TA15", in *Journal of Chinese Society for Corrosion and Protection* Vol. 37 No. 4 pp. 389-394.
- [19] Rao, R.N. and Das, S., (2011) "Effect of SiC Content and Sliding Speed on the Wear Behaviour of Aluminium Matrix Composites", in *Materials & Design* Vol. 32 No. 2 pp. 1066-1071.
- [20] Mohajeri, S., Dolati, A., and Rezagholibeiki S. (2011) "Electrodeposition of Ni/WC Nano Composite in Sulfate Solution" in *Materials Chemistry and Physics* Vol. 129 pp. 746-750.