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Muhammad Zikri Mat Zaki; Z. Kamdi ✉; A. R. Ainuddin; R. Hussin; S. A. Ibrahim

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Wear Behavior of Heat-Treated Coated Carbon Steel

Muhammad Zikri Mat Zaki [1,3, a)], Z. Kamdi[1,3, b)], A. R. Ainuddin[1, 3, c)], R. Hussin[2, 3, d)] and S. A. Ibrahim[2, 3, e)]

[1]*Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia*
[2]*Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Hab Pendidikan Tinggi Pagoh, KM 1, Jalan Panchor, 84600 Panchor, Johor, Malaysia*
[3]*NanoSurf, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia.*

[a)] *dd180087@siswa.uthm.edu.my*
[b)] *Corresponding author: zakiah@uthm.edu.my*
[c)] *ainun@uthm.edu.my*
[d)] *rosniza@uthm.edu.my*
[e)] *saida@uthm.edu.my*

Abstract. A particular type of steel has a higher concentration of carbon than other types of steel called carbon steel. This study focused on the electrodeposition coating of Nickel Silicon Carbide (Ni-SiC) composite coating at 50 ^{o}C. In this study, medium carbon steel was used as a substrate. 25 g/l SiC was used during the deposition. The carbon steel was acted as the cathode and the carbon rod as an anode during electrodeposition. The coated sample was heat-treated at 350 ^{O}C for 1 hour. Scanning Electron Microscope (SEM) was used to analyze the surface morphology and microstructure of the coated and heat-treated sample before and after the wear test. The coated sample's element composition and phase distribution are determined using the Energy Dispersive Spectroscopy (EDS) and X-Ray Diffraction (XRD). To identify the hardness of the composite coating, Vickers micro-hardness test was used on the surface of the sample with 100g load in 10 seconds with ten indentations. Weight loss method was conducted to determine the average wear resistance of the sample. The wear behavior of the Ni-SiC was evaluated using the weight loss method with 3 g/l alumina as the abrasive material. The results showed that the heat-treated coating had higher wear resistance than the without heat treatment. The findings also showed that the sample with the heat-treatment process had a higher hardness. This proved that the heat-treated sample had the best wear behavior and hardness value compared to without heat treatment due to denser coating produced.

INTRODUCTION

Electrodeposition or electroplating is a process of producing and dense coating having good adherent by applying electric current to substrate material like metal or alloys. The process uses electrical current to reduce the cations of a desired material from an electrolyte and coat those materials as a thin film onto a conductive substrate surface. This method aims to achieve the desired electrical and corrosion resistance, reduce wear and friction, improve heat tolerance, and increase thermal conductivity [1]. In addition, the heat treatment following coating deposition has also shown improvement of the wear [2] and hardness behaviour [3]. Furthermore, electroplating is a well-known process nowadays which is very competitive in terms of economic compared to plasma spraying, sputtering of ion and physical vapour deposition (PVD) [4].

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Cermet coating have been popular due to their high corrosion [5, 6] and wear resistance [6 - 8]. Researchers have found methods for combining types of carbides with reinforcing materials such as nickel, which can influence changes in its physical properties or molecular structure which leads to indirectly increase its resistance to wear and corrosion on the surface of the material. The SiC is one of the optimum choices as oxidation protecting coating because composite coating with incorporation of inert particles into metal matrix have various important application such as wear resistance, dry lubrication and disperse hardening [9]. SiC is also had good corrosion and erosion properties [10]

Thus, the findings of this study were redounded to the benefits of the development of heat-treated and Ni-SiC coating. This heat-treated coating is expected to bring significant improvement and enhancement to the carbon steel properties. The effect of these parameters has been determined to produce a heat-treated and coated material with high mechanical properties and high wear resistance and improve their hardness.

MATERIALS AND METHODS

This study was conducted by several processes: material preparation followed by electrodeposition and heat treatment process for the samples. Then, the samples were undergoing the wear analysis, hardness test, surface morphology and phase composition.

Materials

The medium carbon steel was used as the substrate (cathode), carbon rod as the anode, while Watt's bath as the electrolyte. The deposition composition was shown in **TABLE 1**.

TABLE 1. Electrodeposition Parameter

Components	Concentration
Nickel Sulphate	200 g/l
Nickel Chloride	20 g/l
Boric Acid	20 g/l
Silicon Carbide	25 g/l
pH	4
Current Density	0.5 A/cm^2
Bath Temperature	50 °C
Distilled Water	1000 ml

Coating Deposition and Heat Treatment

The electrodeposition processes start with heating distilled water with nickel sulphate ($NiSO_4.6H_2O$), nickel chloride ($NiCl_2.6H_2O$), and boric acid (H_3BO_3) up to 50 ºC. After the bath attained the specified temperature, the SiC powder with a concentration of 25 g/l was added to the bath. The bath was stirred for 2 hours using a magnetic stirrer (**FIGURE 1**). Then, the sample was immersed in the beaker that contains Watts bath for 1 hour. The coated sample was then heat treated at 350 ºC for 1 hour. The coated sample and coated with heat treatment was label as 50S0.5A and HT50.05A respectively.

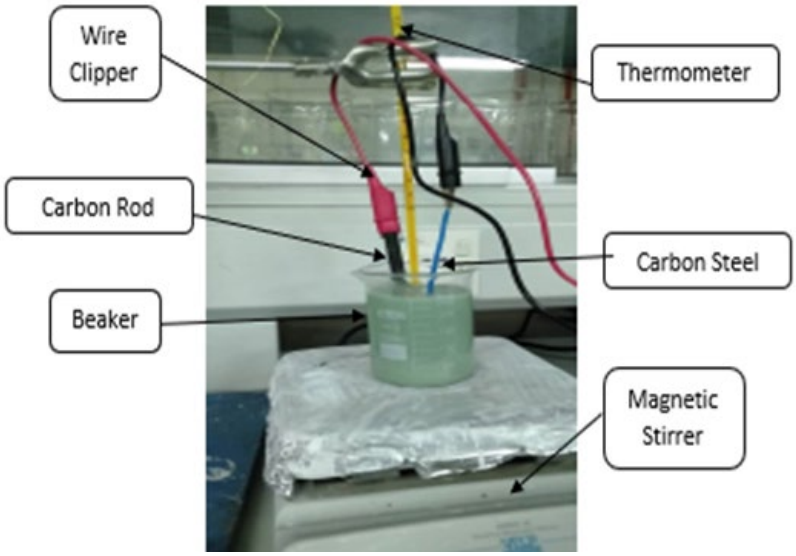


FIGURE 1. Apparatus Set-Up for Electrodeposition Process

Coating Characterisation

The samples was characterize by analyzing the surface morphology, the microstructure, and phase analysis. The surface morphology was observed using Fujitsu Scanning Electron Microscope (SEM) at a magnification of 2000x followed by the Energy Dispersive Spectroscopy (EDS) to identify the elemental weight percentage of coating and distribution of material. The D8 Advance Bruker X-Ray Diffraction (XRD) machine was used to observe the composition on the samples at a scan rate of 2 mV/s in range $20° < \Theta < 90°$ and 0.02° step size. The analysis was done using EVA software.

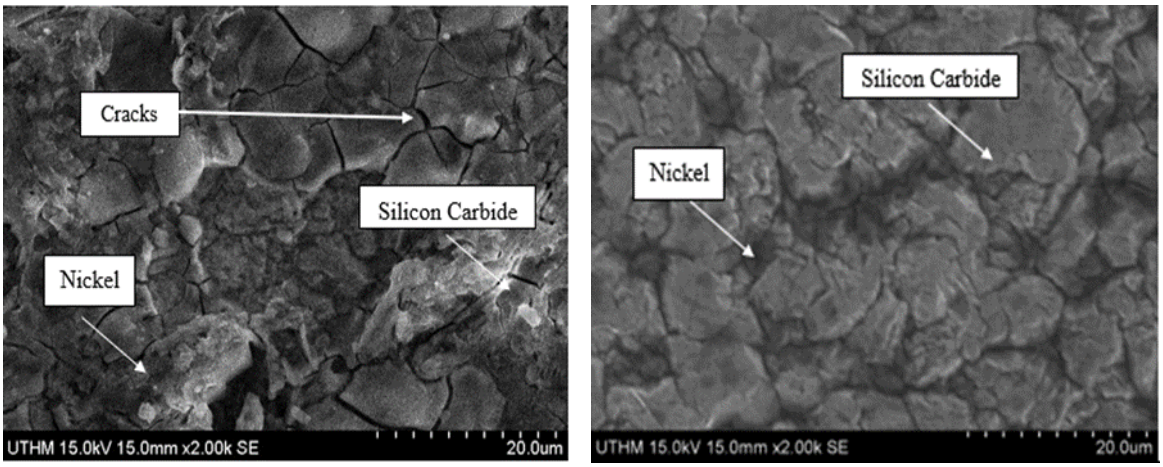
Samples Testing

Vickers Microhardness Tester and Forcipol 2V Grinder were used for hardness and wear analysis. The measurement is carried out under indention loads of 100g for 10 seconds, and the indentation diagonal was measured after the load was removed. For wear analysis, the samples were evaluated using the weight-loss method. The parameters used was a constant load of 3kg at three different distances, 100 m, 200 m, and 300 m. The samples was weight before and after each distance. During the test, the stainless-steel plate was used with a 3 g/l concentration of alumina as the abrasive materials.

RESULTS AND DISCUSSION

Surface Morphology and Microstructure Analysis

After the coating process, the surface of the samples looks different. The grey colour appeared on the surface, indicating that the process of the electrodeposition of Ni-SiC was successfully deposited. Based on the surface, the sample 50S0.5A and HT50.05A does not have much difference because both samples use the same parameters for the electrodeposition method even though sample HT50S0.5A has undergone the heat treatment process. The surface of sample 50S0.5A shows that some cracks occur (Figure 2a), and the dark area shows the nickel deposited while the grey area shows the silicon carbide deposited. Without any cracks visible, the HT50S0.5A sample shows smoother morphology than the sample without heat treatment (Fig. 2b).



(a) (b)

FIGURE 2. SEM image of Surface Morphology for (a) Sample 50S0.5A, (b) Sample HT50S0.5A

Elemental Composition Analysis

Figure 3 shows carbon and silicon element for the sample 50S0.5A is higher than the sample HT50S0.5A, while for the nickel element, sample HT50S0.5A has a higher element than the sample 50S0.5A. Even though the sample goes through a heating process, the oxide content does not increase because the material was not easily oxidized.

Element	Weight%	Atomic%
C K	12.59	25.26
O K	34.89	52.57
Si K	1.36	1.17
Ni K	51.16	21.00
Totals	100.00	

(a)

Element	Weight%	Atomic%
C K	11.58	34.70
O K	6.31	14.21
Si K	1.08	1.39
Ni K	81.03	49.70
Totals	100.00	

(b)

FIGURE 3. Element Composition, (a) Sample 50S0.5A, (b) Sample HT50S0.5A

Phase Analysis

The XRD pattern of the Ni-SiC coating was shown in the Figures 4. The peaks of Ni were clearly visible with high intensity however, the SiC peak was not found when compared to the SiC powdered results. This is possibly due to the lower amount of the SiC on the coating as the silicon element can be detected by the EDX.

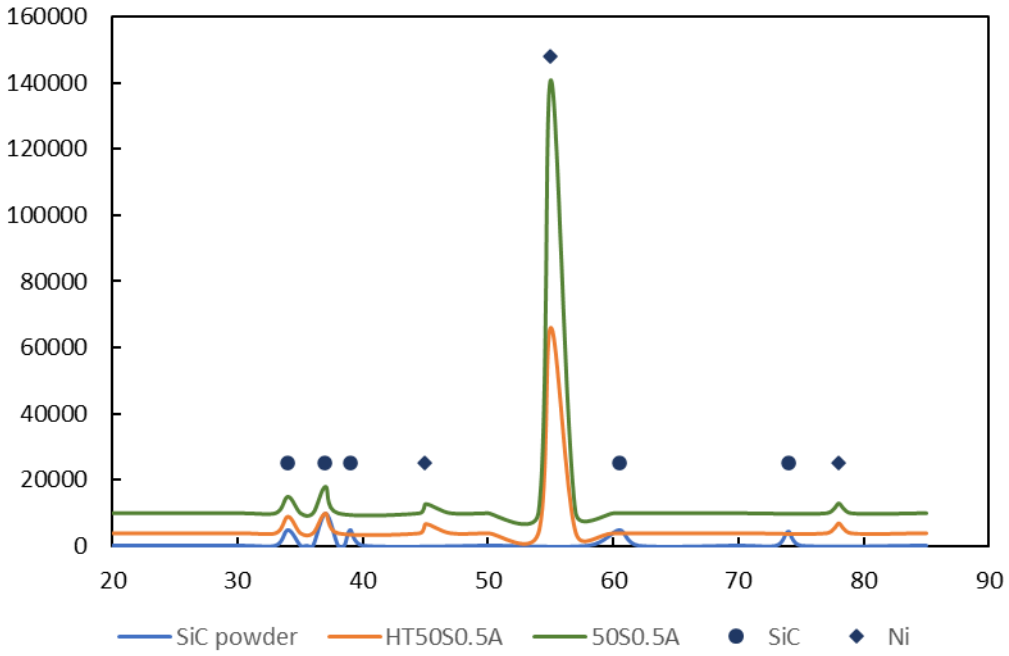


FIGURE 4. XRD Analysis for both coated sample

Hardness Analysis

The analysis clearly shows that the highest value of microhardness number was 464.526 HV for sample HT50S0.5A, while the lowest value of microhardness number was 377.227 HV for sample 50S0.5A. It can be concluded that the microhardness value is higher for the sample HT50S0.5A because of the addition of heat-treatment after the coating compared to the coating sample only. This is because the heat-treatment method had increased the microstructure and improved the grain boundaries between the particles. The relaxation of non-equilibrium grain boundaries in as-plated conditions during annealing brings obstacles and difficulties for dislocation movements [11].

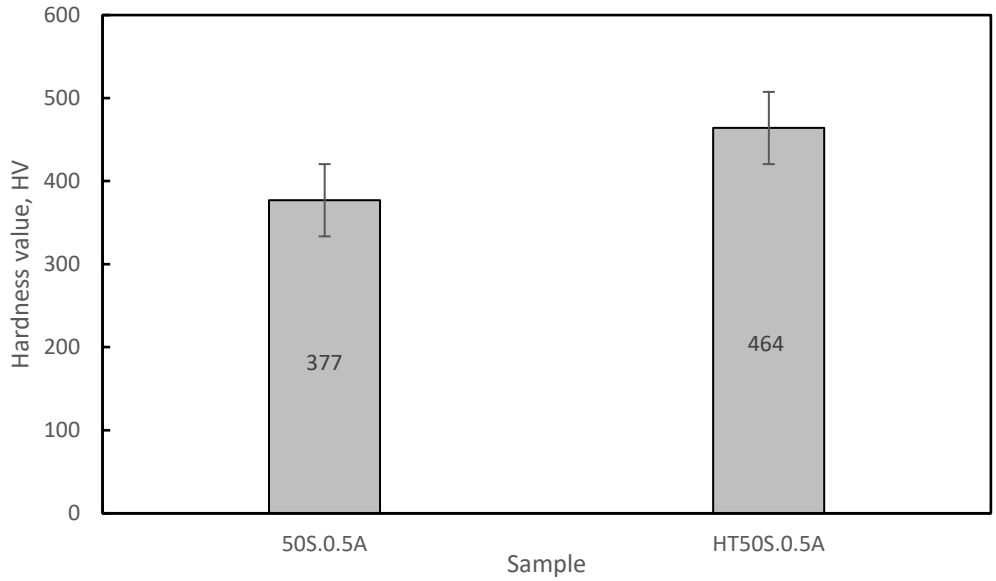


FIGURE 5. Average Microhardness Value of Ni-SiC Coating

Wear Behaviour Analysis

The wear rate of each sample was obtained by the calculated slope from the plotted weight loss graph against sliding distance. Figure 6 shows that the higher the weight loss, the higher the wear rate that contributes to lower wear resistance. This means that sample HT50S0.5A has the highest wear resistance than samples 50S0.5A. The wear rate of heat-treated alloy with stress relief was higher than non-heat-treated alloy [12].

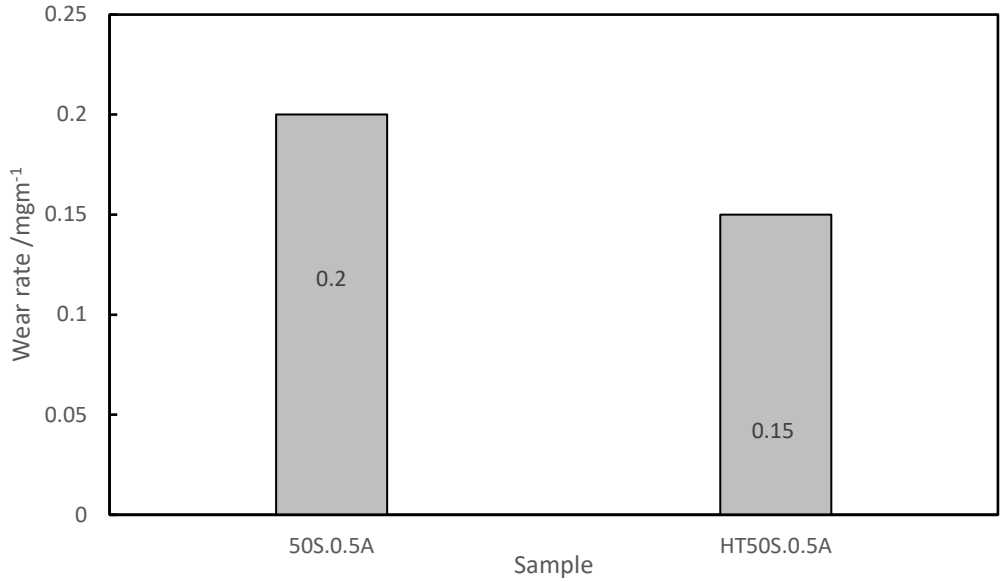
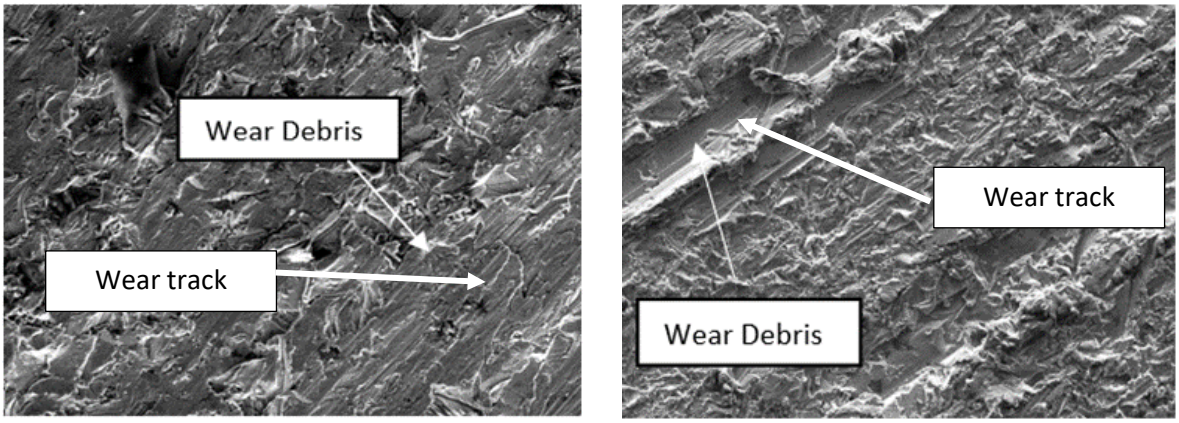


FIGURE 6. Wear rate for both samples

After the wear test, the sample was taken to the Scanning Electron Microscope (SEM) to analyse the surface morphology (Figure 7). Before conducting the test, the surface of the sample was looked good and a little bit uneven, and after conducting the test, the deformation on the surface was obtained. This proved that the wear does occur on the sample surfaces. The wear mechanism is changed from three-body to two-body wear shown by the wear tracks. The wear tracks in the 50S0.5A sample are deeper compared to the HT50S0.5A. This results in higher wear resistance of sample HT50S0.5A than sample 50S0.5A. So, it can be concluded that the highest the weight loss during the wear test, the maximum the wear rate compared to the lowest weight loss during the wear test.



(a) (b)

FIGURE 7. Surface Morphology After Wear Test, (a) Sample 50S0.5A, (b) Sample HT50S0.5A

CONCLUSION

In conclusion, not much different can be seen in terms of the phases of both coatings which is dominated by the Ni. However, the surface structure of the heat-treated coating is denser without any cracks. This results in higher hardness of the heat-treated coating with lower wear rate.

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