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Review on Wear Behavior of Nickel-Silicon Carbide Electrodeposition Coating

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Abstract: Nickel-silicon carbide (Ni-SiC) composites have been widely used as advanced materials, in various application fields, especially in high-temperature processing and abrasive treatment due to the Nickel and Silicon Carbide wear resistance, hardness, strength, and improve morphology and microstructure properties. The technique chosen in this study is electrodeposition, as it is a quick technique for the coating industry. Electrodeposition is a process driven by the electrical process of depositing any substance metallic or non-metallic on any substrate. Nickel and SiC provide excellent performance on wear and corrosion behavior. The hardness and wear resistance of the composites increases as the SiC content increases. Ni-SiC shows excellent performance, such as low density, low thermal expansion coefficient, and high wear resistance. This review looks into the Ni and Ni-SiC coating behavior. This study also reviews the wear behaviour of Ni-SiC at high temperatures.

Keywords: Ni-Sic, Wear, Temperature, and Nickel Electrodeposition

1. Introduction

Nickel-based coatings are widely used in manufacturing industries such as automotive, aerospace, electronics, geothermal, and fluorochemical. This is due to its excellent corrosion resistance, higher strength, and toughness than stainless steel and carbon steel due to the stable single-phase austenite structure [1].

Research by Sindhuja et al., 2018 [2] states that composite coatings with the incorporation of inert particles into a metal matrix such as SiC are popular because of their outstanding wear resistance, dry lubrication, anti-corrosion, and dispersion hardening. The SiC has been established as an oxidation protection coating because of its compatibility with base carbon material to be applied at high-temperature applications. SiC also has excellent properties such as low thermal expansion coefficient, high-temperature strength, high conductivity, and high melting point.

A nickel-based superalloy is widely used in high-pressure turbine blades of aero engines as it has high corrosion resistance and excellent creep and fatigue properties. Nickel-based superalloy type GH 4738 is widely used in critical components such as aerospace, petroleum, and power generation

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industries. It provides high yield strength and has excellent fatigue and corrosion resistance. Ni-SiC coating provides high wear resistance, strength, and hardness. According to the research article by Zhou, 2007, it states the wear resistance of Ni-SiC nanocomposite is much more excellent than Ni film due to the SiC contained [3]. The result firmly states that the wear resistance will significantly increase with the increasing microhardness.

Comparing the coatings techniques which are high-velocity oxy-fuel (HVOF) and electrodeposition, used for improving wear resistance, it shows that electrodeposition is the best coating method as it can work at any temperature. The electrodeposition coating process has a low cost of maintenance, provides an easy method, and most importantly, saves energy. The electrodeposition has environmentally-friendly chemical baths which used a simple process to develop the coating process. Next, this electrodeposition method has greener chemistry to reduce the level of toxic material, energy use, and waste production. Therefore, it also provides the production and characterization of a sustainable alloy system where this electrodeposition can be used for the alloy coating process. Thus, this study was focused on reviewing the electrodeposition of Ni-SiC's wear behavior by analysing its surface morphology and structure at different temperatures.

2. Materials and Method

The coating morphology was evaluated by Scanning Electron Microscope (SEM). SEM was used to observe the microstructure, and surface morphology thickness of nickel and nickel-silicon carbide coating. Energy Dispersive X-Ray Spectroscopy (EDXS) was used to characterise the particle size and elemental composition of the prepared deposits of the surface sample.

2.1 Wear Behavior Analysis

This method has mostly been used to identify the wear rate of the Ni fil and Ni-SiC nanocomposite. It has usually been measured through a wear track's depth or cross-sectional area to identify the wear volume loss or linear dimensional change. The load has been applied to determine the friction coefficient of the Ni film and Ni-SiC nanocomposite.

2.2 Hardness Behavior Analysis

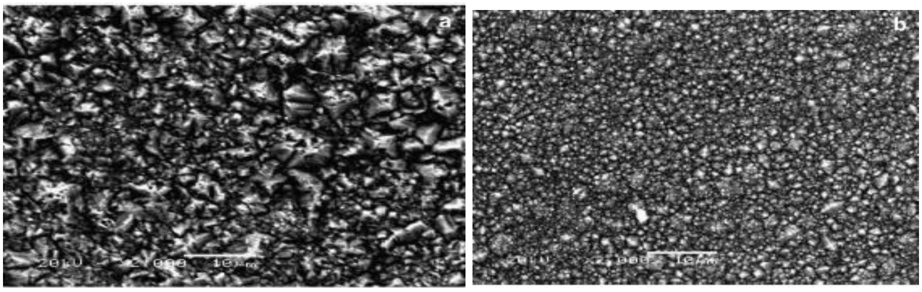
Vickers hardness test is used to identify the abrasive depth and width of Ni film and Ni-SiC nanocomposite. The hardness of the Ni film and Ni-SiC was evaluated by the indentation diagonal after applying a load on the surface area. The basic principle of the testing is to observe a material's ability to resist plastic deformation from a standard source.

3. Results and Discussion

The results show the analysis of surface morphologies and microstructural of Ni-SiC based on several articles chosen. Both the Ni and SiC have been identified through their wear behavior at high-temperature. Thus, their wear behavior is also influenced by the SiC content, affecting its hardness and wear resistance.

3.1 Surface Morphology and Microstructure Analysis

According to Ozkan et al., 2013, the nickel layer deposited with SiC particles shows a different crystal orientation than pure Ni deposits without SiC particles [4]. Figure 1 shows the SEM images for Ni coating without SiC and Ni-SiC coating at the same condition. As can be seen, the distribution grain of nickel deposit shows a pyramidal structure while Ni/SiC nanocomposite coating shows the surface coating smooth, more excellent uniform, and compact surface. Moreover, the size of the grain reduces due to the presence of SiC particles.



(a) (b)

Figure 1: SEM images of (a) pure Ni coating and (b) Ni/SiC coating (5.9 wt.%) coating both prepared under the same experimental conditions ($5Adm^{-2}, 180\ rpm$) [4]

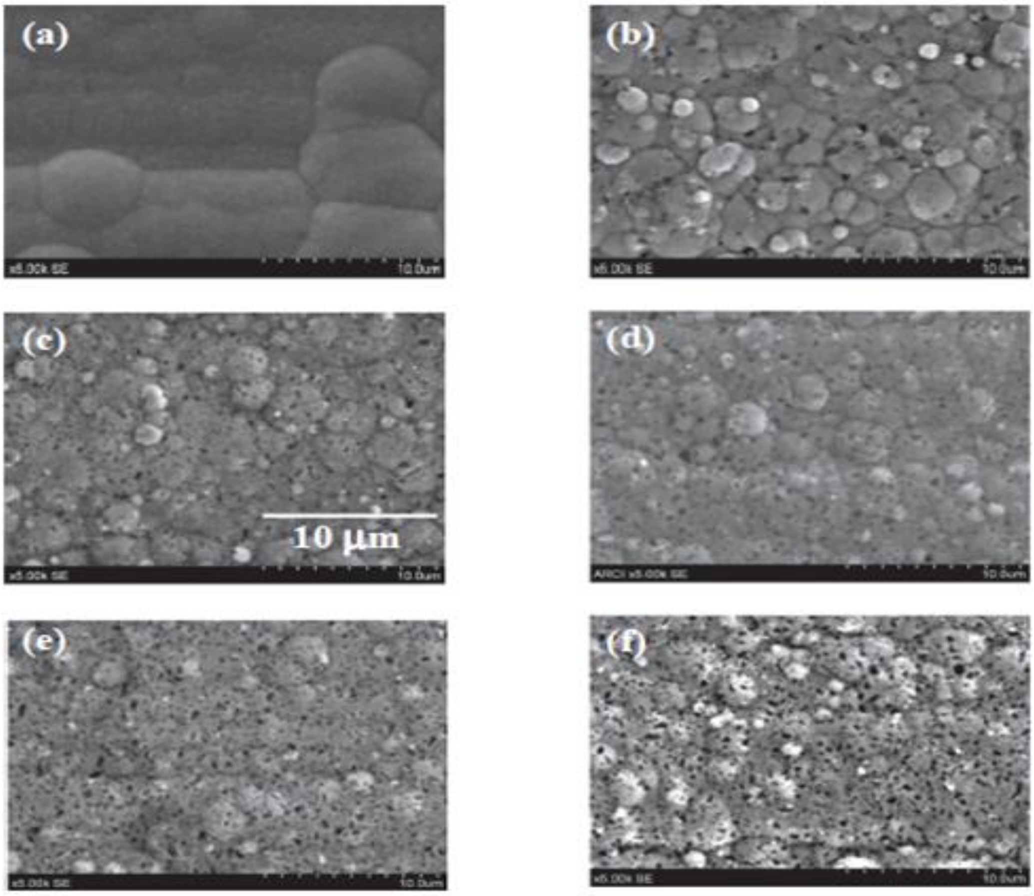


Figure 2: SEM micrograph illustrating surface morphology of as deposited Ni-W alloy with different SiC content in electrolyte (a) 0 g/L, (b) 2 g/L, (c) 5 g/L, (d) 10 g/L, (e) 15 g/L, (f) 20 g/L [5]

Figure 2 represent the topographical features of the as-deposited Ni-W/SiC with different concentration of SiC content in the electrolyte. As the SiC content increase, the nodule size will decrease significantly, and it remained almost identical for all the nanocomposite coatings. The percentage of SiC content attached to the coating is due to their corresponding content in the plating bath [5]. Figure 3 shows the SEM images of Ni-W thin film at different concentrations of SiC nanoparticles. Figure 3 (a) is the SEM analysis of Ni-W films without SiC, and as can be seen, its surface was rough and grainy.

However, Figure 3 (b) – (c) shows that as the concentration of SiC increases, the surface becomes more smooth, fine-grained, and has a uniform surface distribution of SiC nanoparticles [6].

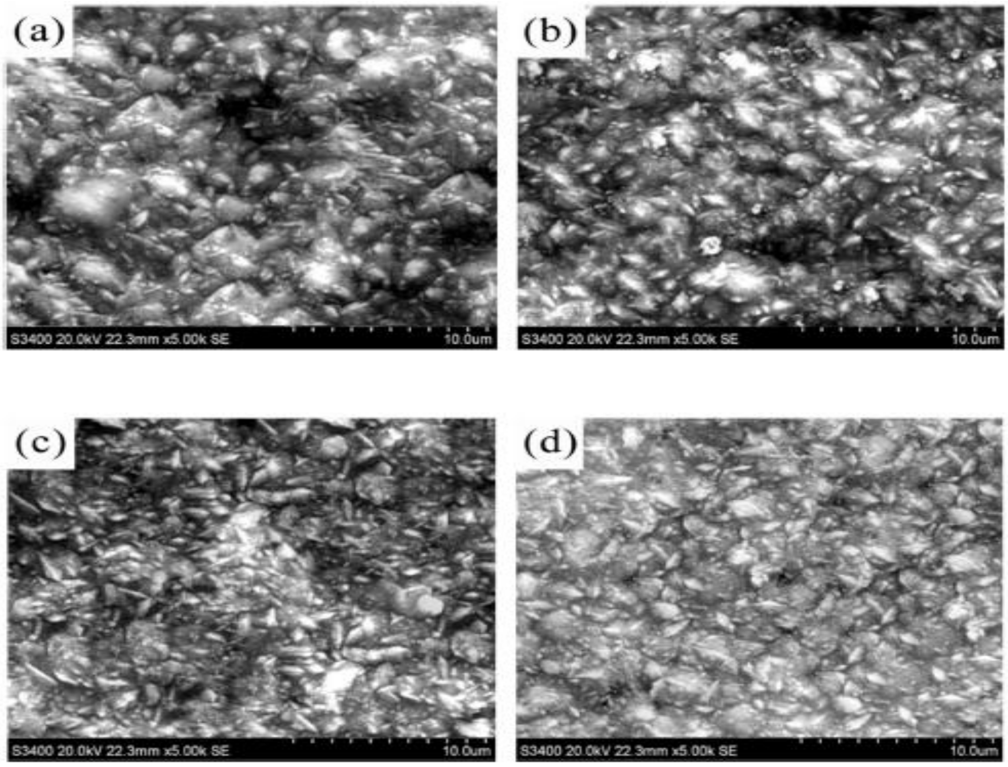


Figure 3: SEM micrograph of Ni-W-SiC thin film deposites at various SiC concentrations (a) 0 g/L, (b) 6 g/L, (c) 9 g/L, and (d) 12 g/L [6]

It can be seen that the inclusion of SiC in the coating results in a smaller, smoother, and homogenous distribution of the microstructure. Increasing the SiC content up to 20g/L has been seen to improve the morphology and particle distribution of the coating. Next, adding small particles of SiC content to the nickel would increase their smooth surface and increase hardness. Moreover, the impact of increasing the SiC content also can decrease the nodule size of the Ni surface.

3.2 Wear Behavior Analysis

A study on the annealing temperature effect on the tribological properties of Ni-P/SiC found that the highest annealing temperature (500ºC) shows the lowest wear rate. In Figure 4, the bar chart represents the wear rate of Ni-P/SiC coatings. It also shows Ni-P/SiC at 350°C has the highest wear rate at ($6.1 \times 10^{-5} mm^3/Nm$) while Ni-P/SiC at 500°C has the strongest wear resistance with the lowest wear rate ($0.78 \times 10^{-5} mm^3/Nm$).

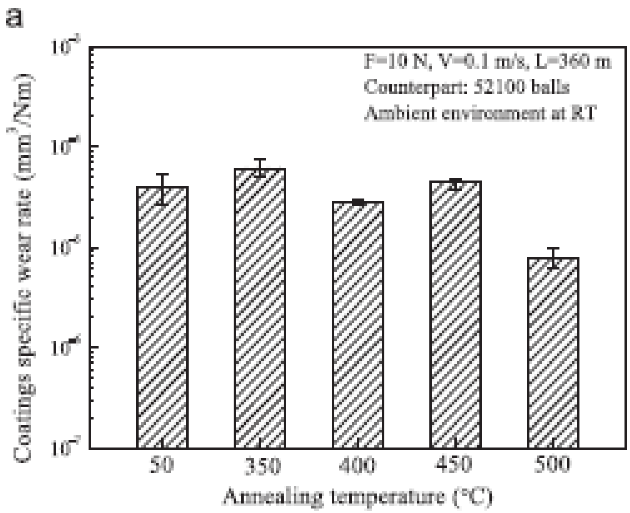


Figure 4: Specific wear rate of Ni-P/SiC coatings [7]

Figure 5 represent the SEM images of partial wear tracks on Ni-P/SiC at different annealing temperature (°C) (a) 50, (b) 350, (c) 400, (d) 450, (e) 500 coatings. By increasing the annealing temperature, more lateral cracks are visible. The track becomes smoother showing plastic deformation [7].

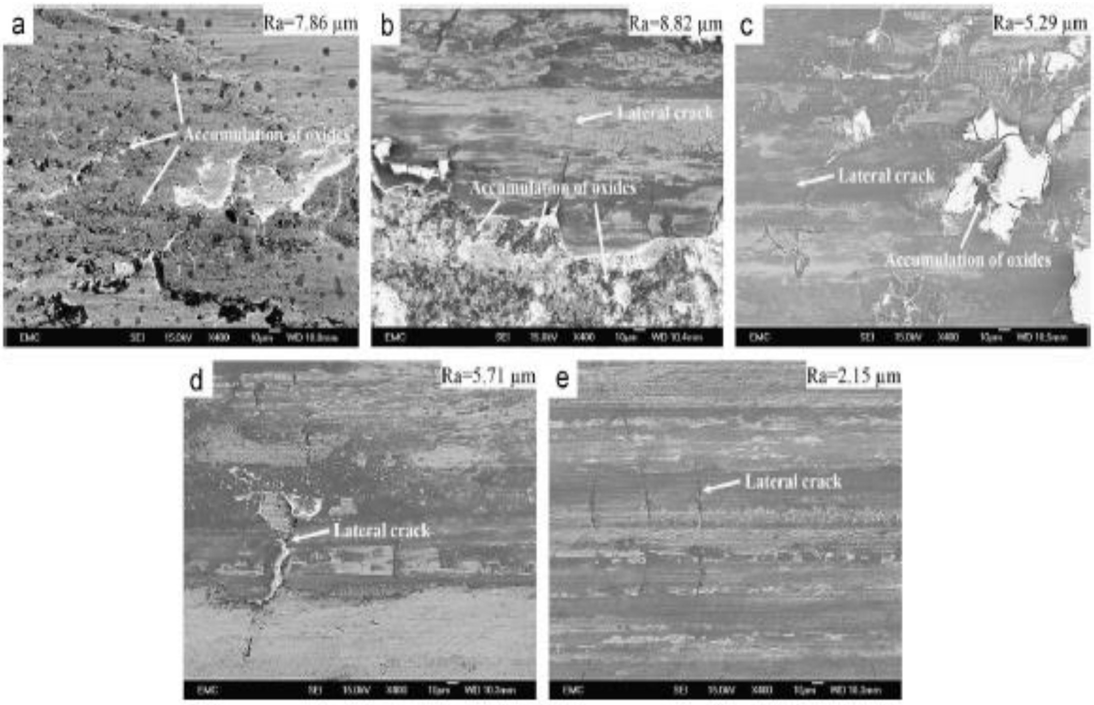


Figure 5: SEM images of partial wear tracks on Ni-P/SiC at (a) 50°C, (b) 350°C, (c) 400°C, (d) 450°C, (e) 500°C annealing temperature coatings [7]

Based on Figure 6, the microhardness of Ni film is about 280 Hv while the Ni-SiC is 550 Hv. This is consistence with the wear loss of Ni-SiC shown 0.5 mg compared to Ni film 1.2 mg which proved that Ni-SiC with higher hardness shows higher wear resistance [3].

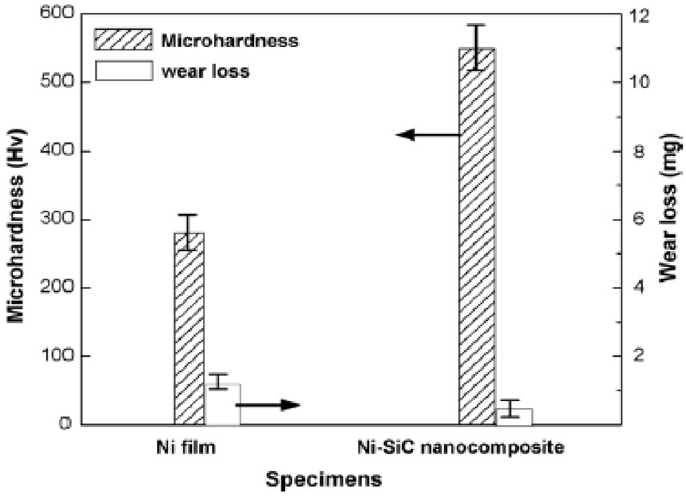


Figure 6: The microhardness and wear loss of the as-deposited Ni film and Ni-SiC nanocomposite [3]

The worn surface morphologies have identified the wear behavior for both Ni film and Ni-SiC in Figure 7. This study stated that as the microhardness increase, the wear resistance would also increase. Figure 7 (a) and (c) show the low magnified images of Ni film and Ni-SiC. The comparison that can be made is that the Ni-SiC nanocomposite exhibits less abrasive width and depth. However, in Figure 7 (b) and Figure 7 (d), the image is highly magnified. The wear track of Ni film has higher wear loss compared to Ni-SiC because the wear track of Ni film shows a more significant extent of adhesion wear. It also has deformation with large grooves in the sliding direction under the combined stresses, compression, and shear for plastic deformation of asperity junctions resulting in higher and unstable friction coefficients. However, for Ni-SiC nanocomposite, the worn surface has slight adhesion wear, a relatively smooth surface with only light grooves, and a scar on the surface [3].

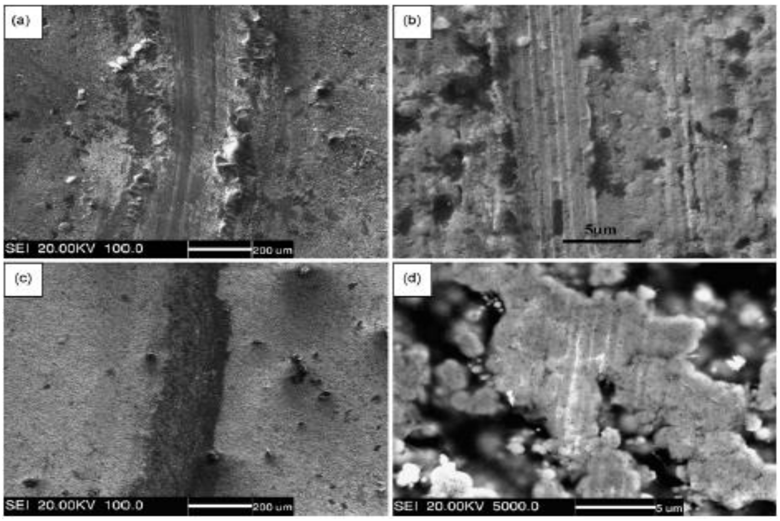


Figure 7: SEM images of worn surface of (a)(b) Ni film and (c)(d) Ni-SiC nanocomposite coating [3]

It can be summarised, the addition of harder SiC to the Ni has improved the wear behavior of the coating. The morphology of the wear tracks shows as the smaller the SiC particles deposit to the nickel, the interface of the Ni-SiC will become more smooth. At both temperatures, Ni/nSiC has excellent wear behavior and the lowest wear rate compared to Ni-SiC and Ni/µSiC. However, at 500°C annealing temperature, the Ni-P/SiC reached the lowest wear rate because the content of the oxide was lower in the wear track. Next, Ni-SiC provides higher hardness than Ni film because the characteristic of both Ni and SiC offers high wear resistance and hardness.

4. Conclusion

In conclusion, this study has achieved its objectives. The parameter used in this study was the concentration of SiC content and the temperature. The result has shown that Ni-SiC has good wear resistance, especially at high temperatures as it also provides high micro-hardness. The wear behavior of Ni-SiC composite coating was successfully conducted using the weight loss method by using the abrasive material to create a sliding wear test to create track wear before identifying the surface morphology and microstructure analysis. Thus, the sample with the best wear behavior was the sample electrodeposited in a high concentration of SiC content. As the temperature increase, the wear behavior of the coating also will be improved respectively to the coatings.

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