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Research Article

COMPARISON OF WEAR AND HARDNESS BEHAVIOR OF NiP - NiPWS$_2$ COATINGS

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Abstract – Wear resistance is a critical factor in various industries where components are subjected to friction, wear and abrasion. In this paper, we investigate the fabrication and characterization of nickel-phosphorus (Ni-P) and nickel-phosphorus-tungsten disulfide (Ni-P-WS$_2$) electroplating coatings, with a particular focus on wear resistance and hardness properties. The focus of this work is to investigate the wear resistance properties and investigate whether the hardness decreases or increases with the addition of WS$_2$ particles of these coatings and evaluate their potential in various applications. In the study, 2 different coatings, Ni-P and Ni-P-WS$_2$, were produced. In addition to the Ni-P-WS$_2$ bath, WS$_2$ particles were added at a concentration of 0.1 g/L. The current density was 18 A/dm^2 and the stirring speed, pH and temperature were kept constant. The obtained samples were characterized by scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis and the tribological behavior of the produced electrocoatings was studied. The results show that the incorporation of WS$_2$ nanoparticles into Ni-P coatings imparts excellent tribological properties to the coating by combining the hardness and wear properties of Ni-P with the lubricating properties of WS$_2$, further reducing friction and wear and increasing hardness. In this case, the benefits of Ni-P and Ni-P-WS$_2$ coatings can be utilized in a wide range of industries. In the automotive sector, these coatings can be applied to engine components such as pistons, connecting rods and crankshafts to increase their durability and reduce friction.

Keywords – Ni-P Coatings, Ni-P-WS$_2$ Coatings, Electrodeposition Coatings, Wear Resistance, Friction,

I. INTRODUCTION

In the world of coatings, electrodeposition and electroless coatings have emerged as innovative solutions to protect and enhance the surfaces of various objects. These advanced coating techniques offer unique advantages by providing durability, corrosion resistance, abrasion resistance and enhanced functionality. The most common coating methods are electroplating and electroless coatings. Both electroplating and electroless coatings have found application in various industries including automotive, aerospace, electronics and manufacturing[1],[2]. Because these coatings enhance numerous properties such as corrosion resistance, abrasion resistance, improved electrical conductivity and enhanced aesthetics, they can be customized to meet specific requirements such as hardness, lubricity and adhesion, making them versatile solutions for a wide range of applications[2].

Electroless coatings, also known as autocatalytic coatings, are a type of coating that does not require an external electric current to deposit the metal onto the substrate[3]. Instead, deposition occurs through an autocatalytic chemical reaction between the metal ions and the reducing agent in solution. Electroless coatings have several advantages over conventional electroplating methods, including their ability to produce uniform coatings on complex geometries and their excellent corrosion resistance[4]. In particular, electroless Ni-P coatings have been shown to have better corrosion resistance and mechanical properties compared to conventional electroplated coatings[5]. The applications of electroless coatings are diverse, including their use in the automotive, aerospace and electronics industries[6]. Electrodeposition coatings, also known as electroplating or electrophoretic lacquering, is a process in which a coating film is deposited on a conductive surface using electric current[7]. This technique uses an external power source to drive the deposition reaction, resulting in a uniform and adhesive coating. Electrodeposition coatings provide excellent control over coating thickness, composition and surface morphology, making them suitable for a wide range of applications.

One of the major advantages of electrodeposition coatings is that they provide high corrosion resistance[8]. The coating is continuous and compact and preferred orientation is possible in this method[8]. This method also produces coatings on very different substrates and has the ability to produce structural features ranging in size from nanometers to micrometers[9]. Electrochemical deposition also has a relatively low cost and has a better interfacial bonding between the coating material and the substrate[10]. Electrodeposition coatings have a wide range of applications, including the metal industry, automotive industry and electronics industry[11]. In the metal industry, e-coatings are used for corrosion protection, while in the automotive industry they are used for car bodies, wheels and other parts[12]. This technology is also used in the electronics industry for printed circuit boards and other electronic components[13]. Traditional uses of composite electrodeposition include Ni-SiC or Co-WC for wear resistance, abrasion and cutting, Ni-PTFE, Ni-MoS_2 or Ni-WS_2 for combined self-lubrication and wear resistance[14],[15],[16]. Electro-deposition is mostly used to apply copper, nickel, tin and zinc coatings[15]. Due to its versatility and cost-effectiveness, electroplating coatings are becoming increasingly popular in various industries. The development of composite coatings has been an active area of research in recent years[15],[16]. Composite coatings involve the incorporation of nanoparticles or other materials into the coating to improve its properties such as wear resistance or corrosion resistance[17]. Electroless Ni-P composite coatings have been particularly promising, with the addition of particles such as SiC or TiC providing significant improvements in wear resistance and other properties[2]. The electroless plating process has been shown to be effective in producing uniform and high quality composite coatings[18]. The continued development of electroless coatings and composite coatings holds great promise for improving the performance and lifetime of a wide range of industrial and consumer products[19],[20].

Ni-P coatings are known for their excellent wear resistance, making them suitable for applications where durability is crucial. These coatings provide a protective barrier against wear and corrosion, making them a popular choice for industries such as oil and gas pipelines[20]. The wear resistance of Ni-P coatings can be further increased by alloying with iron, which improves their performance in high-stress environments. Ni-P-WS_2 coatings offer higher wear resistance compared to Ni-P coatings. This innovative combination of Ni-P and WS_2 opens new possibilities for applications in high-stress environments where both corrosion and wear resistance are critical. Incorporating tungsten disulfide (WS_2) nanoparticles into the electroplating process improves the tribological properties of the coating. WS_2 is a solid lubricant that reduces friction and increases wear resistance. The addition of WS_2 nanoparticles into the Ni-P matrix creates a composite coating that combines the corrosion resistance and wear properties of Ni-P with the lubricating properties of WS_2 and increases wear resistance[21]. The wear resistance of Ni-P-WS_2 coatings has been studied in various research articles and their superior performance compared to other coatings has been highlighted. For example, electroless Ni-P-SiC-WS_2 composite coatings have been shown to exhibit excellent wear resistance and antifriction properties [22]. Similarly, Ni-P-MoS_2-Al_2O_3 composite coatings have been developed with many properties including improved wear resistance.

From the studies, it appears that while Ni-P coatings offer good wear resistance, Ni-P-WS_2 coatings provide even higher wear resistance due to the incorporation of WS_2 nanoparticles. The addition of WS_2 improves the tribological properties of the coating, reduces friction and increases wear resistance, making Ni-P-WS_2 coatings particularly suitable for applications where wear protection is critical. Based on our experimental deductions in this study, we will investigate the effect and comparison of Ni-P and Ni-P-WS_2 flow coatings on wear behavior.

II. EXPERİMENTAL

A. Coating Bath And Conditions

Ni-P-WS_2 composite coatings were produced by the flow method. During the flow coating process, the bath temperature was 70 degrees Celsius, the pH was kept between 4-5, the stirring speed was kept constant at 200 rpm and the current density was 18 A/dm^2 [Table 2]. Before current coating, the solution containing ceramic particles (WS_2) was mechanically stirred for 1 hour and then ultrasonically dispersed for 2 hours to prevent agglomeration during coating. The cathode is a 1040 steel with dimensions of 3x3x2 cm and the anode is a nickel plate with a distance of 30 mm. The substrate (1040 steel) was mechanically polished using 240-400-800-1200 grit sandpaper. In the final treatment prior to flow coating, the steel substrate was kept in HCL acid for 45 seconds to remove contaminants.

Ni-P coating was also produced by the flow coating method. During the coating process, all the processes applied to the Ni-P coating were also applied to the Ni-P coating.

Table 1. Bath Components And Quantities

Bathroom Components	Quantity of Components (Ni-P)	Quantity of Components (Ni-P-WS_2)
$NiSO_4.6\ H_2O$	180 g/L	180 g/L
$NiCl_2.6\ H_2O$	10 g/L	10 g/L
H_3PO_3	20 g/L	20 g/L
H_3PO_4	10 g/L	10 g/L
$Na_3C_6H_5O_7.H_2O$	70 g/L	70 g/L
WS_2	0	0.1 g/L

Table 2. Coating Parameters

Parameter	Condition
Current density	18 A/dm^2
Pulse frequency	600 Hz
Duty cycle	50%
Stirring speed	200 rpm
Bath temperature	70 ± 1 ℃
pH	5 ± 0.1
Deposition time	45 min

B. Characterization Of The Coating

Scanning Electron Microscopy (SEM) was used to analyze the surface morphology and microstructure of the coatings. The phase composition, crystallite size and phase structures of the coating were performed by X-ray diffraction (XRD Rigaku D/max-2400) analysis using a Cu radiation source (XRD Rigaku D/max-2400) at 1°/min increment from 10° to 90°.

The wear resistance of the coatings was tested by sliding tribological tests against an. The wear tests were performed under a load of 1 N, at a sliding distance of 500 m and a sliding speed of 0.2 m/s. The tribological behavior of lumina (Al_2O_3) against ball was investigated on a tribometer. A load of 1 N was applied to the coating surface during the wear process. The hardness of the coatings was measured as 280-571 HV depending on the particle volume in the Ni-P matrix. All friction and wear tests were carried out at room temperature and ambient air (55-65% relative humidity) without lubrication. The elemental content analysis and wear mechanism of the specimens were analyzed by SEM equipped with EDS. The coefficient of friction (COF) of the coating was obtained by friction test.

The hardness of the coatings was evaluated by Vickers microhardness tester under 50 g load loading condition and 15 s loading.

III. RESULTS AND DISCUSSIONS

Surface SEM images of Ni-P and Ni-P-WS_2 composite coatings are given in Figure 1. As can be seen in Figure 1, the surface appearance of the NiP coating was nodular, while the nodules became smaller with WS_2 reinforcement. The reinforced WS_2 powders formed new nucleation areas on the surface of the substrate, which led to significant changes in morphology.

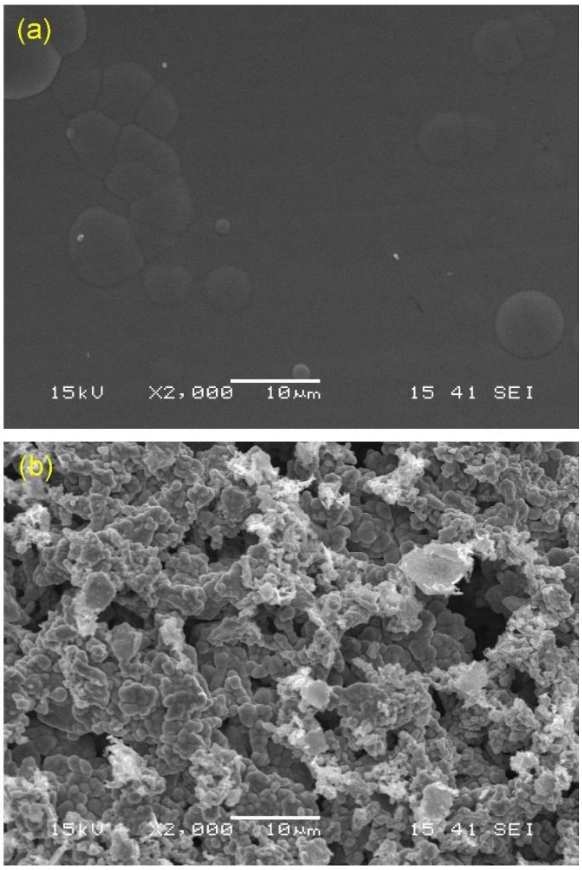
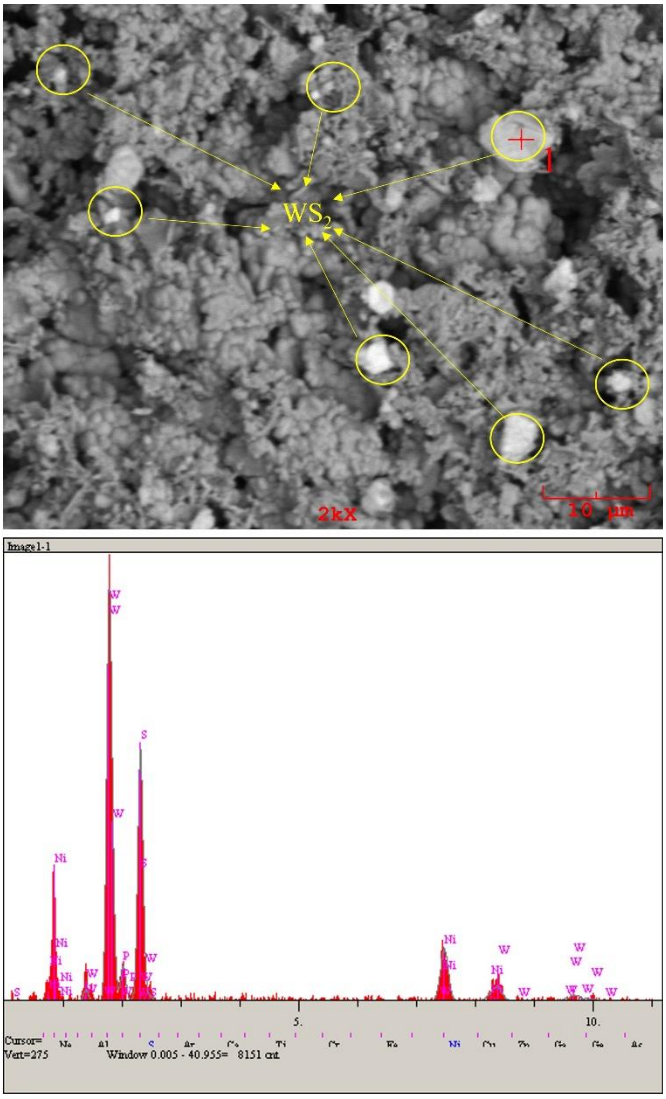


Fig. 1 (a) Ni-P coating surface SEM images

(b) Ni-P-WS2 coating surface SEM images

The EDS analysis result from the surface of the composite Ni-P-WS_2 coating is given in Figure 2. The white spots in the figure are WS_2 powders. The EDS analysis result also shows this. It is also seen that WS_2 powders are dispersed in the structure.



Elt.	Line	Intensity (c/s)	Error 2-sig	Conc	Units	
P	Ka	21.54	2.935	2.969	wt.%	
S	Ka	171.14	8.272	24.259	wt.%	
Ni	Ka	52.38	4.576	28.578	wt.%	
W	La	13.19	2.296	44.194	wt.%	
				100.000	wt.%	Total

Fig. 2 EDS analysis result of Ni-P-WS_2 coating from the surface.

XRD analysis was performed to determine the phases in NiP and Ni-P-WS_2 coatings. The result of XRD analysis is given in Figure 3. In the XRD analysis, the peak belonging to the (111) plane of nickel at 2ϴ=44° is seen in the Ni-P coating. In the composite coating, peaks representing nickel and WS_2 powders are also seen. In the XRD analysis of the composite coating, the peak at 2Θ=44° belongs to nickel, while the remaining peaks belong to WS_2.

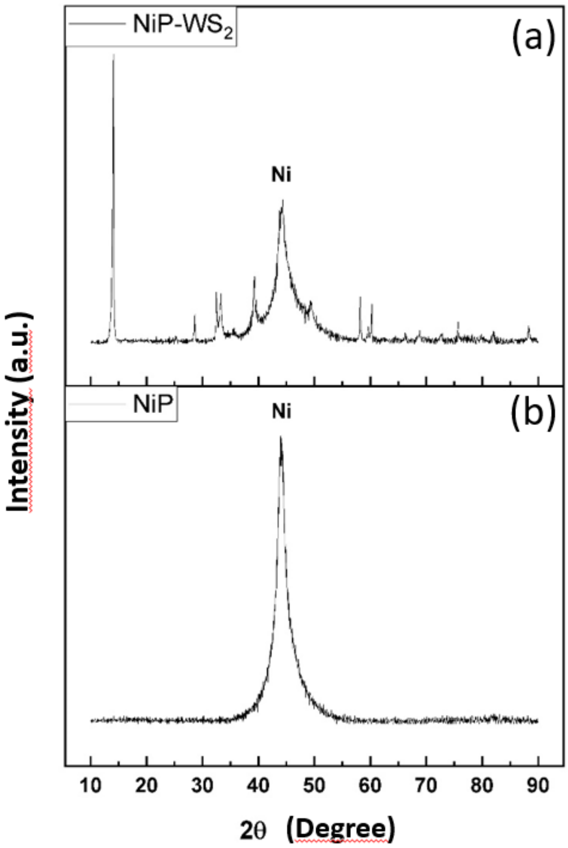


Fig. 3 (a) XRD patterns of the Ni-P-WS_2 coatings

(b) XRD patterns of the Ni-P coatings

A comparison of the hardness of Ni-P and WS_2 reinforced composite coating is given in Figure 4. The average hardness value of the NiP coating was around 630 HV, while the hardness of the WS_2 reinforced Ni-P coating was 720 HV. WS_2 reinforcement caused dispersion hardening in the Ni-P matrix. It also led to the formation of a finer grained matrix as WS_2 powders created new nucleation sites in the coating. This led to an increase in hardness.

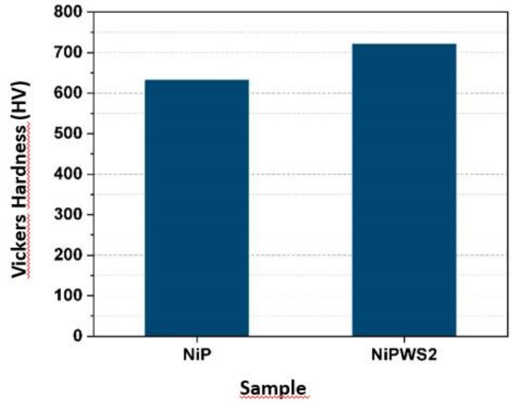


Fig. 4 Hardness of Ni-P and Ni-P- WS_2 coatings

The average coefficient of friction and wear rate graphs of the undoped and doped Ni-P coatings obtained in wear tests at room temperature and dry environment are given in Figure 5. The average coefficient of friction of the Ni-P coating was measured as 0.32 μ and 0.26 μ for the Ni-P- WS_2 coating. The wear rate of the coatings was calculated as $6.51x10^{-7}$ and $4.12\ x10^{-7}$ mm^3/Nm, respectively. There was a significant decrease in the friction coefficient and wear rate of the coating with WS_2 reinforcement. This shows that the wear resistance of the coating has improved with WS_2 reinforcement.

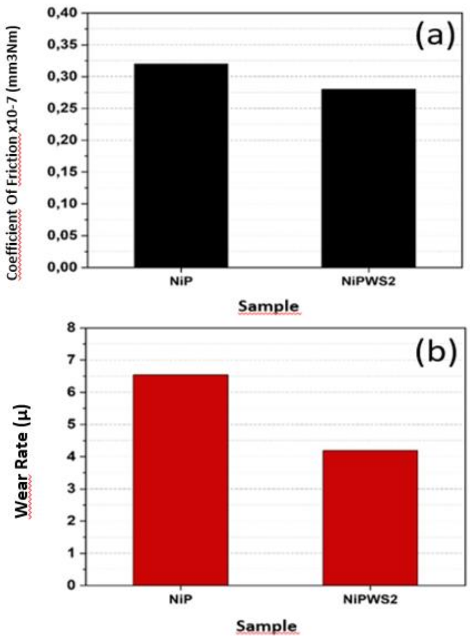


Fig. 5 (a) Wear rate as a function of Ni-P and Ni-P-WS_2 coatings (b) Coefficient of friction as a function of time for Ni-P and Ni-P-WS_2 electrodeposited coatings

SEM images of the worn areas of the coatings after abrasion are given in Figure 6. Figure 6a shows the wear surface of the Ni-P coating. It is observed that crack formation and plastic deformation occur on the surface of the Ni-P coating during wear. In the Ni-P coating, the matrix could not bear the load on it, first deformation hardening occurred and then cracks formed in the areas where hardening occurred. The composite coating shows a compact surface. WS_2 reinforcement increased the hardness and load carrying capacity of the coating. In addition, the lubricity of WS_2 protected the surface from abrasion.

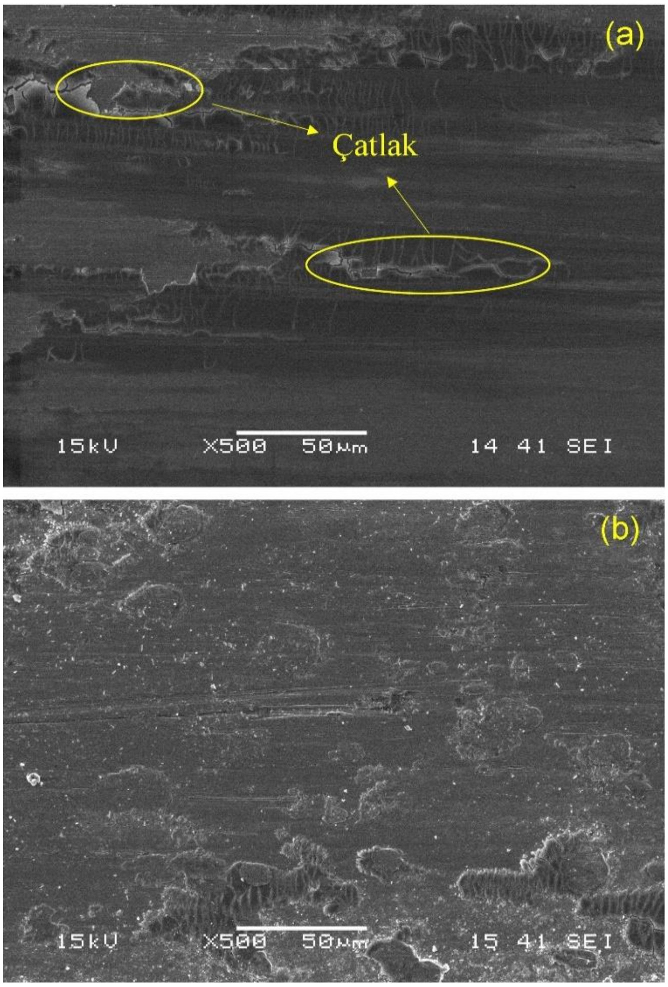


Fig. 5 SEM images of the wear track Comparison of wear patterns for (a) Ni-P coating (b) Ni-P-WS_2 coating

IV. CONCLUSION

Ni-P and Ni-P-WS_2 coatings have been successfully produced and characterized. WS_2 reinforcement led to significant changes in the morphology of the coating and increased the hardness. A decrease in the coefficient of friction and wear rate of the Ni-P-WS_2 composite coating was observed. An improvement in wear resistance was observed with WS_2 reinforcement from the wear surface of the coatings.Nickel-phosphorus (Ni-P) coatings have long been recognized for their outstanding corrosion resistance and wear properties. By electro-precipitating nickel and phosphorus onto a substrate, a highly uniform and adhesive protective layer is formed, which can greatly extend the life of the coated material. The phosphorus content in the coating can be adjusted to achieve specific properties such as increasing hardness or improving lubricity[23]. These coatings offer numerous advantages such as increased hardness, wear resistance and corrosion protection. Ni-P-WS_2 coatings, on the other hand, take the advantages of Ni-P coatings one step further by incorporating tungsten disulfide (WS_2) nanoparticles into the electroplating process[23]. The addition of WS_2, a solid lubricant, gives the coating excellent tribological properties, further reducing friction and wear. The incorporation of WS_2 nanoparticles into Ni-P coatings creates a unique composite coating that combines the corrosion resistance and wear properties of Ni-P with the lubricating properties of WS_2. This combination offers improved performance and durability, making Ni-P-WS_2 coatings ideal for applications where friction reduction and wear protection are required[24].

In summary, while Ni-P coatings provide excellent corrosion resistance and wear properties, Ni-P-WS_2 coatings take this a step further by incorporating WS_2 nanoparticles to further reduce friction and improve wear resistance. The addition of WS_2 improves the tribological properties of the coating, making it suitable for high-stress environments where both corrosion and wear resistance are important[25].

In this case, the benefits of Ni-P and Ni-P-WS_2 coatings can be utilized in a wide range of industries. In the automotive sector, these coatings can be applied to engine components such as pistons, connecting rods and crankshafts to increase their durability and reduce friction. In the aerospace industry, Ni-P and Ni-P-WS_2 coatings can be used on aircraft parts to improve resistance to wear, corrosion and fatigue [26].

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