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Modification of Nanoparticle Absorption Using Sodium Dodecyl Sulfate Addition in Composite Plating Bath

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ABSTRACT

The present research aimed to compare nickel-alumina nanocomposite coatings. The content of alumina nanoparticles has the greatest impact on these coatings. In this research, the electrolyte composition was modified by adding Sodium dodecyl sulfate (SDS). The concentration of alumina nanoparticles in the plating bath was 3 grams per liter. The nickel-alumina nanocomposite coating was created by pulsed electric current and under ultrasonic turbulence in electroplating baths. Two nickel plating baths with the combination of Watt with the addition of SDS and without SDS were used to create coatings, and before plating, the zeta potential of alumina nanoparticles was measured in two different baths. After the plating process, the cross-section of the coatings, the amount of alumina nanoparticles incorporated in the coating, and the morphology of each coating were analyzed by a scanning electron microscope (SEM) equipped with an Energy Dispersive x-ray Spectroscopy (EDS). The results showed that by increasing the SDS to the Watt solution, the zeta potential of nanoparticles increased from negative 2 mV to positive 42.5 mV and subsequently, the content of alumina reinforcing nanoparticles in the coatings increased from 2.6% volume percentage to 3.5% volume percentage. It appears that the SDS might be able to act as a proper surfactant, affect the hydrated layer on the nanoparticles, and improve the co-deposition of alumina nanoparticles with nickel in the composite coatings.

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Introduction

Nickel-based coatings have received a great deal of attention due to their desirable mechanical properties, and resistance to wear and corrosion. With the progress of the industry, pure nickel coatings cannot meet existing needs. For this reason, many efforts have been made to modify the properties of nickel coatings using different methods. Among these methods is the creation of a secondary phase in the form of non-metallic particles scattered in the field, which are referred to as nickel field composite coatings [1]. These coatings are often created using ceramic particles. In recent years, the global research approach has been directed towards the application of these coatings using nanometer particles [2]. Nickel-based composite coatings can provide unique physical, mechanical and chemical properties which could be used as wear and corrosion-resistant coatings [3-5]. This holds promise for low-cost advanced materials that can be produced using electrochemical plating [6; 7]. The advantages of the electrochemical plating method compared to other coating methods such as physical vapor deposition, chemical vapor deposition and powder metallurgy include more homogeneous distribution of particles, reduction of waste and process capability and continuous production [8; 9]. However, particle dispersion (especially for nanoparticles) in a co-plating bath can become a problem. In most cases, problems such as agglomeration of particles occur, which causes a lack of successful deposition or non-uniform distribution of particles in the particulate composite [10; 11].

Electroplated nanocomposite coatings are obtained by electrochemical deposition of the base material in addition to reinforcing particles suspended in it. Composite electroplating baths consist of solutions containing base metal ions and suspended particles such as oxides, carbides, nitrides and metal powder [12; 13]. This method was used in the present work using alumina particles with nanometer size to produce a nanocomposite coating. Due to the high wear resistance and low cost of alumina powder, nickel-alumina composites have been widely used and commercialized to protect mechanical parts from wear corrosion [14; 15]. In this study, the role of adding sodium dodecyl sulfate (SDS) in the formation of nickel-alumina nanocomposite coatings was analyzed. The effects of adding sodium dodecyl sulfate to the composite plating bath on the deposition rate of alumina nanoparticles, the structure of nanocomposite coatings and the zeta potential of nanoparticles in the plating solution were also investigated.

Methodology

CK45 steel bases were used to create the covers. Samples were prepared in dimensions of 20x25x80 mm. The surface of the samples was sanded with sandpaper up to number 1000 and then degreasing was carried out in a solution of 20% by weight of NaOH and KOH. Before the electroplating stage, the samples were acid-washed in a solution of 10% by weight of sulfuric acid. Washing with distilled water and alcohol and drying were also undertaken between each of the mentioned steps. Nickel-alumina nanocomposite coatings were deposited on steel samples using Watt solution with the selected composition for this research. The chemical composition of the electrolytic bath and plating conditions are shown in Table 1.

Table 1. The chemical composition of the plating bath and plating conditions.

The composition of the composite plating solution		Applied conditions of composite plating	
Nickel sulfate $NiSO_4.6H_2O$	300 g/l	temperature (degrees Celsius)	50
Nickel chloride $NiCl_2.6H_2O$	50 g/l	time (minutes)	20
Boric acid H_3BO_4	40 g/l	pH	3.7
Alumina nanoparticles	3 g/l	Cathodic current density (A/dm^2)	7

The plating was carried out by pulsed electric method. The homogenization of the electroplating solution was undertaken in two ways: magnetic and ultrasonic. Before the start of electroplating, the solution and nanoparticles were homogenized by the two mentioned methods, and this homogenization continued during electroplating. The characteristics of magnetic and ultrasonic homogenization and pulsed current parameters are presented in Table 2.

Table 2. Pulsed current parameters and characteristics of creating magnetic and ultrasonic turbulence.

Pulsed current		Applied conditions of composite plating	
Current frequency	1000 Hz	Mechanical turbulence speed	100 rpm
Duty cycle	50 %	Ultrasonic turbulence	20
T on and T off	500 µs		

The coating was carried out in a nickel plating bath with the combination of Watt with the addition of 10 g/L of sodium dodecyl sulfate (SDS) and without SDS. Before the electroplating processes, the zeta potential of alumina nanoparticles was analyzed in each of the electroplating baths. A Zetasizer Malvern model (Nano-ZS) device was used to measure the zeta potential in the solutions. Before coating, stirring by the ultrasonic probe was repeated for 20 minutes. Each experiment was repeated three times. Then, the morphology of the coatings was studied followed by their quantitative analysis. For this purpose, the cross-section of the coatings was made and after surface preparation, they were subjected to EDX microscopy using a MIRA 3 electron microscope.

Results and discussion

Characterization of alumina nanoparticles and coating surface morphology

The TEM image of alumina nanoparticles is presented in Figure 1. As observed in this image, the nanoparticles have an elliptical shape and their diameter is between 30 and 40 nm. This result confirms the average value given by the manufacturer (30 nm). Electroplated composite coatings were examined using a light microscope and electron microscope equipped with EDX.

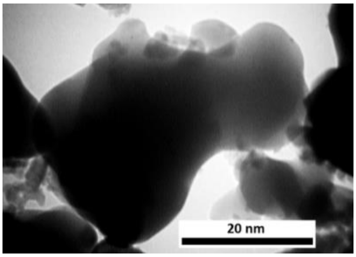

Figure 1. Transmission electron microscopic (TEM) image of alumina nanoparticles.

As previously mentioned, steel samples were subjected to the electro-pulse electroplating process after surface preparation with plating baths without sodium dodecyl sulfate (SDS) and containing SDS for 20 minutes at a temperature of 50 degrees Celsius to create nickel-alumina nanocomposite coatings. Examining the samples taken out of the electroplating solution by the naked eye indicates the formation of a coating on the samples. Figure 2 shows the electron micrograph of the outer surface of the electroplated coating in the electroplating bath containing SDS and without SDS. As can be observed in Figure 2, alumina nanoparticles are scattered and visible in the form of white-colored phases on the surface of the coating, and EDX analysis confirms this result.

Viewing the cross-section and comparing the amount of alumina nanoparticles in the coatings

The cross-section of nickel-alumina nanocomposite coatings plated in the electroplating bath without SDS and containing SDS is shown in the electron microscope images of Figure 2. Figure 2, part (a) shows that nickel-alumina plated coatings corresponding to the SDS-free plating bath have a bright background with very few dark spots. These dark spots have been detected by EDX analysis, and show alumina nanoparticles trapped in the nickel field. From the comparison of electron images in parts (a) and (b) of Figure 2, it is clear that the deposited alumina in nanocomposite coatings increases with the addition of SDS to the plating bath.

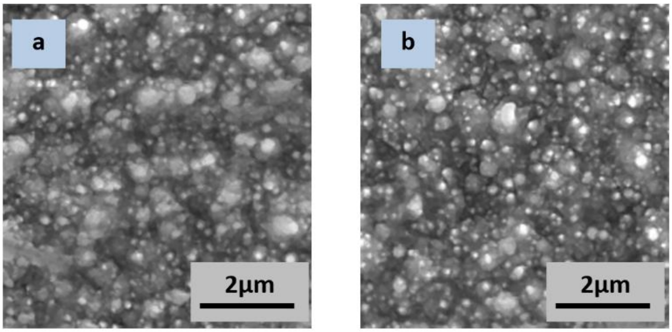

Figure 2. Electron microscope image of the cross-sectional view of nickel-alumina nanocomposite coatings plated in (a) Watt solution without sodium dodecyl sulfate (SDS) and (b) Watt's solution containing sodium dodecyl sulfate (SDS).

Figure 3 shows the effect of adding SDS on the difference in alumina absorption in nanocomposite coatings as well as zeta potentials measured in electroplating baths containing SDS and without SDS. Based on the results shown in Figure 3, the percentage of alumina nanoparticles deposited on the nickel substrate coating by adding SDS to the plating bath recorded up to 3.5% by volume while the nanocomposite coatings plated in the plating bath without SDS contained 2.6% by volume of alumina nanoparticles. These results show that the percentage of nanoparticles in the coating increased by more than one and a half times through adding SDS to the plating bath. According to the research of Mirzamohammadi et al. [16], the maximum amount of alumina deposited in the coating occurs when a stable equilibrium state is established on the surface of the cathode. This implies that the number of alumina nanoparticles that enter the coating and are trapped in the coating is equal to the number of alumina nanoparticles that approach the cathode surface. When the suspended alumina near the cathode exceeds the maximum amount of alumina deposition in the stable equilibrium, the suspended alumina nanoparticles are agglomerated in the plating bath and the amount of nanoparticles introduced in the nickel field is reduced [17]. In addition, the agglomerates of nanoparticles themselves can block other nanoparticles to further enter the nanocomposite coating. This phenomenon is called the barrier effect [18].

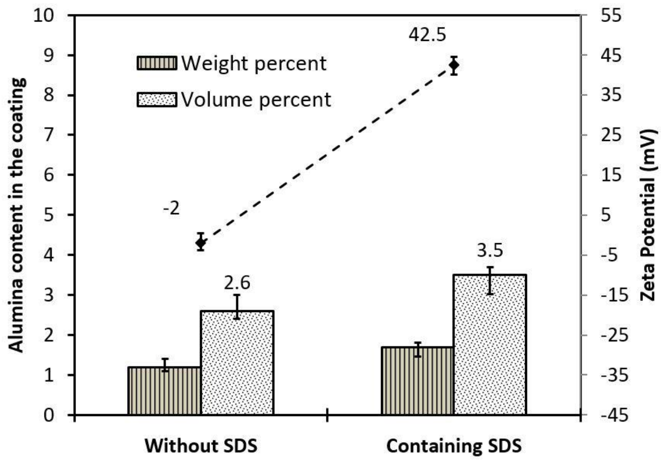

Figure 3. The effect of sodium dodecyl sulfate (SDS) on zeta potential of alumina nanoparticles in Watt solution and alumina precipitation in electroplated nickel alumina nanocomposite coatings.

The performance of SDS surfactants is based on reducing surface tension. When SDSs are added to an aqueous environment, their molecules are transferred to the surface of the water and form a microscopic layer. The hydrophilic head of the SDS is placed towards the water and their hydrophobic tail towards the powders [19]. This structure reduces the surface tension and enables the formation of micelles. Micelles are collections of surfactant molecules that enclose powders and suspend them in water. There are different types of surfactants, which are classified according to their polar head group because the hydrophobic tails of this material are often similar. Different types of surfactants can be placed in two categories, anionic and cationic. SDS is placed in the anionic category [20]. As illustrated in Figure 4, surfactants have different heads in terms of electrical charge. SDS has a positive charge head.

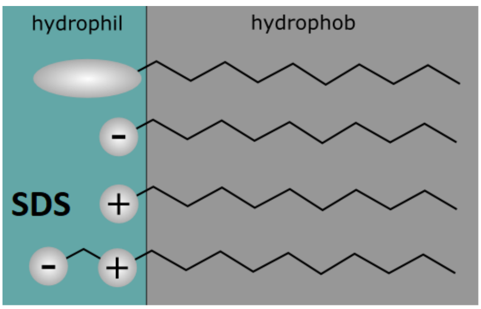

Figure 4. In different heads of surfactants in terms of ionic charge, SDS has a positive charge.

The Zeta potential of alumina nanoparticles in Watt solution without additives and Watt solution containing SDS is also depicted in Figure 3. This value is very low according to research results [18; 21]. These studies have shown that the zeta potential is a key value for suspending nanoparticles and preventing their agglomeration in plating electrolytes. Chen et al. have reported [21] that this is due to the modification of the surface charge of nanoparticles by absorbing ions and molecules and as a result increasing the electrophoretic movement of suspended nanoparticles. When the potential of nanoparticles is significantly lower than other samples (here 2 mV), the amount of nanoparticles in the coating is the lowest value (Figure 3). Low zeta potential and close to zero increases the probability of agglomeration of nanoparticles and reduces the absorption of nanoparticles in the coating. This is because the hydrated or double layer, formed around the nanoparticles, is not sufficiently thick to maintain separation of the nanoparticles [22]. One of the characteristics of the hydrated layer formed around the nanoparticles is to prevent their agglomeration and improve the dispersion of nanoparticles in the electrolyte [23]. Therefore, it can be concluded that the effect of SDS in this research in increasing the zeta potential of alumina nanoparticles can be a highly effective factor in increasing the absorption of alumina nanoparticles in the coating as can be observed in the resulting process in Figure 3. The addition of SDS causes a significant increase in the zeta potential and subsequently an increase of more than one and a half times in the content of reinforcing nanoparticles in the electroplated nanocomposite coating.

Conclusion

Nanocomposite coatings of nickel and alumina metal base were successfully plated on a steel surface from a Watt bath containing organic solvent sodium dodecyl sulfate (SDS) and alumina nanoparticles. The morphology, the amount of alumina nanoparticles incorporated and the zeta potentials of the nanoparticles were investigated in the electroplating bath. The following are the general results.

- The Zeta potential of alumina nanoparticles increased from minus 2 mV to 42.5 mV. This was due to the addition of sodium dodecyl sulfate (SDS) to the Watt solution.
- By adding sodium dodecyl sulfate (SDS) to the Watt solution, the content of alumina in plated nanocomposite coatings increased significantly.
- It appears that the increase in alumina content from 2.6% by volume to 3.5% by volume was due to the following reasons: (a) reducing the possibility of elastic collision of nanoparticles in the electrolyte-cathode

interface; (b) reducing the barrier effect; and (c) reducing the possibility agglomeration in the electrolyte.

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