Journal of Mechanical and Construction Engineering, 2023,
Vol. 03, Iss. 01, S. No. 005, pp. 1-10
ISSN (Online): 2583-0619

A Comprehensive Analysis of the Properties of Electrodeposited Nickel Composite Coatings

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How to cite this paper: A. A. Bhadre and H. P. Ghongade, "A Comprehensive Analysis of the Properties of Electrodeposited Nickel Composite Coatings," *Journal of Mechanical and Construction Engineering (JMCE),* Vol. 03, Iss. 01, S. No. 005, pp. 1–10, 2023.

https://doi.org/10.54060/jmce.v3i1.24

Received: 02/01/2023
Accepted: 12/03/2023
Published: 25/04/2023

Abstract

For a long time, environmental protection of metallic components has become a pressing concern for the engineering and manufacturing industries. Coating technology has gained prominence to meet the needs of industrial demands. The coating is used to protect the metals and ensure the product's performance for a long time. Among other coating processes such as thermal spray, spark plasma sintering, and chemical vapor deposition, the electrodeposition process has proven to be the most cost effective and simple. The paper discusses the properties of various Nickel composite electrodeposited Protective coatings.

Keywords

Protective Coatings, Electrodeposition, Nickel composites, Composite Materials.

1. Introduction

Electrodeposition is one of the most successful methods for coating metal due to its uncomplicated and consistent process which has unique advantages in the microstructure and property modification of the depositions. The components, phases, and microstructures of the deposits can be regulated by modifying the electrodeposition parameters, such as the deposition potential, current density, electrolyte composition, PH value, temperature, etc. [1]. Due to flaws like wear, corrosion, and fatigue, a lot of machine parts fail. The characteristics like tribological, mechanical, and corrosion resistance are boosted by coating the reinforcing material on it [2]. The recommended method is nickel plating because it is renowned for its consistent plating thickness on the plated surface and the easiness with which intricate components can be coated. It also possesses exceptional levels of hardness and corrosion resistance [3]. The anti-wear qualities of the nickel coating have expanded their range of possible uses for dies, tools, and working parts for cars and other vehicles. With the available one, the spectrum of alloys might be expanded for functional purposes. By modifying the composite coating on the materials, it is feasible to avoid using pricey heat treatment procedures on standard alloys. [4]. The electro-chemical process is important in the field of nanotechnology. The co-deposition of composite material particles dispersion and the presence of these particles in the coating are accomplished using electrolyte baths containing micron/sub-micron-sized particles. The type of composite coating material particles and their inclusion determine the qualities of the coating material. [5-6].

2. Methodology of Electrodeposition

2.1. Electrodeposition

Electrodeposition process can accomplish the reduction of the desired metal's cations before they are deposited on the surface of a conducting substrate. Two conductive electrodes are used in the coating setup, and they are submerged in an electrolyte bath. The working-cathode or electrode is thought to be a single terminal connected to the negative terminal. One more is referred to as a counter-electrode or anode and is attached to the positive terminal. The cations travel to the cathode, are discharged, and then deposit as a metallic layer when an external electric field is introduced. Electrodeposition is the ideal technique for achieving smooth and ideal contact between the matrix metal and ceramic particles [7-8]. Electrodeposition, often known as electroplating, is a technique for electrolytically depositing a coating on a substrate that is immersed in an electrolyte. An aqueous medium at room temperature can be used for this. Aqueous solution electroplating refers to the method of electroplating aqueous solutions at room temperature. using a fused-salt solution, also known as electroplating, or in a high- temperature fusion salt. One of the major drawbacks of electrodeposition is the inability to obtain consistency in coating thickness. Other limitations of the substrate include hydrogen ion assessment and essential surface preparation [9]. Electrodeposition is widely utilized for aesthetic coatings as well as corrosion and wear resistance. It is also used in specialized applications including high temperature resistance, biomedical, and ceramic coating by increasing the electrode potential [10]. Electrodeposition can produce metallic systems with all of these dimensionalities, while three-dimensional systems have the largest variety of applications [11]. Both direct (DC) and pulse current can be used in the electrodeposition process (PC). The coating can be applied to the substrate's surface to improve solderability, lubricating characteristics, electrical conductivity, corrosion resistance, wear and thermal resistance [12]. Deep recesses and irregularly shaped geometries can be deposited upon using electrodeposition with less sophisticated plating conditions and equipment [13].

2.2. Composite Coating

Composite coating is a new type of coating developed by modern experts. Normally, several types of composite materials are used depending on the matrix. Examples of these materials composites include ceramic matrix composites and metal matrix composites. Composites include things like carbon matrix composites and polymer matrix composites [14]. Metal matrix composite coating is one of the most widely utilized in the industry due to its efficiency [15]. MMC coatings, which combine the ceramic phase's high hardness and strength with the matrix's sound toughness, are frequently utilized for surface repair and strengthening of engineering metal components. The inclusion of reinforcing particles can be done in two ways. Due to the low wetting capabilities of the ceramic and metallic phases, particle-matrix bonding is fundamentally difficult with external addition or ex situ. The ceramic reinforcing phase of the coating is created by an in-situ chemical reaction between elements of the precursor material at a very high temperature, followed by in situ nucleation and growth. These hard particles are consequently more thermodynamically stable and finer than hard particles injected from the outside. There are multiple sorts and designs of composite coatings. Composite coatings of different forms, shapes, sizes, and quality can be produced by choosing the right ceramic and matrix coating materials, procedures, and technologies [16]. Al, Fe, Mg, Ti, Ni, Be and Co are some of the commonly used materials for metal matrix composites [17-18]. Metal matrix composites' (MMC) properties are generally determined by their composition and structure [19]. To maximize coating characteristics, a homogeneous distribution and large number of particles participating in the metal matrix are required [20-21]. Enhanced coating performance is often caused by modifications to the growth mode or grain size of the metal matrix [21-22]. The size, diversity, and shape of the implanted particles, as well as current density, pH, electrolyte agitation, and bath composition, are all dependent factors that affect particle incorporation [23]. Due to the enormous potential for developing materials with specialized features, MMCs have found use in a variety of fields [13]. The Ni-based MMC coating is one of the most challenging and interesting metal matrix coatings [15]. Many composite coatings have been extensively electrodeposited, including Ni-SiC, Al203, Tio2, Zro2, Si3N4, Mo, Cr, and others [8]. Nickel-based composite coatings have opened up new possibilities because of their exceptional wear and corrosion resistance as well as their high hardness [15]. On tribological parameters including coefficient of friction, hardness, roughness, and wear rate, various alloying elements and hard particles incorporated in the nickel matrix have a variety of effects. These factors can cause the value of characteristics to rise or fall [24].

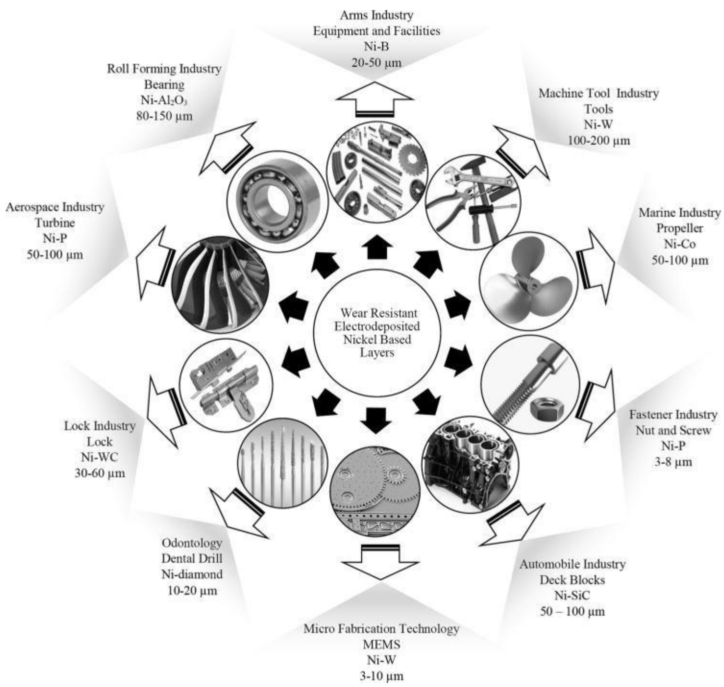

Figure 1. Applications of Electrodeposited Nickel coating [24]

Numerous chemical, mechanical, and electrical processes require nickel and alloys including nickel phosphorous, nickel tungsten, nickel cobalt, and others. The importance of composite coatings with superior wear resistance is rising along with the demand for longer industrial component service lives [25]. The applications of nickel composite coatings are shown in

Figure 1, which range from the maritime sector to the lock industry. The addition of the particles raises the coating's hardness and wear resistance while also lowering its coefficient of friction. Among other engineering components, a nickel-based coating is applied to cutting tools, turbine blades, rollers, plungers, rolling mill rolls, extruders, piston heads, and rods [15].

2.3. Similar Electrodeposition Work Carried Out

Mohan reddy et al. [26] studied the electrodeposition procedure used to make a Ni-Si3N4 coating. More corrosion resistance was seen in Ni–Si3N4 nanocomposites containing 3 g/L Si3N4 nanoparticles in the bath solution. The performance of Ni-Si3N4 nanocomposites prepared in the presence of SDS was subpar in comparison to Ni-Si3N4 nanocomposites prepared without SDS. Without the use of a surfactant, Ni-Si3N4 nanocomposites have higher corrosion resistance and particle inclusion. In the investigation, about 9% of the nanoparticles were deposited in the coating.

D Rashmi et al. [27] investigated the electro fabrication of nanostructured Ni-Fe alloy coatings on mild steel using a sulphate bath. For the coating, the composition of the electrolytic bath and current density were adjusted. Energy dispersive X-ray spectroscopy has been used to identify the composition of the Ni-Fe alloy. The coatings are unique in kind. Tests for corrosion using potentiodynamic polarisation and electrochemical impedance Spectroscopic techniques indicate that 4 A dm-2 is the lowest corrosion rate in a solution of 3.5 percent NaCl. The Vickers hardness test and atomic force microscopy were used to measure the coatings' hardness and roughness, respectively. The surface morphology of the coatings was examined using scanning electron microscopy. X-ray diffraction was used to calculate and analyze the texture coefficient, phase structure, and crystallite grain size of the coating.

Roberta Lee et al. [28] investigated the electrodeposition of niobium oxide from a variety of aqueous and non-aqueous solvent systems using sol-gel processing techniques. The process depends on protons and hydroxide ions being produced electrochemically by adjusting the electrochemical pH of the solution. In non-aqueous solutions containing tertiary niobium alkoxides, two-electron reduction results in hydroxide ions. In aqueous alkaline systems containing niobate, water undergoes electrochemical oxidation, which results in a pH drop. Niobium oxide and mixed niobate are created as the niobate sol destabilizes and an electrode coating form.

Bapu Gr et al. [29] studied the dispersion-strengthened nickel was generated utilizing the electro-code position method using a nickel fluoborite electrolyte containing vanadium pentoxide (V2O5) particles in solution. The effects of particle size, particle concentration in the bath, current density, pH, and temperature on the volume percent (vol. percent) integration of V2O5 particles in the composite were investigated. Investigation and comparison of the composite's corrosion behaviors in a 5% sodium chloride (NaCl) solution with mild steel and nickel deposits were also conducted. The percentage of V2O5 particles in the composite increased with rising V2O5 content in the bath and rising current density. The bath's operation at 6.0-amp dm-2, pH 3.0, and 50 "C produced the best incorporation of V2O5 (12.6 vol. percent). According to corrosion testing, the composite prevents steel from corroding when there is NaCl present. In a NaCl solution with a pH of 3.0, the composites' corrosion resistance is weaker to that of nickel deposits, but in a NaCl solution with a pH of 6.5, they offer comparable defense.

2.4. Components of Electrolytic Bath

The preparation of the electrolytic bath with the right proportion is very much essential for the electrodeposition quality. The nickel electrodeposition mainly consists of Nickel sulphate, Nickel Chloride and Boric acid in its electrolytic solution. The related particle size zinc, graphene, iron etc. are to be added with required proportion for nickel composite coating along with the electrolytic solution. The electrolytic composition data of the various composite coatings are given in the table.

SDS (Sodium Do-Decyl Sulphate), an anionic surfactant, has been shown to boost the coating's hardness and improve its adherence to the matrix [30]. The corrosion resistance has increased, and the particle distribution has become more uniform due to the addition of more SDS, a surfactant, to the electrolytic solution for Ni-Alumina [31]. The composition and operational parameters of various Nickel composite coatings are listed in Table 1.

Table 1. The composition and operational parameters of various Nickel composite coatings

Composite Coating	$NiSo_4.6H_2O$ (Nickel Sulpate) (gL^{-1})	$NiCl_2.6H_20$ (Nickel Chloride) (gL^{-1})	H_3 $B0_3$ (gL^{-1})	Particles (gL^{-1})	pH	T temperature (°C)	Current Density (A dm^{-2})	Time (min)	Reference
Nickel–graphene	85-100	12 to 15	25-35	0.2	3 – 4	45±5°C	5	60	[32]
Nickel-Graphene	330	35	40	0.1	3.5	51±1°C	5	55	[33]
Nickel-Graphene	300	50	40	0.5,0.25,0.1	4±2	45±5°C	5	50-60	[34]
Nickel-Graphene	26.26	56.81	18.54	0.1	3.8-4	40°C	5.66	50	[35]
Nickel-Graphene	110-115	18-25	35-45	0.2,0.4	3 – 4	50°C	5	30	[36]
Nickel-Graphene oxide	240	45	30	0.1(GO)	3.5 - 4.5	55-60 °C	6 to 10	65	[37]
Nickel-Reduced Graphene oxide	250	35	35	4.37	3 - 4	55°C	3.5	12 h	[38]
Nickel-Graphene	300	35	40	0.05	4±1	50°C	0.15-4	1-3 hours	[39]
Nickel-Graphene	95-110	15-20	30-40	0.2	3-4	50-55 °C	5	50	[40]
Nickel-Vanadium pentoxide	280	5	40	5 to 50	1- 5	30-70 °C	2 to 10	8h	[29]
Nickel-Si_3N_4	27	57	19	3	3	40°C	5	60	[41]

As per the various literature data being listed out in Table 1 it is understood that high temperature is the prerequisite for electrodepositing nickel composite coating. Temperature ranging from 50-60oC is required for nickel composite electrodeposition. The PH is to be maintained between 3-4 and an average current density of 5-6 A/dm-2 is to be maintained during the process. Most of the researchers have carried out electrodeposition work for 60 mins.

Results and discussions

The commonly measured result parameters of the electrodeposited coatings are surface morphology, Corrosion potential, Roughness, Microhardness and Contact angle measurements. The various results of Nickel composites are listed in Table 2.

Table 2. Results Summary of Nickel composites

Coating Composition	XRD /EDAX Analysis	Corrosion Potential	Microhardness	SEM Analysis	AFM Analysis	Ref
Ni-Si_3N_4	Peaks detected for Ni, Si_3N_4 not detected due to lower concentration	Improved corrosion resistance observed with current of 0.00812 A/cm^2.	Increased hardness value observed with about 400HV	More uniform grain structure is observed	Hill- valley like structure with homogenous distribution of grains	[26]
Ni- Fe alloy	Increased percentage of Ni was observed than Fe	Coating at 4a/dm^{-2} demonstrated maximum corrosion resistance.	Increasing Trend observed till coatings of current density 4a/dm^{-2}	Homogeneity and grain size increased with the current density.	The roughness value increased with the increase in current density.	[27]
Ni- Nb	The bath containing the Maximum Nb content (50 µm) led to least deposition of niobium.	Improved corrosion resistance was observed	The microhardness of the Ni-Nb coating improved	Good particle distribution was obtained for 20 µm particles.	NA	[42]
Ni-Gr	Higher carbon content attained with the increase in surfactant (SDS)	Enhanced corrosion resistance observed as the surfactant (SDS) increases.	The microhardness increased with the increase in SDS content.	Bulge morphology is observed in 0.4 g/l SDS content coating.	The roughness has greatly enhanced with the use of anionic surfactant.	[32]
Ni-Gr	Reduction in Crystallite size is observed with growing nucleate size.	Ni-Gr composite coating has high corrosion resistance.	Compared to the Ni coating, the Ni-Gr composite coating demonstrated greater hardness.	Fine grained structure with intact arrangement of Ni ions is observed	NA	[43]
Ni-Zn	γ Phase is observed from the different intensities.	Improved corrosion resistance observed for both alkaline and acidic deposition.	The hardness value was found to be 97±4 HV	Pyramid Structure with porosity levels observed in the coating.	The coatings obtained at lower current densities had more uniform grain distribution.	[44], [45]
Ni-TiO_2	Both the nickel and TiO_2 peaks were observed.	The corrosion resistance increased with the TiO_2 Content.	Increase in TiO_2 and surfactant showed an increasing trend in Microhardness.	Nickel facets along TiO2 particles with sizes less than 2 m.	Roughness value increased with the addition of TiO_2 particles	[46], [47]
Ni-MoS_2	Sharp peaks observed for the composition.	Better corrosion resistance observed for the composite coating.	The composite coating is harder than mild steel specimen.	Crystallinity structure was clearly visible.	NA	[48]

Ni-Co_3O_4	Related peaks of the composition were found	Corrosion resistance improved for the composite coating	The hardness number increased for the composite coating.	Pyramid type protuberance was observed	NA	[49]
Ni-B-Al_2O_3	Mainly Single broad peaks observed, the presence of all the elements confirmed	Improvement in corrosion behavior is observed for addition of both the elements	Increased microhardness observed for the composite coating	Uniform, well crystallized dense structure is observed	Rough surfaces are revealed in the composite coating	[50]
Ni-B-V_2O_5	Single clear peak is being reflected in the XRD pattern.	Improved corrosion resistance observed with the addition of V_2O_5	The microhardness increased for the addition of V_2O_5	Homogenous distribution of the Particles observed with few microcracks	Surface roughness increased with the addition of V_2O_5	[51]
Ni-Co-CeO_2	Addition of CeO_2 influenced the growth of the crystallites	Corrosion resistance increased with the addition of CeO_2	With the addition of CeO2, the composite coating's microhardness enhanced.	Polyhedral crystals to nodular crystals have been observed	NA	[52]

The results of the various nickel composite electrodeposition coatings have been presented in table 2. It was found from the literature that mild steel was the most commonly used substrate, and it is a widely used material in industries, and hence it is prone to corrosion. The mechanical properties, surface characteristics and corrosion potentials have been listed for most of the varieties of nickel composite coating. Researchers have discovered better surface properties and corrosion resistance which could pave the path for widespread usage in industrial and commercial usage.

2.5. Corrosion Investigation Techniques

Tafel extrapolation method and AC impedance method are the most commonly used corrosion resistance measurements methods. Tafel extrapolation method uses potential excitation in the form of direct current to give larger and appreciable currents to measure the corrosion rate, Since the current and potential are nonlinear, semi logarithmic plots is obtained called as Tafel Plots. Utilizing alternating current potential excitation, the AC impedance measuring approach offers crucial details on the capacitive behavior of the double layer that contributes to the coatings' corrosion resistance. It offers details on the polarity and quantity of charges present at the electrode and electrolyte, which are easily comprehended by examining the impedance curves.

All of the studies described that inclusion of particles like Graphene, Niobium, Vanadium, Titanium Oxide, Zinc and boron with nickel by electrodeposition has proved to provide enhanced corrosion resistance and mechanical characteristics. The majority of the researchers have not focused on the lower electrolyte concentration of the particles, further the mechanical properties like microhardness, scratch resistance, roughness, profile and contact angle are barely unexplored.

3. Research Gap

All of the studies described that inclusion of particles like Graphene, Niobium, Vanadium, Titanium Oxide, Zinc and boron with nickel by electrodeposition has proved to provide enhanced corrosion resistance and mechanical characteristics. The majority of the researchers have not focused on the lower electrolyte concentration of the particles, further the mechanical properties like microhardness, scratch resistance, roughness, profile and contact angle are barely unexplored.

4. Conclusion

Nickel is increasingly used in many new fields, putting it in competition with other materials due to its special combination of qualities and traits and its many industrial applications. This has led to the development of innovative nickel processing methods. The review paper provides a comprehensive overview of the overall elements of electrodeposition of nickel composite coating. Nickel Composite coating has been vastly researched with various combinations of the particles. The inclusion of nanoparticles in the coating exhibit improved properties in terms of roughness, microhardness, and corrosion resistance with a uniform distribution of the particles. The electrodeposition of these particles at lower concentrations with nickel and its impact on corrosion and mechanical properties must be explored in the current study. The researchers can start working on the analysis with the help of this paper.

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