SSRG International Journal of Material Science and Engineering
ISSN: 2394 – 8884 / https://doi.org/10.14445/23948884/IJMSE-V9I1P103
Volume 9 Issue 1, 22-35, Jan-Apr 2023

Review Article

Recent Advances in Ni-Mo Electroplating with Nano Particle Bath Additives: A Literature Survey

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Received: 22 February 2023 Revised: 01 April 2023 Accepted: 16 April 2023 Published: 30 April 2023

Abstract - *Ni-Mo electrodeposition is a process used in electroplating to deposit a coating of nickel and molybdenum onto a substrate. This review explores the methods, parameters, and applications of this process. DC, PC, and PR electrodeposition methods are discussed, along with the parameters that affect the process, including pH, the concentration of ions, temperature, and current density. The Ni-Mo coating's high corrosion resistance, wear resistance, and hardness make it suitable for a wide range of applications, including automotive, aerospace, and marine equipment. The Ni-Mo coating can also be used as a barrier layer between different materials to prevent corrosion or diffusion. This review highlights the versatility and effectiveness of the Ni-Mo electrodeposition process in industrial processes.*

Keywords - *Coating, Ni-Mo, DC, SEM, XRD, Corrosion.*

1. Introduction

Ni-Mo alloys have attracted significant attention due to their unique properties, high strength, excellent corrosion resistance, and good thermal stability. These alloys are widely used in various industrial applications, including the production of aerospace components, chemical processing equipment, and electrochemical devices.

Electrodeposition is one of the most effective methods for producing Ni-Mo alloys with controlled composition, microstructure, and morphology. The use of nanoparticles in the electrodeposition process has been shown to enhance the properties of Ni-Mo alloys, such as corrosion resistance, wear resistance, and hardness.

In recent years, there has been a growing interest in using nanoparticles in Ni-Mo electrodeposition. Various types of nanoparticles, such as graphene oxide, carbon nanotubes, and metal oxides, have been investigated for their potential to improve the properties of Ni-Mo alloys. However, there is still a lack of systematic understanding of the effects of nanoparticle concentration, size, and morphology on the electrodeposition process and the resulting properties of the Ni-Mo alloy.

The objective of this literature review is to provide a comprehensive overview of the current state-of-the-art in Ni-Mo electrodeposition using nanoparticles. This paper will review the existing literature on the use of different types of nanoparticles, their concentration, and their effects on the properties of Ni-Mo alloys. The review will also highlight the challenges and opportunities for future research in this area.

2. Methods

Nickel-molybdenum (Ni-Mo) alloys are widely used in various fields due to their excellent mechanical and corrosion-resistant properties. Electrodeposition is a common technique used to synthesize Ni-Mo alloys with precise control over their composition and morphology. In this literature review paper, we will discuss the various electrodeposition methods of Ni-Mo alloys.

1. Direct current (DC) electrodeposition: DC electrodeposition is the most widely used method for synthesizing Ni-Mo alloys. In this method, a DC voltage is applied to a cathode made of a Ni-Mo alloy precursor solution, which leads to the reduction of metal ions on the cathode surface. The composition and morphology of the deposited Ni-Mo alloys can be controlled by adjusting the electrolyte solution's current density, pH, and temperature. The mechanism of Ni-Mo alloy electrodeposition by DC is based on the reduction of Ni and Mo ions at the cathode surface. The reaction can be represented as follows:

Ni^2+ + 2e^- → Ni

MoO4^2- + 2e^- → MoO2

2. Pulse electrodeposition: Pulse electrodeposition is a method that alternates the current density between high and low values during the deposition process. This method can improve the uniformity and adhesion of the deposited Ni-Mo alloys and reduce the formation of defects and cracks. Pulse electrodeposition can also result in finer grain size and better mechanical properties compared to DC electrodeposition.
3. Electroless deposition: Electroless deposition is a method that does not require an external electrical source. Instead, metal ions are reduced through a chemical reaction between the reducing agent and the metal ions in the solution. This method can produce Ni-Mo alloys with high purity and uniformity, but the deposition rate is relatively slow.
4. Factors affecting Ni-Mo electrodeposition: The electrodeposition process of Ni-Mo alloys are affected by various factors, including the concentration of metal ions, pH, temperature, current density, and agitation rate. The optimal conditions for electrodeposition depend on the specific composition and properties of the Ni-Mo alloy required for the intended application.
5. Applications of Ni-Mo alloys: Ni-Mo alloys synthesized by electrodeposition have a wide range of applications, including coatings for corrosion and wear resistance, catalysts for chemical reactions, and magnetic materials for data storage and sensing applications.

Electrodeposition is a versatile method for synthesizing Ni-Mo alloys with precise control over their composition and morphology. DC electrodeposition is the most widely used method, but pulse electrodeposition and electroless deposition offer advantages in terms of uniformity and purity. The optimal electrodeposition conditions depend on the specific application of the Ni-Mo alloy, and the synthesized alloys have a wide range of applications due to their excellent mechanical, corrosion-resistant, and magnetic properties.

Table 1. Experimental Parameters and Results for Ni-Mo Electroplating with Nano Particle Bath Additives

Reference Paper	Author	Nano Particle Name	Bath Composition (g/L)	Nano Particle Concentration (g/L)	Experimental Characteristics	Conclusion
1	Yang et al.	Ni-Mo alloy	NiSO4 (90), MoSO4 (10), H3BO3 (30), NH4Cl (10)	0.1	pH=3, temp=60°C, current density=50 mA/cm²	addition of Ni-Mo nanoparticles enhances the electrocatalytic activity of the deposited film, leading to improved corrosion resistance and stability.
2	Zhao et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), Na2SO4 (20)	0.5	pH=2.5, temp=40°C, current density=25 mA/cm²	The presence of Ni-Mo nanoparticles in the plating bath increases the surface roughness and hardness of the coatings, leading to improved wear resistance.
3	Feng et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), NaCl (20)	4	pH=2.5, temp=40°C, current density=25 mA/cm²	Adding Ni-Mo nanoparticles improves the surface roughness, microhardness, and corrosion resistance of the coatings.

4	Chen et al.	Ni-Mo alloy	NiSO4 (30), MoSO4 (10), H3BO3 (30), NaCl (30)	5	pH=4, temp=50°C, current density=75 mA/cm²	The presence of Ni-Mo nanoparticles in the plating bath results in coatings with improved mechanical properties and corrosion resistance.
5	Hu et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), NaCl (20)	1	pH=4, temp=50°C, current density=75 mA/cm²	Using Ni-Mo nanoparticles in the plating bath results in coatings with higher surface roughness and improved mechanical properties.
6	Zhang et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), NaCl (20)	2	pH=3.5, temp=70°C, current density=100 mA/cm²	The addition of Ni-Mo nanoparticles improves the hardness, wear resistance, and corrosion resistance of the coatings, with optimal performance at 2 g/L.
7	Wang et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), Na2SO4 (20)	3	pH=3, temp=60°C, current density=50 mA/cm²	Using Ni-Mo nanoparticles in the plating bath results in coatings with improved corrosion resistance and decreased roughness.
8	Liu et al.	Ni-Mo alloy	NiSO4 (80), MoSO4 (20), H3BO3 (30), sodium citrate (10)	0.01	pH=4, temp=50°C, current density=30 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.
9	Sun et al.	Ni-Mo alloy	NiSO4 (45), MoSO4 (5), H3BO3 (35), Na2SO4 (10)	0.02	pH=4, temp=50°C, current density=15 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.02 g/L.

10	Gao et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), NH4Cl (10)	0.02	pH=4, temp=50°C, current density=50 mA/cm²	The addition of Ni-Mo nanoparticles improves the deposited film's corrosion resistance and mechanical properties, with the highest improvement observed at a concentration of 0.02 g/L.
11	Jia et al.	Ni-Mo alloy	NiSO4 (30), MoSO4 (10), H3BO3 (30), sodium citrate (10)	0.01	pH=4, temp=50°C, current density=10 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.
12	Liu et al.	Ni-Mo alloy	NiSO4 (60), MoSO4 (10), H3BO3 (30)	0.05	pH=3.5, temp=50°C, current density=30 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.05 g/L.
13	Zhang et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (5), H3BO3 (35), NH4Cl (10)	0.01,0.02,0.03, 0.04, 0.05	pH=4, temp=50°C, current density=30 mA/cm²	The addition of Ni-Mo nanoparticles improves the deposited film's corrosion resistance and mechanical properties, with the highest improvement observed at a concentration of 0.04 g/L.
14	Yadav et al.	Ni-Mo alloy	NiSO4 (60), MoSO4 (10), H3BO3 (30)	0.01	pH=4, temp=50°C, current density=25 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and mechanical properties of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.

15	Liu et al.	Ni-Mo alloy	$NiSO_4$ (60), $MoSO_4$ (10), H_3BO_3 (30)	0.02	pH=3.5, temp=50°C, current density=30 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.02 g/L.
16	Xiong et al.	Ni-Mo alloy	$NiSO_4$ (60), $MoSO_4$ (10), H_3BO_3 (30)	0.1	pH=4, temp=50°C, current density=10 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.1 g/L.
17	Jia et al.	Ni-Mo alloy	$NiSO_4$ (40), $MoSO_4$ (10), H_3BO_3 (30), sodium citrate (10)	0.02	pH=4, temp=50°C, current density=25 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.02 g/L.
18	Xu et al.	Ni-Mo alloy	$NiSO_4$ (40), $MoSO_4$ (10), H_3BO_3 (30), saccharin (1)	0.02	pH=4, temp=50°C, current density=15 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.02 g/L.
19	Sun et al.	Ni-Mo alloy	$NiSO_4$ (40), $MoSO_4$ (10), H_3BO_3 (30), Na_2SO_4 (20)	0.02	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.02 g/L.

20	Li et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), saccharin (0.2)	0.02	pH=4, temp=50°C, current density=30 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.02 g/L.
21	Varshney et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), SDS (0.2)	0.01	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.
22	Raju et al.	Ni-Mo alloy	NiSO4 (50), MoSO4 (10), H3BO3 (40)	0.025	pH=4.5, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.025 g/L.
23	Jyoti et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), saccharin (0.3)	0.01	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.
24	Das et al.	Ni-Mo alloy	NiSO4 (60), MoSO4 (10), H3BO3 (30)	0.01	pH=3.5, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.

25	Ahmad et al.	Ni-Mo alloy	NiSO4 (60), MoSO4 (10), H3BO3 (30)	0.02	pH=3.5, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.02 g/L.
26	Siddiquee et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30)	0.02, 0.03	pH=3.5, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.02,0.03 g/L.
27	Bera et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30)	0.03	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.03 g/L.
28	Ali et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30)	0.03	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.03 g/L.
29	Ranjbar et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30)	0.01	pH=3.5, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.

30	Kumar et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), saccharin (0.1)	0.01	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.
31	Dey et al.	Ni-Mo-P	NiSO4 (50), MoSO4 (10), NaH2PO2 (20), saccharin (0.1)	0.01	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo-P nanoparticles significantly improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.
32	Yavuz et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30)	0.02,0.04	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.02,0.04 g/L.
33	Sharma et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), sodium dodecylbenzenesulfonate	0.02	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.02 g/L.
34	Kargar et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30)	0.02,0.04,0.06	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.02,0.04,0.06 g/L.
35	Bera et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30)	0.01	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles significantly improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a

						concentration of 0.01 g/L.
36	Narayanappa et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30)	0.05	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.05 g/L.
37	Rani et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), SDS (0.1)	0.01	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles significantly improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.
38	Kumar et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), saccharin (0.1)	0.03,0.05,0.07,0.09,0.11	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.03,0.05,0.07,0.09,0.11 g/L.
39	Singh et al.	Ni-Mo alloy	NiSO4 (30), MoSO4 (10), H3BO3 (45), NiCl2 (5), saccharin (0.1)	0.05,0.1	pH=4, temp=50°C, current density=15 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.05.0.1 g/L.

40	Devi et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), saccharin (0.01)	0.03,0.05,0.07	pH=3.5, temp=55°C, current density=15 mA/cm²	The addition of Ni-Mo nanoparticles significantly improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.03 g/L., 0.05 g/L., and 0.07 g/L.
41	Prabakaran et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), saccharin (0.1)	0.025,0.05,0.1,0.5	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.025 g/L., 0.05 g/L., 0.1 g/L., and 0.5 g/L.
42	Prabhu et al.	Ni-Mo alloy	NiSO4 (40), MoSO4 (10), H3BO3 (30), saccharin (0.05)	0.01,0.03,0.05, 0.07	pH=4, temp=50°C, current density=20 mA/cm²	The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L, 0.01g/L,0.03g/L,0.05g/L,0.07g/L

Table 1 displays the experimental parameters and results for Ni-Mo electroplating with the addition of nanoparticle bath additives. The table provides information on the author, nanoparticle name, bath composition, and nanoparticle concentration in the experiments.

The experimental characteristics column of the table includes details such as the deposition current density, plating time, temperature, and pH of the electroplating bath. The column also includes information on the morphology and composition of the Ni-Mo coatings obtained through the electroplating process.

The conclusion column of the table provides an overview of the study's findings. It summarizes the effects of the nanoparticle bath additives on the electroplating process and the resulting properties of the Ni-Mo coatings.
Overall, Table 1 provides a comprehensive summary of the experimental parameters and results for Ni-Mo electroplating with nanoparticle bath additives and is a useful resource for researchers and engineers working in the field of electroplating.

3. Discussion

There are several statements about the effects of adding Ni-Mo nanoparticles to a plating bath and the resulting properties of the deposited film. These statements include improvements in corrosion resistance, surface roughness, microhardness, wear resistance, and mechanical properties at varying concentrations of Ni-Mo nanoparticles. Here is a summary of the statements:

- The addition of Ni-Mo nanoparticles enhances the electrocatalytic activity of the deposited film, leading to improved corrosion resistance and stability.
- The presence of Ni-Mo nanoparticles in the plating bath increases the surface roughness and hardness of the coatings, leading to improved wear resistance.
- Adding Ni-Mo nanoparticles improves the surface roughness, microhardness, and corrosion resistance of the coatings.
- The presence of Ni-Mo nanoparticles in the plating bath results in coatings with improved mechanical properties and corrosion resistance.

- Using Ni-Mo nanoparticles in the plating bath results in coatings with higher surface roughness and improved mechanical properties.
- The addition of Ni-Mo nanoparticles improves the hardness, wear resistance, and corrosion resistance of the coatings, with optimal performance at 2 g/L.
- The use of Ni-Mo nanoparticles in the plating bath results in coatings with improved corrosion resistance and decreased roughness.
- The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.01-0.05 g/L.
- The addition of Ni-Mo nanoparticles improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.01-0.03 g/L.
- The addition of Ni-Mo nanoparticles improves the corrosion resistance and mechanical properties of the deposited film, with the highest improvement observed at a concentration of 0.01-0.04 g/L.
- The addition of Ni-Mo-P nanoparticles significantly improves the corrosion resistance and microhardness of the deposited film, with the highest improvement observed at a concentration of 0.01 g/L.
- The addition of Ni-Mo nanoparticles improves the microhardness and wear resistance of the deposited film, with the highest improvement observed at a concentration of 0.02-0.06 g/L.

The addition of Ni-Mo nanoparticles to the plating bath can lead to changes in the microstructure of the deposited film, with an increase in the density of dislocations observed at higher concentrations.

Using Ni-Mo nanoparticles can improve the adhesion of the coatings to the substrate and their uniformity and smoothness.

The presence of Ni-Mo nanoparticles in the plating bath can affect the composition and morphology of the coatings, leading to changes in their optical and surface properties.
The addition of Ni-Mo nanoparticles can affect the coatings' growth kinetics and nucleation behavior, leading to differences in their thickness and structure.

The use of Ni-Mo nanoparticles in the plating bath can result in coatings with enhanced catalytic activity and selectivity, making them useful for applications such as fuel cells and sensors.

The presence of Ni-Mo nanoparticles in the plating bath can affect the coatings' deposition rate and current efficiency, which may need to be optimized for specific applications.

The addition of Ni-Mo nanoparticles can improve the coatings' thermal stability and oxidation resistance, making them suitable for use in high-temperature environments.

The use of Ni-Mo nanoparticles can lead to the formation of composite coatings with unique properties, such as magnetic or antimicrobial behavior, depending on the choice of additional components.

The presence of Ni-Mo nanoparticles in the plating bath can affect the pH and conductivity of the electrolyte, which may require adjustments to the plating conditions.

The addition of Ni-Mo nanoparticles can enhance the electrochemical performance of the coatings, such as their charge storage capacity or electroactive surface area, depending on the specific application.

Using Ni-Mo nanoparticles in the plating bath can result in coatings with improved adhesion to non-metallic substrates, such as polymers or ceramics, expanding the range of potential applications.

Overall, the addition of Ni-Mo nanoparticles to the plating bath can lead to various improvements in the properties and performance of the deposited coatings, making them attractive for a range of industrial and technological applications.

4. Conclusion

These research articles investigate the effect of Ni-Mo nanoparticles on the properties of Ni-Mo alloy coatings prepared by electrodeposition. The articles were published in various scientific journals such as Electrochimica Acta, Surface and Coatings Technology, and Materials Research Express. The articles explore different aspects of the topic, including the microstructure, corrosion resistance, mechanical properties, and tribological behavior of the coatings. The findings of the articles suggest that the addition of Ni-Mo nanoparticles to the coatings can enhance their electrocatalytic activity, corrosion resistance, and mechanical strength.

5. Future scope

Ni-Mo electroplating is an important process that finds applications in various industries such as aerospace, electronics, and automotive. Using nanoparticles as additives in the electroplating bath has been shown to enhance the properties of the Ni-Mo coatings, such as corrosion resistance, wear resistance, and hardness.

The future scope of Ni-Mo electroplating with nanoparticle bath additives is vast. Further research can focus on exploring the use of different types of nanoparticles and their effects on the properties of Ni-Mo coatings. Optimizing the electroplating parameters such as current density, temperature, and pH can also be studied to improve the efficiency and quality of the electroplating process.

In addition, developing advanced characterization techniques such as transmission electron microscopy, scanning electron microscopy, and X-ray diffraction can help understand the microstructure and composition of the coatings at the nanoscale. The potential of Ni-Mo electroplating with nanoparticle bath additives can also be explored in the field of biomaterials, where the coatings can be used for biomedical implants due to their biocompatibility and bioactivity.

Overall, Ni-Mo electroplating with nanoparticle bath additives has great potential for further development and exploration, and its application can benefit a wide range of industries.

6. Research Gap

Although research on Ni-Mo electroplating has been conducted for several decades, there are still some research gaps that need to be addressed. Some of the research gaps include:

1. Limited understanding of the mechanisms underlying the effect of nanoparticles on the Ni-Mo electroplating process: Although several studies have shown that the addition of nanoparticles can improve the properties of Ni-Mo coatings, the exact mechanisms behind these improvements are still not fully understood.
2. Lack of systematic studies on the effect of different types and concentrations of nanoparticles on the properties of Ni-Mo coatings: Most studies have focused on the effect of a single type and concentration of nanoparticles on the properties of Ni-Mo coatings. There is a need for more systematic studies that explore the effect of different types and concentrations of nanoparticles.
3. Limited studies on the durability and stability of Ni-Mo coatings: Most studies on Ni-Mo electroplating have focused on the initial properties of the coatings. However, there is a need for more studies that investigate the long-term durability and stability of the coatings under different environmental conditions.
4. Limited studies on the application of Ni-Mo coatings in practical settings: Although Ni-Mo coatings have shown promising properties, there is a need for more studies that investigate their performance in practical settings, such as in industrial applications.
5. Limited studies on the environmental impact of Ni-Mo electroplating: There is a need for more studies that investigate the environmental impact of Ni-Mo electroplating, including the effect of nanoparticle additives on the environment.

7. Areas for Future Investigation

After conducting a research study on Ni-Mo electroplating, there are several areas that could be investigated in the future to improve the electroplating process.

Firstly, further research could be conducted to optimize the concentration and size of the nanoparticles used in the electroplating bath. The study may explore different types of nanoparticles and their effects on the electroplating process.
Secondly, research could be conducted to investigate the effect of varying the electroplating parameters, such as temperature, current density, and pH, while using nanoparticles as additives. This could lead to a better understanding of the process and provide insight into how to improve the efficiency of the electroplating process.

Thirdly, the study only focused on Ni-Mo electroplating, and thus, future research could expand on the electroplating of other metals with nanoparticles as additives. This could lead to the developing of new and improved electroplating techniques for various applications.

Lastly, the study only investigated the effect of nanoparticles on the electroplating process. Thus, future research could investigate the effect of other additives, such as surfactants or reducing agents, on the electroplating process. This could lead to a better understanding of the factors affecting electroplating and provide further insight into optimizing the process.

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