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# REVIEW ON ELECTROLESS PLATING Ni–P COATINGS FOR IMPROVING SURFACE PERFORMANCE OF STEEL

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**Abstract**: This paper reviews the methods of formation of electroless Ni–P, multiple coatings, rare earth included coatings, nano-coatings and their effect on coating characteristics, applications and their recent developments. Evidence from the literature showed that the properties of electroless coatings could be improved by controlling different process.

**Keywords**: electroless coating, Ni–P, coating characteristics, nano-coatings**.**

## I. INTRODUCTION

Electroless plating has been considered as an effective approach to provide protection and enhancement for metallic materials with many excellent properties in engineering field. This paper begins with a brief introduction of the fundamental aspects underlying the technological principles and conventional process of electroless nickel–phosphorus (Ni–P) coatings. Then this paper discusses different electroless nickel plating, including binary plating, ternary composite plating and nickel plating with nanoparticles and rare earth, with the intention of improving the surface performance on steel substrate in recent years in detail. Based on different coating process, the varied features depending on the processing parameters are highlighted. Separately, diverse preparation techniques aiming at improvement of plating e±ciency are summarized. Moreover, in view of the outstanding performance, such as corrosion resistance, abrasive resistance and fatigue resistance, this paper critically reviews the behaviors and features of various electroless coatings under di®erent conditions.

## II. TECHNOLOGICAL PRINCIPLE OF ELECTROLESS PLATING NICKEL-COATING

In electroless nickel plating process, the sample is immersed in the bath, metal ion will deposit on the specimen under the action of reducing agent. According to the difference in pH values of plating bath, the techniques can be classified as acid electroless plating and alkali electroless plating . The electroless nickel plating mechanism was proposed by Malecki who investigated the kinetics of this reaction and developed an empirical rate equation for the plating baths. The general process of conventional electroless plating is usually conducted as suggested in Fig. 1. The commonly used acid baths solution consist of nickel salts (sulfate or chloride), a reducingagent (sodium hypophosphite or borohydride), a complexing agent (acetic, citric, lactic acid, succinic, glycolic acid usually), stabilizing compound (heavy metal salts, thiourea, fluoride compounds) and the pH conditioning agent (ammonia, hydrochloric acid). Then, multiple electroless plating can be achieved by adding some elements into the bath. In the beginning, the improvement of technology committed to selecting appropriate process parameters, such as different kinds of reducing agent or complexing agent, pH values, plating temperatures and post-heat treatment temperatures, to obtain coatings with better properties. Ashtiani et al. investigated of complexing agents on the structure and corrosion behavior of electroless plating by using the weight loss and potentiodynamic polarization techniques. The sodium citrate lead to the increase of microhardness, the Ni–P composite coating with homogenous surface and less nodular structure showed higher anti-corrosion resistance in 3.5 wt. % NaCl.10 post-heat treatments of the Ni– P-nano-Al2O3 composite coatings on medium carbon steel were carried out in Zheng's research. A promising coating was obtained after heat treated at 400C for 1 h under argon atmosphere. Different from conventional heat treatment, laser heat treatment endowed the coatings with high hardness and good wear resistance.

  

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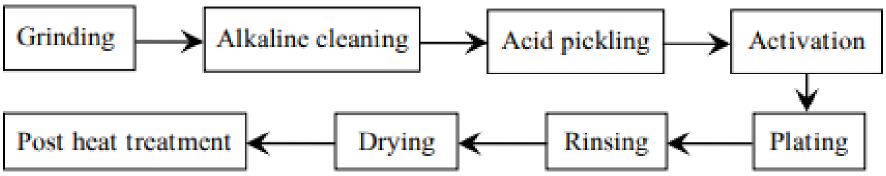


Fig. 1. The technical flow chart of the electroless plating.

## III. ELECTROLESS PLATING WITH NANOPARTICLES

Nanomaterial-based composites in electroless nickel plating bath have various applications in industrial and engineering felds. Compared with the conventional electroless plating process, the nanoparticles should be synthesized and immersed in acid to activate the surface before plating. Different pretreatment depends on the properties of particles. Song et al. prepared Ni–P/TiO2 ¯lm by combining with sol–gel process, which had a good anticorrosion property in 0.5 mol/L H2SO4 and 0.5 mol/L NaCl solution.34 Sarret indicated that the nano-sized coatings behaved better than nanometer or micrometer particles, SiC and Si3N4. 35 Moreover, the growth mechanism of the metallic matrix was much more modi¯ed by the nanoparticles. It has been reported that Ni–P alloy incorporated with 2.5% TiO2 nanometer powder could decrease the coe±cient of friction by seven times as compared with that of Ni–P deposit.36 Zarebidaki et al. deposited a Ni–P–CNTs composite coating under optimum condition using ultra violet visible (UV-vis) spectroscopy method. The incorporation of CNTs could enhance both the corrosion resistance and microhardness of coatings.

This behavior could be attributed to the decreasing of metallic area prone to corrosive media and the filling of the micro-holes by CNTs particles.37 Gay's Ni–P– ZrO2 coating, with the content of ZrO2 of 7.4% presents high hardness, low friction coe±cient and good wear resistance.38 Shibli et al. incorporated nano-ZnO particles into Ni–P plates by an alkaline bath on mild steel which showed a VHN of 505. In addition, the incorporation of nano-ZnO also resulted in the improvement of corrosion resistance characteristics.39 Liu and Chen et al. prepared reinforced electroless plating Ni–P composite coating with nano-SiC particles and nano-WC particles on the 45 steel in an optimized acidic electroless bath, respectively.40,41 The maximum hardness of the Ni–P–nano-SiC composite coating was 1341 HV after heat-treatment at 400C for 1 h. Nano-SiC particles can promote electroless plating and improve the growth of the composite coating with a thin sub-layer mode.39 Mazaheri et al. successfully incorporated the nano-diamond (ND) particles in a Ni–P matrix on API-5L X65 steel substrates by electroless plating.

The optimum concentration of diamond nanoparticles was found; the results demonstrated higher corrosion resistance and greater hardness as compared to the deposited Ni– P.42 It was found that the ND particles were able to signi¯cantly improve mechanical and tribological behaviors as well as corrosion resistance of the composite coatings. The corrosion resistance of the N–P– ND coatings is superior to the Ni–P coating due to the chemical stability and the effects of reducing the hole in the composite coatings and preventing corrosive pits growing up of the ND particles. The highest micro-hardness of the Ni–P–ND composite coatings was obtained by heat treated at 673 K.43,44 Ji et al.first synthesized nickel-phosphorus composite coatings containing potassium titanate whisker (PTW) by electroless plating on 45 steel.

The corrosion resistance of coating in neutral salt spray was improved significantly. Under pin-on-plate wear tester, the wear rate of the composite coating was approximately one-fourth of that of Ni–P coating, which beneffted from its \inlay-embedding" composition that was useful to automatic compensation for wear process.45 Electroless Ni–P/diamond composite deposits have been synthesized in alkaline bath under special pretreatment in Winowlin Jappes's research, indicating substantial increase in wear resistance after heat treatment.46 Meng prepared Ni–P-multiwalled carbon nanotubes (MWNTs) composite coatings on 45 steel, in which the MWNTs was wet-mild before plating, the process was divided into two parts. Because of the introduction of MWNTs, which plays both roles of reinforcements and solid lubricant during the wear process, the Ni–P–MWNTs composite coatings possessed much better friction reduction and anti-wear performances.47 Alexis et al. characterized Ni–P coatings co-deposited with talc particles on steel, which were developed to serve as hard coatings with a lubricating effect at 600C. The hardness and stiffness values slightly decrease when the amount of talc increases for untreated coatings. In contrast, a 420C heat treatment improved the adherence and the cohesion of the coatings containing talc, leading to high hardness and Young's modulus values due to crystallization.48 Besides, polymeric compounds were discovered to improve wear resistance and sliding process. Zhao synthesized Ni–P–PTFE deposits and studied the effects of cationic surfactant and PTFE on the coating rate and PTFE content incoatings.49 Furthermore, the adhesion of the Ni–P–PTFE coating was improved by graded electroless Ni–P–PTFE coatings267

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## IV. SUMMARY AND OUTLOOK

It has been found that the main salts concentration and post heat treatment play important role in the resultant microstructure and properties of the electroless plating coating. The deposition mechanism of binary plating is nearly discussed, but the codeposition of mechanism of multi-component alloy is still unclear. The current state about the techniques of electroless plating consist of two main aspects: One is the improving of assistant technique for mass transfer enhancement, which tends to be a combination of different ways as magnetic stirring, gas sparging, hydrothermal, sonication, etc. The other direction is double plating technology, sometimes accompanied by other surface coating technologies like electroplating or sol–gel, and so on. The properties of electroless nickel coatings are improved through the incorporation of various elements (copper, tungsten, cerium, etc.) and nanoparticles (Al2O3, TiO2, SiC, ZrO2, CNTs, etc.) to suit the various applications. Electroless nickel composite coatings could have a bright future for wear-resistant or self-lubricating coatings and other special treatments. In future, new composite material may fulfill new benefits and property. With more advanced operation technology and automatic controllers, composite coatings may become the next frontier of electroless plating. Thus, the composite coatings can provide an excellent layer containing nickel and other components which can be used for intelligent materials. Similarly, the electroless Ni–P plating coatings containing nanoparticles have also gained more attention in research community due to its excellent physical and mechanical properties. While most of the aforementioned electroless plating coatings exhibit better corrosion resistance under various conditions, researchers have their own systematic academic viewpoint on the analysis of the infuential factors and mechanism of anti-corrosion behavior. The complicated corrosion and wear behavior leads to limited use in many practical environments. Therefore, in an effort to search ways of improving the coating's corrosion resistance, the internal mechanism of corrosion should also be concerned strictly. Furthermore, the fatigue resistance of electroless plating on steel has not been checked clearly, interface bonding strength is a crucial problem. Thus, analyzing and improving the bonding force between the coating and substrate is also an important research field. In addition, other properties of electroless plating coating on steel such as magnetism remains to be found and unearthed, in order to achieve more broad application. The electroless nickel plating industry is committed to research and development of cleaner production technologies and more e±cient use of raw materials. The inputs of environmental friendly materials and processing attract the concern of researchers. In the aspect of improving production efficiency, the electroless nickel deposition bath has a major problem of sudden bath decomposition, which would result in an increase of operation cost and the generation of environmentally hazardous waste. Improving the stability and life of plating bath is the key to realize large scale production of electroless plating. Hence, the properties of electroless nickel plating coatings can be realized better. As a whole, the future of electroless plating will depend on the newer requirements and applications, as well as changes in plating technology. In the long run, electroless nickel plating will make a substantial contribution to the resources and energy saving and environmental friendly society.

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