



# Tribological and electrochemical corrosion behavior of Ni–W/BN (hexagonal) nano-composite coatings

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## Abstract

Ni–W/BN (hexagonal) nanocomposite coatings were successfully electrodeposited on mild steel by direct current (DC) and pulse current (PC) methods. Electrodeposition was carried out by dispersing 2–8 g/l of BN (h) nanopowder into the nickel sulfate electrolytic bath. The coatings were characterized by Scanning electron microscopy (SEM), Energy dispersive analysis of X-Ray (EDAX), X-ray diffractometry (XRD), and Vicker's microhardness tester. Tafel polarization and electrochemical impedance methods were applied to measure the corrosion resistance properties of the nanocomposite coatings in 3.5% NaCl solution. Surface roughness and friction coefficient of the coated samples were assessed by Mitutoyo SurfTest SJ-310 (ISO1997), and Scratch tester TR-101-M4. The tribological characteristics and corrosion resistance properties of the nanocomposite coatings were increased with the content of the BN (h) in the plating bath. Co-deposited BN (h) nano-particulates were uniformly distributed in the Ni–W alloy matrix. The Pulse current nanocomposite coatings have offered uniform surface, higher microhardness and excellent corrosion resistance properties than the DC composite coatings.

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## 1. Introduction

Electrodeposition is the process of selection for the novel metal matrix composites (MMCs) due to the major advantages of (a) fast deposit (b) inexpensive (c) reproducibility (d) create more dense structures (e) high clarity etc. [1]. It has been proved that, the application of pulse current in composite plating results in deposits with more particles embedded, more uniform particle distribution and better surface morphology than those obtained under direct current conditions [2–4]. Ni–W nanostructured alloys are recognized to exhibit better chemical and mechanical properties [5,6]. Electrodeposition formed by electroplating depends on a lot of parameters such as current density, temperature, pH, time of deposition, etc. [7,8]. To attain better deposits with high caliber, it is essential to control the plating parameters [9]. An agglomeration of particles is an undesirable problem during electrodeposition of a nanocomposite coating, which would decline the properties of the

deposition. The addition of cationic surfactant in an electrolytic bath has improved the distribution of co-deposited particles. The performance of the composite materials mostly depends upon the co-deposition of second phase nanoparticles and their homogeneous distribution in metal medium [10]. Pulse current electrodeposited composite coatings have possessed higher particle incorporations and enhance corrosion resistance and tribological properties compared to direct current electrodeposits [11,12]. The Ni/BN composite coating has revealed superior hardness and wear resistant properties as compared to pure Ni [13,14]. On the other hand, BN (h) particles with related crystal structure to graphite is a solid lubricant that demonstrates a very low friction coefficient and wear rate in composite deposits. BN (h) is a soft material with a low coefficient of friction and also a candidate for dry machining applications [15]. In relation to such properties, the span of application of BN (h) as a solid lubricant has established significant research attention [16,17]. Its high temperature steadiness, small coefficient of friction and inertness in a wide variety of chemical environments have made BN (h) as a perfect alternative to other solid lubricants in many high performance applications. This

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inorganic solid powder has kept its capability to lubricate in excessive cold or heat [18–21]. The purpose of the inclusion of heavy particles (SiC, TiC, Al<sub>2</sub>O<sub>3</sub>, and ZrO<sub>2</sub>) into metal surface is to enhance the wear resistance and hardness of coatings. A lesser amount of hard with lubricant particles such as boron nitride, graphite and molybdenum disulfide has transformed the coating hardness softly but pick up the tribological properties, predominantly dry lubricity [22]. Effect of solid lubricant particles such as graphite and MoS<sub>2</sub> on the tribological properties of Cu and Ni matrix has been already reported. The applications of lubricating material to Ni–W coatings are one path to enhance the tribological properties of these coatings which could prolong the lifetime expectancy of machine components. Electrodeposited BN (h) particles combined with other constituents have been used in engine parts as self-lubricating and high wear-resistance properties [23]. In the BN (h) structure, the bonding among the molecules surrounded by every layer is covalent and the bonding between layers determined by weak Vander Waals forces. The layered lattice structure of BN (h) has provided the fine lubricating properties [24,25]. It will not wet by the majority molten metals, glasses and salts and hence it delivers a high resistance to chemical attack and oxidation. Established on such properties it displays extensive applications like electrical insulation, medical treatment, and optoelectronic devices [20]. Extremely little information is known about the tribological and electrochemical properties of BN (h) nanopowder co-deposited with Ni–W alloy matrix. The aim of the present study was to fabricate Ni–W/BN (h) nanocomposite coatings by the direct and pulse electrodeposition technique. Also to investigate the effect of BN (h) particle incorporation on the surface morphology, tribological properties and corrosion properties of the composite coatings.

## 2. Experimental process

Ni–W/BN (h) nano-composite coatings used in this study were deposited on mild steel substrates from a nickel sulfate solution containing hexagonal boron nitride particles with a mean diameter of 70 nm. Nickel sulfate was used as a plating electrolyte bath. The contents and their bath composition are given in Table 1. The mild steel plates of size 3.00 × 2.50 × 0.05 cm<sup>3</sup> were dipped in 5% HCl for 10 min and then cleaned with distilled water followed by drying. Then the specimen was degreased with trichloroethylene to

remove the oily impurities adhered on the surface. The prepared mild steel specimens were used as a cathode. Pure nickel bar (99.9%) of size 5 × 5 × 0.5 cm<sup>3</sup> was used as the anode. All solutions were prepared by using Millipore water. Cetyltrimethyl ammonium bromide (CTAB) surfactant was employed for particle dispersion to prevent agglomeration of BN (h) particles in solution. The cationic surfactant can adsorb on the particle surface developing a net positive charge on its surface, so increasing their affinity towards the cathode and hence increases the stability of particle suspension and prevents agglomeration. Like this it is understood that cationic surfactant enhances the incorporation of particles in the metal matrix. Besides, zeta potential of the nanoparticles would be increased by the addition of cationic surfactant CTAB. The positive Zeta potential gives the extra adhesion force between the inert particles and the cathode. Thus CTAB prevent agglomeration [26]. Additionally, mechanical stirring (600 rpm) was used for thorough mixing of all the components and heated to plating temperature at 65 °C. We have kept the inert particles in contact with the bath solution for 24 h and then followed the stirring. Certainly, the stirring has offered a uniform mass transfer and particle attachment to the cathode. By the use of magnetic stirrer the suspended particles were thoroughly stirred in order to attain the uniform distribution of nanoparticles in bath solution. It is well known that the tungsten content of the alloy deposition mostly depends upon the type of the complexing agent used in the electrolytic bath. Citrate bath has been used to give higher tungsten content. BN (h) concentration in the electrolyte was varied between 2 and 8 g/l. Both Ni–W alloy and Ni–W–BN (h) nanocomposite coatings are produced on mild steel substrates by using the direct and pulse current techniques. Pulse and direct current electrodepositions were carried out by employing a Myriad bipolar pulsed power supply. The microhardness of the electrodeposits was measured by using MHG Everyone Hardness tester (Hong Kong) on the Vicker's scale. It had a diamond pyramid of a square base with an angle of 136° at the vertex between two opposite faces. The microhardness of the deposits in kg/fmm<sup>2</sup> was determined in each case by using the formula

$$H_v = 1854 \times \frac{L}{d} \quad (1)$$

where  $L$  is the load applied in (50 g) and  $d$  the diagonal of the indentation ( $\mu\text{m}$ ). The reported microhardness value of incorporating boron nitride particles into the Ni–W alloy matrix is an average value of the three measurements. Scanning electron microscope (SEM) was used to characterize the surface morphology of the composite coatings of size 1 cm × 1 cm. The deposited surface was subjected to EDAX (Energy Dispersive X-ray analysis) for the determination of chemical composition of the composites deposited on the surface. The crystalline structure of the plated substrate was identified by X-ray diffraction using Brooker D8 advance X-ray diffractometer operated with Cu K $\alpha$  radiation (nickel filtered) at a rating of 40 kV, 20 mA. The scan rate was 0.05° C per step and the measuring time 15/step. The crystallite size was calculated by using Scherrer's equation [27]

$$D = \frac{0.9\lambda}{\beta \cos \theta} \quad (2)$$

Table 1  
Plating bath composition and conditions.

Plating bath	Composition	Plating conditions
Nickel sulfate	0.17 M	Pulse peak c.d 1.2 A/ cm <sup>2</sup>
Sodium tungstate	0.15 M	pH 8 time 60 min
Tri ammonium citrate(TAC)	0.3 M	Temperature 65° C
Ammonium chloride	0.2 M	Constant stirring
Dimethyl sulfoxide	0.06 M	<b>Pulse duty cycle</b>
Cetyltrimethyl ammonium Bromide (CTAB)	0.5 g/l	On time-40 ms
BN (h) powder	2–8 g/l	Off time-60 ms

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