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Effect of Coating Bath Parameters on Properties of Electroless Nickel-Boron Alloy Coatings

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ABSTRACT

Electroless nickel-boron binary coatings were obtained with various bath compositions to investigate the effect of bath parameters on tribological and mechanical behaviours of the coating. Characterisation of the coating for surface morphology and phase structure is done using scanning electron microscopy (SEM) and x-ray diffraction (XRD), respectively, whereas tribological behaviour of coatings is evaluated on a pin-on-disc tribo-tester. Elastic modulus and surface hardness of coatings have been obtained using nano-indentation technique, while the scratch behaviour of the coatings has been determined using micro-scratch test. Corrosion resistance of coatings is also determined. It is observed that surface roughness of the coatings increased with increase in sodium borohydride concentration but decreased slightly with increase in nickel chloride concentration. Friction and wear characteristics are found to increase with surface roughness which occurs due to increased boron content. Surface hardness and scratch hardness are also seen to vary with coating bath parameters.

KEYWORDS

Bath Parameter, Corrosion, Electroless Coating, Friction Coefficient, Nano-Indentation, Nickel-Boron, Scratch, Wear

1. INTRODUCTION

The electroless coating developed by Brenner and Riddell in 1946 (Brenner and Riddell 1946) is a plating process in absence of electricity. Electroless coating has become popular gradually since the time of invention for its excellent properties. Electroless nickel-phosphorous coating is well known for its mechanical properties and nickel-boron coating is popular for its tribological properties. The use of electroless coatings can be found in industries like automobile, chemical, oil, gas and aerospace for their excellent mechanical, physical and tribological behaviours. Chemically deposited nickel-boron coatings were analysed based on deposition rate, plating thickness, surface morphology and surface texture etc. (Anik et al. 2008; Kanta et al. 2009; Kanta et al. 2010; Hamid et al. 2010; Bonin et al. 2019; Mohanty et al. 2019; Sukackiene et al. 2020). Coating characteristics depend on the

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composition, temperature and pH of the coating bath (Anik et al. 2008; Bonin et al. 2018; Bonin et al. 2019; Sukackiene et al. 2020, Bonin et al. 2020). The behaviour of the coatings can further be modified through annealing (Bekish et al. 2010; Pal et al. 2011; Taha-Tijerina et al. 2019). Heat treatment of as-deposited coating modifies its surface morphology and phase structure. The amorphous phase of as-deposited coatings turns crystalline upon annealing (Hamid et al. 2010, Taha-Tijerina et al. 2019). Boron content in the coating also depends on sodium borohydride concentration as well as coating bath temperature (Baskaran et al. 2006; Hamid et al. 2010; Sukackiene et al. 2020). The as-deposited coating with low boron content (of about 4%) possess crystalline phase structure which becomes a combination of amorphous and crystalline structure with the rise in boron content in the coatings (Baskaran et al. 2006, Venkatakrishnan and Karthik 2019). The behaviour of coatings also depends on concentration of boron. The surface morphology and phase structure found to vary with the coating's chemical composition which leads to a change in coatings behaviours (Pal et al. 2011; Venkatakrishnan and Karthik 2019; Sukackiene et al. 2020). Chemically deposited nickel-boron coatings with 8% boron content usually exhibit nano-crystalline structure which becomes a combination of amorphous and crystalline structure as the B content lies within the range of 10-15%. This changes into amorphous structure upon increasing the B concentration upto 20% (Bekish et al. 2010). Therefore, phase structure of chemically deposited nickel-boron coating is a dependent function of boron concentration (Baskaran et al. 2006, Venkatakrishnan and Karthik 2019). It is observed that the coatings with nano-crystalline structure exhibit higher resistance against corrosion compared to amorphous structure (Bekish et al. 2010). Surface hardness and wear behaviour improved due to chemical plating of nickel-boron over pure magnesium and AZ91D alloy while friction coefficient remained almost similar to base metal (Correa et al. 2013). Hence, surface hardness as well as wear resistance of as-plated coatings increase with boron concentration (Bekish at el. 2010) and this improvement in hardness is possible for the homogeneous distribution of boron and amorphous structure. The same can be improved further with heat treatment (Balaraju et al. 2016; Mohanty et al. 2019) and is attributed with the evolution of various boride phases like Ni_2B, Ni_3B during thermal treatment (Krishnaveni et al. 2005; Anik et al. 2008; Kanta et al. 2009; Hamid et al. 2010; Vitry et al. 2012; Yildiz et al. 2017). On the other hand, corrosion resistance becomes worse upon annealing (Riddle and Bailer 2005; Anik et al. 2008). Heat treated nickel-boron coatings show reduced friction value besides wear rate relative to as-deposited coatings (Krishnaveni et al. 2005). Tribological behaviour of coatings also depends on working environment temperature (Mukhopadhyay et al. 2018). Tribological and mechanical behaviours are also seen to vary with the change in microstructure (Pal and Jayaram 2018). Amorphous structure of coating shows improved adhesion strength to aluminium substrate which results in an increase in surface hardness as well as friction and wear behaviour (Delaunois et al. 2002; Hamid et al. 2010; Vitry et al. 2011). Surface hardness of the as-deposited coatings does not change much with the boron content upto 6% but the same improves due to increase in boron concentration upto 9% (Vitry and Bonin 2017). Nano-hardness and elastic modulus of coatings are estimated using loading-unloading curve obtained from nano-indentation based model (Musil et al. 2002; Wei and Lin 2005) which shows good agreement for lower indentation depth with the data obtained from "Korsunsky and Kings" model (Domínguez-Ríos et al. 2012). Surface hardness and Young's modulus of chemically deposited nickel-boron coating increased after annealing at temperatures between 300°C to 450°C. Similarly, mechanical properties are found to increase with annealing duration and this increase can be attributed to the dissipation of hard boride phases like Ni_2B, Ni_3B etc during annealing (Vitry et al. 2011; Domínguez-Ríos et al. 2012). Similarly, hardness and elastic modulus can also be improved by incorporation of hard nano-particles like ZrO_2, Al_2O_3 resulting in grain refinement (Radwan et al. 2015). Addition of nano-particles also increased the corrosion behaviour of nano-composite coatings as the active area decreased with the augmentation of nano-particles into nano-composite coatings (Radwan et al. 2015). Surface hardness, corrosion resistance as well as wear behaviour of as-plated as well as thermal treated nano-composite coatings improve with reinforcement of hard nano-particles