Chapter 9
Tribological and Micro-Structural Characterization of Ni-Cu-P-W Coatings

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ABSTRACT

Ni-Cu-P-W coating was deposited by electroless method on mild steel substrate to study the crystallization and tribological behavior at different annealing temperatures. Energy dispersive x-ray (EDX) analysis, scanning electron microscopy (SEM), x-ray diffraction (XRD), and differential scanning calorimeter (DSC) were used to study the composition, surface morphology, phase behavior, and thermal behavior of the coating, respectively. Tribological study was conducted using Pin-on-Disc tribotester. EDX analysis confirms the presence of Ni, Cu, P, and W in the deposit. SEM image shows the surface is dense, smooth, and without any observable nodule. Some of the samples were heat treated to 300°C, 500°C, and 700°C for 1 hour to observe the crystallographic change by XRD. One sharp crystalline peak of Ni (111) is present in all condition, but the intensity increases rapidly with the heat treatment temperature. The phase transition temperature of this quaternary coating analyzed by DSC was 431.8°C.

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INTRODUCTION

Tungsten and copper already have gained much attention to material scientists and researchers as alloying elements due to their excellent material properties. Tungsten has high hardness, high melting point, high density and good corrosion resistance, on the other hand, copper possess high corrosion resistance, good conductivity, ductility etc. Thus for last two decades, researchers have deposited these elements as alloy along with Ni-P binary electroless coating to explore their properties and also to correlate the structure of alloy with their properties(Sudagar, Lian, and Sha 2013; Agarwal and Agarwala 2003; Ghosh,2019). Several researchers have studied the thermal stability and correlation between crystalline phase and hardness of Ni-W-P ternary alloy coatings (Tsai et al. 2001; Zhou et al. 2019; Luoet al. 2018). It was reported, that crystallization temperature of ternary Ni-W-P deposit is higher than binary Ni-P deposit due to elemental diffusion of W which has high melting point. The hardness of ternary coatings is higher than binary coatings in both as-plated and heat treated condition due to formation of Ni-W solid solution. The hardness of Ni-W-P coatings increased sharply within the temperature range 350°C to 400°C. Wu et al. (2003) studied surface characteristics of as deposited and heat treated ternary Ni-W-P coatings. Nodular surface was observed in as-plated condition of electrolessly deposited ternary alloy with an average roughness of 10 nm. After heat treatment to 400°C and 450°C the nodules started disappearing and smoother surface was generated. XRD and DSC results confirmed the precipitation of Ni_3P phase after heating 300°C for long time (Tien and Duh 2004; Tien, Duh, and Chen 2004a; Tien, Duh, and Chen 2004b; Wu, Tien, Chen, and Duh 2004). At higher temperature all the metastable phases (Ni_5P_2, $Ni_{12}P_5$) transform in to stable Ni_3P phase. Roy and Sahoo studied the friction, wear and corrosion behavior of ternary Ni-P-W coatings at different coating conditions and heat treatment temperature (Roy and Sahoo 2012; Roy and Sahoo 2013). It was revealed that, incorporation of tungsten in to binary Ni-P matrix enhanced the wear and corrosion properties up to 500°C heat treatment temperature due to formation of stable Ni_3P phase (Palaniappa and Seshadri 2008). On the other hand, crystallization characteristics of electroless ternary Ni-Cu-P alloy were studied by several researchers (Yu, Luo, and Wang, 2001; Valova et al. 2005; Yu et al. 2002). It was reported that during heat treatment process low P with high Cu alloy first transform to metastable phase of Ni_5P_2, $Ni_{12}P_5$ then at higher temperature it is converted to Ni_3P phase. As like Ni-W-P, Ni-Cu-P alloy also has higher crystallization temperature compared to Ni-P binary alloy. Incorporation of copper in to Ni-P deposit significantly improves the corrosion resistance (Liu et al. 2010; Liu and Zhao, 2004; Meng, M., Leech, A., & Le, H. 2019; Chen et al. 2019a; Chen et al. 2019b). Concentration of copper ion, pH of the electroless bath and bath temperature has great influence on the corrosion properties of the coating. However, detailed study on the concentration of electroless bath constituents and heat treatment temperature on the tribological and corrosion characteristics of Ni-P-Cu ternary coatings were investigated (Roy and Sahoo, 2014). The comparative study between Ni-P, Ni-W-P and Ni-Cu-P revealed that, in respect to tribological behavior ternary Ni-W-P is better than binary Ni-P and with respect to corrosion characteristics ternary Ni-Cu-P is better that binary Ni-P alloy (Sahoo and Roy, 2017). Thus, to have a coating with good tribological as well as anti-corrosive property electroless quaternary Ni-Cu-W-P can be deposited. There are very few papers reported about the deposition of quaternary Ni-W-Cu-P from sulphate or chloride-based baths and their corrosion properties (Balaraju and Rajam, 2005; Balaraju et al. 2006; Balaraju, Anandan and Rajam, 2006). But, dependency of bath constituents and heat treatment temperature on the tribological and corrosion behavior of this quaternary coating is still untouched. The structural characterization and