Seminar Nasional Fisika
Universitas Negeri Jakarta, 1 Juni 2013

Electrodeposition of Ni-TiAlN Nanocomposite Coating For Wear and Corrosion Protection: A Review

Esmar Budi[1,*)], Hadi Nasbey[1], Agus Setyo Budi[1]

[1]Material Physics Laboratory, Departement of Physics
Faculty of Science and Mathematics, Universitas Negeri Jakarta
Jl. Pemuda No. 10 Rawamangun Jakarta Timur 13220
*) Email: esmarbudi@unj.ac.id

Abstract

Development of nanocomposite thin coating has improved the wear and corrosion resistance of materials. Hard nano particles such as SiC, TiC and TiN was electrodeposited on metal or alloy matrix such as Ni to form a hard nanocomposite thin coating. However, the development of Ni-TiAlN nanocomposite coating by using electrodeposition for wear and corrosion protection is still lack of reports. TiAlN is a transition metal nitride with mechanical and corrosion protection, especially at high temperature operation. This compound is widely used in technology applications such as diffusion barrier of electronic components and hard coating on cutting tools. One of methods to fabricate the nanocomposite coating is electrodeposition since it is easy, low cost and high rate production. This paper is aimed to review on the development of Ni-TiAlN nanocomposite coating by using electrodeposition for wear and corrosion protection.

Keywords: *Ni-TiAlN nanocomposite coating, electrodeposition, wear, corrosion.*

1. Introduction

Recently, the development of electrodeposited nanocomposite coating or film such as Ni-TiN, Ni-TiC, Ni-SiC have being investigated to protect the materials from friction and corrosion [1-3]. Nickel (Ni) is an engineering material with excellent ductility and corrosion resistance and usually used as metal matrix in nanocomposite coating. The addition of nano particles such as TiN, TiC and SiC into Ni matrix improve the hardness, wear and corrosion resistance of electrodeposited nanocomposite coating.

Electrodeposition is a technique to develop a coating on a conductive substrate [4]. The technique works based on the electrochemical reaction and is commonly used to deposit a composite coating due to the posibility of cotrolling the composite coating properties such as morphology, structure and composition by controlling electrodeposition parameters. The Ni coating is one of metal coating that is commonly deposited by electrodeposition. The addition of nano hard particles such as TiN, TiC and SiC in the Ni coating is subjected to modify the coating properties.

One of the hard nano particles is nitride compound. Transition metal nitride such as Titanium Nitride (TiN) and Titanium Alumunium Nitride (TiAlN) has excellent mechanical and corrosion resistence especially in high temperature operation [5-7] and one of the promising material since its ability to form superhard and ultrahard coating with retained hardness at elevated temperature [8]. However, the development of electrodeposited Ni-TiAlN nanocomposite coating is still lack of reports.

In the present paper, the development of Ni-TiAlN nanocomposite coating by using electrodeposition for wear and corrosion protection are reviewed. The influence of electrodeposition condition on the nanocomposite coating are discussed.

2. Ni-TiAlN Nanocomposite coating

Ni (nickel) is an VIII group elements of the periodic table whith its atomic number and weight of 28 and 58.69 gram/mol (Callister, 2010). The crystal structure of Ni is face center cubic structure with atomic radius is 0.1246 nm. Its elastic modulus and yield strength is about 207 GPa and 138 MPa, respectively. While its tensile strength is about 480 MPa. Ni (99.99%wt.) has a melting point and recrystalization temperature of 1455^{0}C and 370^{0}C, respectively [9]. Ni is an noble element that does not react with oxygen, epecially at high temperature, therefore, beside excellent ductility, nickel has excellent corrosion resistance.

Since Ni is ductile thus it is commonly used as interlayer material in thin film fabrication in order to tough the film [10]. Alloying of metal element such as Cr and Co into thin film of Ni, can improve the wear resistance [11,12]. In fabrication of Ni-based nanocomposite coating, Ni is utilized as a matrix while hard nanoparticle such as SiC, TiC and TiN as reinforced particles.

The structure of transition metal nitrides (e.g., TiAlN) is determined by ratio of nitrogen atomic radius to metal transition radius (Hagg rule). If ratio is less than 0.59 thus, a simple structure such as B1 or simple hexagonal will be formed [13]. For TiN, the ratio is 0.504 while AlN is 0.527. Therefore, if Ti is replaced by Al thus, the typical B1 structure of TiN is still retained. TiAlN film has a metastable NaCl structure at Al content of 0 – 60 at.%. The structure undergoes decomposition to NaCl-structured TiN and ZnS-structured AlN at above Al content of 60 at.% (and supposedly at higher temperature process [14,15]. The NaCl structure is described with a simple face-centered-cubic (fcc) Bravais lattice with atoms placed in (0,0,0) and (1/2, 1/2, 1/2). The ZnS-structure is described with a hexagonal Bravais lattice with atoms placed in (1/3, 2/3, 0), (2/3, 1/3, 1/2), (1/3, 2/3, z) and (2/3, 1/3, z). TiAlN structure model schematic is shown in Figure 1 and Figure 2

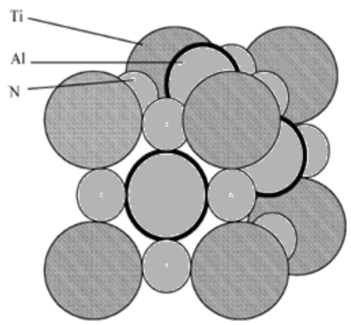
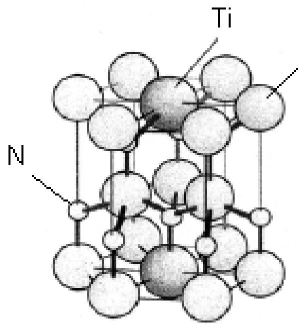
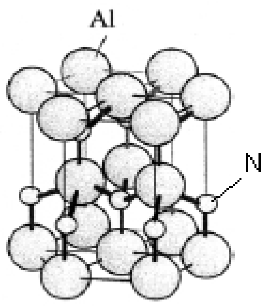


Figure 1 TiAlN structure (fcc-NaCl structure) models schematic. Ti occupies fcc positions and the cube corners. Al occupies the octahedral sites at the centers of the cube edges [16].



(a)



(b)

Figure 2 Model schematic of (a) hexagonal-TiAlN; (b) hexagonal-AlN [17].

Development of nickel-based composites coating by adding hard nano particles have been done in order to improve the nickel layer such as hardness, wear and corrosion resistance. TiAlN is one of the hard materials which is excellent in wear and corrosion resistance especially at high temperature operation.

3. Electrodeposition

Electrodeposition is one of the techniques for producing a nanocomposite coating of metal and non-metal. The technique is quite easy, simple, low cost and high rate production thus it is suitable for industrial production scale.

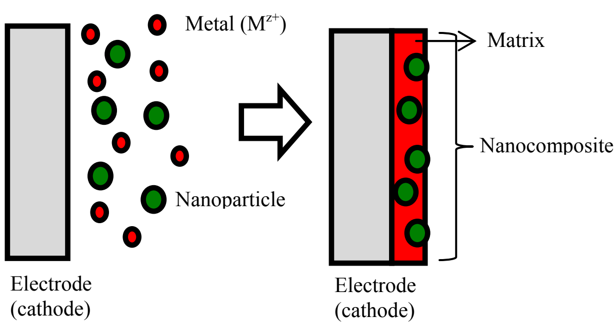


Figure 3. Electrodeposition of nanocomposite

Electrodeposition is a deposition proses that is based on the electrochemical and involving the interchange of electrical and chemical energies through oxidation-reduction [18]. A spontaneous reaction is occured when an electric current flow to the electrode (anode) that is immersed within the electrolyte solution. The proccess is called as reduction reaction since a metalic ion is released followed by releasing one or two electrons. Then, both metalic ion and electrons react and are deposited onto the electrode (cathode). The reaction is written by equation 1 and 2.

$M^{+Z}(aq) + ze^- \rightarrow M(s)$ cathode (1)
$M(s) \rightarrow M^{+Z}(aq) + ze^-$ anode (2)

where M^{+Z} = metal ion, M = metal, z = atomic number, e^- = electron.

Electrochemical process is a process based on the electrolysis principle that was firstly proposed by Faraday (1834). Faraday's law states that numerous charges are produced by a metal when electric current flow through it. The number of charges is proportional to the loss metal mass. Mathematically, the relationship of these quantities is written by equation 3.

$$m = \left(\frac{q}{F}\right)\left(\frac{M}{z}\right) \quad (3)$$

Where m = loss mass of metal (gram), q = number of charge (Coulomb), F = Faraday constant (96485 Coulomb/mol), M = equivalent mass, z = number of metal ion valence.

The development of nanocomposite coating using electrodeposition is devided into 4 steps. Firstly, the development of particle surface charge whithin suspension solution. Secondly, the interchange of mass from suspense bulk to the cathode surface. Thirdly, the interaction between particles and electrode surface and lastly, thin coating growth onto the electrode surface [19]. The schematic diagram of electrodeposition is presented in Figure 3.

Many investigation results were reported that the electrodeposited composite coating was influenced by electrodeposition parameters such as current density, particle concetration, solution agitation speed, batch pH and temperature. The surface morphology of nanocomposite is refined with increasing nanoparticle concentration, current density, solution agitation speed, batch pH and temperature [3]. However, the morfology does not further refined as those parameteres are further increased. Looking at corrosion behavior, the nickel-based nanocomposite coating showed better corrosion resistance than pure nickel coating.

The increase of current density enhances the composite coating hardness due to the formation of nano hard particle precipitation that are uniformly distributed in the Ni matrix and cuases refined Ni grain size [2]. The hardness of electrodeposited nanocomposite coating can be also improved by adding an inorganic additive element such as Co [21]. The presence of this additive element refines the grain size of nanocomposite coating and improves the content of nanoparticles dispersed in metal matrix.

The increase of composite coating hardness followed by the increase of wear and corrosion resistance due to the increase of nano particle content within the coating [1]. The particle content of composite coating is sstrongly influenced by particle concentration in bath, current density, stir rate and temperature.

Recently, the effect of current modes electrodeposition such as pulse and direct current on the hardness and corrosion resistance of composite coating was studied [20]. It was shown that the pulse current composite coating produced high hardness and corrosion resistance than direct current composite coating.

4. Summary

Electrodeposited Ni-TiAlN nanocomposite coating has a promising coating as wear and corrosion protection of materials. The electodeposited composite coating is influenced strongly by process parameters such as current density, particle concentration, stir speed, temperature etc. The development of electrodeposited Ni-TiAlN nanocomposite coating is being prepared and the optimum coating characterictics will be investigated.

Acknowledgement

The authors gratefully acknowledge financial and research facilities support from Departement of Physics, Faculty of Science and Mathematics, Universitas Negeri Jakarta. The authors also thankful to Riser Fahdiran, Doctoral Candidate at Kairlstein University for valueble discussions.

References

1. ZHU Xu-bei, CAI Chao, ZHENG Guo-qu, ZHANG Zhao, LI Jin-feng (2011). Electrodeposition and corrosion behavior of nanostructured Ni-TiN composite films. Trans. Nonferous Met. Soc. China, Vol. 21, pp. 2216-2224.

2. M. Karbasi, N. Yazdian, A. Vahidian. (2012). Development of electro-co-deposited Ni–TiC nano-particle reinforced nanocomposite coatings. Surface & Coatings Technology, Vol. 207, pp. 587–593.
3. M.R. Vaezi, S.K. Sadrnezhaad, L. Nikzad. (2008). Electrodeposition of Ni–SiC nano-composite coatings and evaluation of wear and corrosion resistance and electroplating characteristics. Colloids and Surfaces A: Physicochem. Eng. Aspects, Vol. 315, pp. 176–182.
4. Allen J. Bard and Larry R. Faulkner. *Electrochemical Methods: Fundamental and Application.* 2nd edition. New York: John Wiley & Sons, Inc (2001).
5. Yoon, S.Y., Lee, K.O., Kang, S.S., Kim, K.H. (2002). Comparison for Mechanical Properties Between TiN and TiAlN Coating Layers by AIP Technique. Journal of Material Processing and Technology, Vol.130-131, pp. 260-265.
6. Sergiy Korablov, M.A.M. Ibrahim, Masahiro Yoshimura Hydrothermal corrosion of TiAlN and CrN PVD films on stainless steel Corrosion Science 47 (2005) 1839–1854.
7. R.M. Soutoa, H. Alanyali. Electrochemical characteristics of steel coated with TiN and TiAlN coatings Corrosion Science 42 (2000) 2201-2211.
8. Veprek, S., Haussmann, M., Reiprich, S., Shizhi, Li., Dian, J. (1996). Novel Thermodynamically Stable and Oxidation Resistant Superhard Coating Materials. Surface and Coating Technology, Vol. 86-87, pp. 394-401.
9. W.D. Callister and D.G. Rethwisch. *Material Science and Engineering*, 8th edition, John Wiley & sons (2010).
10. Zhang, S., Sun, D., Fu, Y., Pei, Y.T., De Hosson, J.Th.M. (2005b). Ni-Toughened nc-TiN/a-SiN_x Nanocomposite Thin Film. Surface Coating and Technology, Vol. 200, pp. 1530-1534.
11. M. Laribi,T, A.B. Vannes, D. Treheux. (2006). On a determination of wear resistance and adhesion of molybdenum Cr–Ni and Cr–Mn steel coatings thermally sprayed on a 35CrMo4 steel. Surface & Coatings Technology, Vol. 200, pp. 2704– 2710.
12. L. Shia, C.F. Sun, P. Gao, F. Zhou, W.M. Liu. (2006). Electrodeposition and characterization of Ni–Co–carbon nanotubes composite coatings. Surface & Coatings Technology, Vol. 200, pp. 4870 – 4875.
13. Huang, C.T., Duh, J.G. (1995). Deposition of (Ti,A1)N Films on A2 Tool Steel by Reactive R.F. Magnetron Sputtering. Surface and Coatings Technology, Vol. 71, pp. 259-266.
14. Hugosson, H.W., Hogberg, H., Algren, M., Rodmar, M., Selinder, T.I. (2003). Theory of the Effects of Substitutions on the Phase Stabilities of $Ti_{1-x}Al_xN$. Journal of Applied Physics, Vol. 93, No. 8, pp. 4505-4511.
15. Santana, A.E., Karimi, A., Derflinger, V.H., Schutze, A. (2004). The Role of HCP-AlN on Hardness Behaviour of $Ti_{1-x}Al_xN$ Nanocomposite During Annealing. Thin Solid Films, Vol. 469-470, pp. 339-344.
16. PalDey, S., Deevi, S.C., Alford. T.L. (2004). Cathodic Arc Deposited Thin Film Coatings Based on TiAl Intermetallics. Intermetallics, Vol. 12, pp. 985–991.
17. Kimura, A., Kawate, M., Hasegawa, H., Suzuki, T. (2003). Anisotropic Lattice Expansion and Shrinkage of Hexagonal TiAlN and CrAlN Films. Surface and Coatings Technology, Vol. 169 –170, pp. 367–370.
18. Zumdahl, S.S., Zumdahl, S.A. *Chemistry.* 7th edition, Boston: Houghton Mifflin Company (2007). P. 229-273.
19. Anabela Gomes, Isabel Pereira, Beatriz Fernandez and Rosario Pereiro (2011). Electrodeposition of Metal Matrix Nanocomposites: Improvement of the Chemical Characterization Techniques, Advances in Nanocomposites - Synthesis, Characterization and Industrial Applications, Dr. Boreddy Reddy (Ed.), ISBN: 978-953-307-165-7, InTech.
20. K. Arunsunai Kumar, G. Paruthimal Kalaignann, V.S.Muralidharan.Direct and pulse current electrodeposition of Ni–W–TiO2 nanocomposite coatings. Ceramics International 39 (2013) 2827–2834.
21. Yang Xiu-ying, Li Kang-ju, Peng Xiao, Wang Fu-hui. Beneficial effects of Co2+ on co-electrodeposited Ni-SiC nanocomposite coating. Trans. Nonferrous Met. Soc. China, Vol. 19 (2009), pp. 119 – 124.