THE EFFECT OF SUBSTRATE TEMPERATURE OF (Ti,Al)N COATING ON AISI 304L STAINLESS STEEL AND HIGH SPEED STEEL USING PHYSICAL VAPOR DEPOSITION (PVD) METHOD

CHOO SHYH JING

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Specially dedicated to

My beloved family and friends

For their support and inspiration

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ABSTRACT

The purpose of (Ti,Al)N coating was to provide adherent coating on steel substrates to improve mechanical properties of steel tools in industrial applications. The effect of substrate temperature of physical vapour deposition (PVD) was an important parameter to study which affect the adhesion strength of (Ti,Al)N coating on alloy steel substrates. In this research, two types of substrates were chosen: AISI 304L stainless steel and high speed steel (HSS). The coating was deposited on both substrates at four different substrate temperatures which are 200^{o}C, 240^{o}C, 300^{o}C, and 400^{o}C for 90 minutes deposition time with 200 watt DC power, gas flow rate was maintained at ratio of 10 sccm N_2 : 20 sccm Ar, and 10 mTorr working pressure was used using a pure TiAl target with 50 wt% Ti : 50 wt% Al ratio. The coating morphology was observed as columnar type structure and the surface roughness was decreased with substrate temperatures. From the adhesion test results it shows that the adhesion strength of (Ti,Al)N coating was increased with substrate temperature for both 304L stainless steel and HSS but, the deposition rate of coating was decreased for both substrates.

ABSTRAK

Tujuan penyalutan (Ti,Al)N adalah untuk menghasilkan salutan yang baik di atas substrat keluli aloi untuk memperbaiki sifat-sifat mekanik keluli alat dalam aplikasi-aplikasi industri. Kesan suhu substrat adalah parameter yang sangat penting untuk mengkaji kesan kekuatan lekatan salutan (Ti,Al)N atas keluli aloi dalam pemendapan wap fizikal. Dalam kajian ini, dua jenis substrat telah dipilih: AISI 304L keluli tahan karat dan keluli kelajuan tinggi (HSS). Penyalutan telah dilakukan untuk kedua-dua jenis substrat dengan menggunakan empat suhu substrat yang berlainan iaitu 200^oC, 240^oC, 300^oC, dan 400^oC dengan 90 minit masa pemendapan, 200 watt kuasa DC, kadar aliran gas telah ditetapkan pada nisbah 10 sccm N_2 : 20 sccm Ar, and tekanan kerja 10 mTorr telah digunakan dengan menggunakan sasaran TiAl tulen pada kandungan 50 wt% Ti : 50 wt% Al. Morfologi salutan yang terhasil adalah berstruktur kolum dan kekasaran permukaan adalah berkurangan dengan suhu. Daripada uijian-ujian salutan ianya menunjukkan kekutan lekatan salutan (Ti,Al)N semakin meningkat dengan peningkatan suhu untuk kedua-dua jenis substrat, keluli tahan karat 304L dan HSS, tetapi kadar salutan adalah berkurangan..

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LIST OF SYMBOLS / ABBREVIATION

TiN	Titanium Nitride
CrN	Chromium Nitride
(Ti,Al)N	Titanium Aluminium Nitride
AISI	American Iron and Steel Institute
XRD	X-Ray Diffractometer
EDX	Energy Dispersive X-ray Analysis
AFM	Atomic Force Microscope
FESEM	Field Emission Scanning Electron Microscope
304L	304 Low Carbon
HSS	High Speed Steel
PVD	Physical Vapour Deposition
RF	Radio Frequency
DC	Direct Current
GDS	Glow Discharge Spectrometer
SCCM	Standard Cubic Centimeters Per Minute
RMS	Root Mean Square
Ra	Arithmetic Average

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Alloy steels are one of the most commonly used and cost effective structural materials in modern industry. However when steel is used for critical wear resistant components and machining tools such as bearings, taps, dies, twist drills, saw blades, and other cutting tools in harsh environments, accelerated damage are usually occur because of its low wear resistance properties.

Nowadays due to the low mechanical properties of alloy steel, a hard coating such as TiN, CrN, and (Ti,Al)N was introduced as a protective coating on mechanical tools. The exceptional mechanical and corrosion resistant properties of these hard coatings such as high hardness and wear resistant, and good oxidation resistance at high temperature make the surface of the hard coating to be potentially ideal as coatings for wear resistant components and machining tools. Since the early failure of tool steels is always on the outermost surface, hence with well-adhered surface hard coating films deposited on the steel can lead to major improvements of life time and performance of such tool steels.

1.2 Background of Study

Physical vapour deposition (PVD) is one of the preferred techniques for the development of hard coating due to many advantages such as better control of process parameters and stoichiometry of the deposition coating. Besides that, it is also more cost effective as compared to plasma enhance chemical vapour deposition and low pressure chemical vapour deposition [1,2]. 304L stainless steel and high speed steel were chosen as the substrate material in this research and (Ti,Al)N hard coating was deposited because it has excellent high oxidation resistance, high hardness and high corrosion resistance. Besides that, this coating is suitable used for cutting tools especially for dry and high speed machining application [3,4].

1.3 Problems Statement

The (Ti,Al)N coating was deposited on the steel substrate using physical vapor deposition (PVD) METHOD. However, the PVD parameters will influence the (Ti,Al)N coating adhesion strength to the steel substrate. Hence, in this project there is a necessary to conduct a research to investigate an optimum PVD parameter in order to produce good (Ti,Al)N coating on the surface of stainless steel and high speed steel without delamination.

1.4 Objective of the Study

The objective of this research is to study the effect of substrate temperature of (Ti,Al)N coating on AISI 304L stainless steel and high speed steel using Physical Vapor Deposition (PVD) method.

1.5 Scope of the Study

1. To produce (Ti,Al)N interlayer on AISI 304L stainless steel and high speed steel using direct current (DC) magnetron sputtering method.
2. To do microstructural evaluation on the coated specimen using XRD, EDX, and AFM.
3. To conduct Rockwell C indentation test and knife test to evaluate the coating adhesion strength.

1.6 Significant of the study

Nowadays, ferrous metals or steels are become one of the most popular used material for engineering applications. Although the properties of steels are suited for most of the engineering applications such as taps, dies, twist drills, and other cutting tools, but in order to fulfil more demanding application of steels, the (Ti,Al)N deposition as an adherent coating on steel surface will gain more advantages. With the combine properties of steel and (Ti,Al)N coating, the new properties of the system will provide much better than the normal steel, besides that the performance and the life span of the tools will also improved.

However, in order to deposit a good adhesion (Ti,Al)N coating on steel, the deposition parameters for (Ti,Al)N coating on steel substrate become important to study. Thus, this research will focus on the study of the effect of substrate temperature of (Ti,Al)N coating on AISI 304L stainless steel and high speed steel using PVD method.

8. Chemical and Physical Properties of AISI 304 Stainless Steel (2011). Atlas Steels Australia. http://www.azom.com/article.aspx?ArticleID=965.

9. L.A.Geller (1961). Instrumental'nye stali 2nd Edition. Moscow.

10. Product Data Bulletin of 304/304L stainless steel (2007). AK STEEL Coorparation.

11. High Speed Steel Tool Data (1994). ISC Cutting Tools INC.

12. R.Polini, F.P.MAntini, M.Amar, W.Ahmed, and H.Taylor (2005). Effects of Ti- and Zr-based interlayer coatings on the hot filament chemical vapor deposition of diamond on high speed steel. Thin Solid Film 494.116.116-122

13. C.Harish, Barshilia, M.S.Prakash, A.Jain, and K.S.Rajam (2004). Structure, hardness and thermal stability of TiAlN and nanolayered TiAlN/CrN multilayer films. Vacuum77, 169-179

14. F.Quesada, A.Marino, and E.Restrepo (2006) TiAlN coatings deposited by r.f. magnetron sputtering on previous treated ASTM A36 steel. Surface & Coating Technology 201, 2925-2929

15. S.Paldey, and S.C.Deevi (2002). Single layer and multilayer wear resistant coating of (Ti,Al)N: a review. Material Science and Engineering A 342, 58-79

16. R.Polini, F.P.Mantini, M.Braic, M.Amar, W.Ahmed, H.Taylor, and M.J.Jackson (2005). Effects of Ti- and Zr-based interlayer coatings on the hot filament chemical vapour deposition of diamond on high speed steel. Thin Solid Film 494.116.116-122

17. E. Lugscheider, C.Barimani, C.Wolff, S.Guerreiro, and G.Doepper (1996). Comparison of the structure of PVD-thin films deposited with different deposition energies. Surface and Coatings Technology. vol. 86-87, pp. 177-183.

18. D.M.Mattox (1997). PVD Hand Book. New Mexico

19. L.Q.Jie (2008). Silicon Self-Assembled Nanodots Fabricated Using A Radio-Frequency Magnetron Sputtering Method. Universiti Teknologi Malaysia: Master Thesis

20. H.N.Shah, R.JAyaganthan, D.Kaur, and R.Chandra (2010), Influence of sputtering parameters and nitrogen on the microstructure of chromium nitride thin films deposited on steel substrate by direct current reactive magnetron sputtering. Thin Solid Films. 518, 5761-5768

21. P.C. Jindal., Thin Solid Films 154 1987. 361–375

22. W.Heinke, A.Leyland, A.Matthews, G.Berg, C.Friedrich, and E.Broszelt (1995), Evaluation of PVD nitride coatings, using impart, stratch and Rockwell-C adhesion tests. Thin Solid Films. 270, 431-438

23. J.Gerth, and U.Wiklund (2008). The influence of metallic interlayers on the adhesion of PVD TiN coating on high speed steel. Wear 264, 885-892

24. O.Golzman, G.HAlperin, I.Etsion, A.Berner, D.Shectman, and G.H.Lee (1999), Study of wear behavior and adhesion of diamond films deposited on steel substrates by use of a Cr-N interlayer. Diamond and Related Material 8,859-864

REFERENCES

1. J.musil, P.Baroch, J.Vicek, K.H.Nam, and J.G.Han (2005). Reactive magnetron sputtering of thin films: present status and trends. Thin Solid Films 457,208

2. I.Safi (2000). Measurement of energy transfer at an isolated substrate in a pulsed magnetron discharge. Journal Of Apply Physic 127,203

3. A.K.Singh, N.Kumari, S.K.Mukherjee, and P.K.Barhai (2013). Atomic force microscopy analysis of effect of RF/DC power ratio on the properties of co-sputtered $Ti_xAl_{1-x}N$ thin films. Jharkhand, Inda.

4. J.C.Oliveira, A.Manaia, and A.Cavaleiro (2008). Hard amorphous Ti-AlN coatings deposited by sputtering. Thin Solid Films 516p5032

5. W.D.Calister (2007). Materials Science and Engineering: An Introduction 7th Edition. John Wiley & Sons, Inc.

6. H.K.D.H. Bhadeshia (2006). Steels 3rd Edition: Microstructure and Properties. Elsevier Ltd.

7. A.Ahmad (2011). Surface Morphology Studies of Silicon Interlayer On Stainless Steel Substrate Using Physical Vapor deposition (PVD) Method. Degree Thesis. Universiti Teknologi Malaysia.

25. Standard test method for evaluating adhesion by knife. ASTM International Designation : D6677-07 (2012)

26. S.R.Jiang, D.L.Pend, X.Y Zhao, L.Xie, and Q.Li (1995), Study on the mechanical and chemical properties of (Ti,Al)N films prepared by DC magnetron sputtering. Appied Surface Science. 84, 373-377

27. K.Singh, P.K.Limaye, N.L.Soni, A.K.Grover, R.G.Agrawai, and A.K.Suri (2005), Wear studies of (Ti-Al)N coatings deposited by reactive magnetron sputtering. Wear 258, 1813-1824