Faculty of Manufacturing Engineering

MODELING OF REACTIVELY SPUTTERED TiAlN COATING ON TUNGSTEN CARBIDE INSERT TOOL: ITS PROPERTIES AND CUTTING PERFORMANCE IN DRY TURNING OF AISI D2 STEEL

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Ph.D in Manufacturing Engineering

2010

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ESMAR BUDI

A thesis submitted
in fulfillment of the requirements for the degree of Doctor of Philosophy in Manufacturing Engineering

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2010

ABSTRACT

An extended theoretical model of reactive sputtering of TiAlN coating has been developed to study the effect of substrate bias (V_b) and nitrogen (N_2) flow rate on the coating composition and deposition rate. The model simulation results showed that the critical N_2 flow rate ($f_{N_2}^c$) to achieve a stoichiometry composition of unbiased (V_b = 0 V) and biased (V_b = -80 V) substrate was 4 sccm and 3 sccm, respectively. At N_2 flow rate lower than $f_{N_2}^c$, the coating composition increased with an increase in V_b and N_2 flow rate due to the increase of ion flux to the substrate while the deposition rate decreased due to the coating densification and the decreased sputtering rate. At N_2 flow rate higher than $f_{N_2}^c$, the coating composition and deposition rate did not depend on the V_b and N_2 flow rate due to the domination of neutral particles deposition than ions deposition. The model verification using secondary data showed an accurately prediction on the coating composition and deposition rate at N_2 flow rate higher than $f_{N_2}^c$. The calculated coating composition at N_2 flow rate lower than $f_{N_2}^c$ showed a deviation due to heterogeneous reactions between the sputtered particles (Ti and Al) and N at the substrate surface, while the deviation of calculated deposition rate was due to coating densification. The experimental investigation was designed by using Response Surface Methodology (RSM) and conducted by using magnetron sputtering in deposition of TiAlN coating on WC inserts. The coating composition and thickness were obtained by using SEM/EDX. The coating structure and morphology were obtained by using XRD and AFM, respectively. The coating hardness and adhesion were obtained by using ultra-micro hardness test and indentation test, respectively. The cutting test was carried out in CNC dry turning of AISI D2 steel. The flank wear and surface roughness were obtained by using optical microscopy and surface roughness tester, respectively. The results showed that generally the coating composition of biased substrate (-100, -150, -200 V) was consistently higher than that of unbiased substrate whereas the deposition rate of biased substrate is lower than that of unbiased substrate. Analysis of the coating thickness showed that generally the coating thickness decreased with an increase in the V_b and N_2 flow rate. At N_2 flow rate lower than 50 sccm, the thinnest coating (~ 1000 nm) is achieved by unbiased substrate due to low ions fluxes for reaction at the substrate surface. The coating hardness, structure and morphology were significantly influenced by the V_b while the interaction of the V_b and N_2 flow rate significantly influenced the coating adhesion. The coating hardness increased (~7 GPa) with an increase in the V_b up to -200 V due to decreased coating crystal size. At N_2 flow rate of 70 sccm, the adhesion strength increased with an increase in the V_b up to -200 V due to decreased compressive stress. The lowest flank wear (~0.4 mm) due to high adhesion strength was achieved at -200 V and 70 sccm.

ABSTRAK

Sebuah model percikan reaktif salutan TiAlN lanjut telah dibangunkan untuk kajian kesan pincangan substrat (V_b) dan kadar aliran nitrogen (N_2) pada kandungan salutan dan kadar pengendapan. Hasil simulasi model menunjukan bahawa kadar aliran N_2 genting ($f_{N_2}^c$) substrat tak terpincang (V_b = 0 V) dan terpincang (V_b = -80 V) untuk mencapai kandungan stoikiometri masing-masing adalah 4 sccm dan 3 sccm. Pada kadar aliran N_2 kurang daripada $f_{N_2}^c$, kandungan salutan bertambah dengan penambahan V_b disebabkan penambahan fluks ion ke permukaan substrat, sedangkan kadar pengendapan berkurang disebabkan penumpatan salutan dan pengurangan kadar percikan. Pada kadar aliran N_2 di atas $f_{N_2}^c$, kandungan salutan dan kadar pengendapan tidak bergantung pada V_b dan kadar aliran N_2, disebabkan penguasaan pengendapan zarah neutral daripada pengendapan ion. Pengesahan model dengan menggunakan data sekunder menunjukan jangkaan jitu kandungan salutan dan kadar pengendapan pada kadar aliran N_2 di atas $f_{N_2}^c$. Kandungan salutan jangkaan pada kadar aliran N_2 di bawah $f_{N_2}^c$, menunjukan sebuah sisihan disebabkan tindak balas heterogen antara zarah percik (Ti dan Al) dan N pada permukaan substrat, sementara itu sisihan kadar pengendapan jangkaan disebabkan penumpatan salutan. Ujikaji dirancang dengan menggunakan kaedah permukaan gerak balas (RSM) dan dilaksanakan dengan menggunakan percikan magnetron dalam pengendapan salutan TiAlN pada sisip WC. Kandungan dan ketebalan salutan diperolehi dengan SEM/EDX. Struktur dan morfologi salutan masing-masing diperolehi dengan XRD dan AFM. Kekerasan dan lekatan salutan masing-masing diperolehi dengan ujian kekerasan mikro ultra dan ujian lekuk. Ujian pemotongan dilaksanakan dengan larik CNC pada keluli AISI D2. Keausan sisi dan kekasaran permukaan masing-masing diperolehi dengan menggunakan mikroskop optik dan ujian kekasaran permukaan. Hasil kajian menunjukan bahawa pada umumnya kandungan salutan substrat terpincang (-100, -150, -200 V) adalah tekal lebih tinggi daripada kandungan substrat tak terpincang sebaliknya kadar pengendapan substrat terpincang adalah lebih rendah daripada kadar pengendapan substrat tak terpincang. Analisis pada ketebalan salutan menunjukan bahawa umumnya, ketebalan salutan berkurang dengan penambahan V_b dan kadar aliran N_2. Sungguhpun begitu pada kadar aliran N_2 di bawah 50 sccm, ketebalan salutan paling nipis (~1000 nm) dicapai oleh substrat tak terpincang disebabkan fluks ion yang rendah untuk tindak balas pada permukaan substrat. Kekerasan, struktur dan morfologi salutan adalah dipengaruhi secara signifikan oleh V_b, sementara saling tindak antara V_b dan kadar aliran N_2 mempengaruhi lekatan salutan. Pada umumnya, kekerasan salutan bertambah (~7 GPa) dengan penambahan V_b kepada -200 V disebabkan pengurangan saiz hablur. Pada kadar aliran N_2 70 sccm, kekuatan lekatan bertambah dengan penambahan V_b kepada -200 V disebabkan pengurangan tegangan mampat. Keausan sisi terendah (~0.4 mm) yang disebabkan kekuatan lekatan tinggi dicapai pada -200 V dan 70 sccm.

ACKNOWLEDGEMENTS

The author would like to express sincere appreciation to Prof. Dr. Mohd. Razali bin Muhamad, my principal supervisor, for guiding and giving inputs to the present work. I am very thankful to En. Saifudin Hafiz bin Yahaya, my co-supervisor, for his contribution in the model development and to Dr. Md Nizam bin Abdul Rahman for very valuable discussions and advice during the course at my study.

I gratefully acknowledge the support from the staff at the Advanced Manufacturing Center (AMC), CNC, Metrology and Material Engineering Laboratory during the experimental work. I am also grateful to Faculty of Manufacturing Engineering and Universiti Teknikal Malaysia Melaka (UTeM) for providing research facilities and funds and I would like to thank Physics Department and Universitas Negeri Jakarta (UNJ) for their approval and support during study leave.

Thank you to my colleagues, postgraduate students and staff of UTeM. Finally, I am very grateful to my family, wife and children, for their patience and support.

DECLARATION

I declare that this thesis entitled "Modeling of reactively sputtered TiAlN coating on tungsten carbide insert tool: its properties and cutting performance in dry turning of AISI D2 steel" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : ESMAIL BUDI

Date : 10 Mei 2010

DEDICATION

To my beloved father, mother, wife and children:
Sumarna (alm.), Komariah, Pepi, Giga and Tera

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