Faculty of Manufacturing Engineering

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

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ESMAR BUDI

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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 TiAIN 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 menunjukkan bahwa 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 penumpukan 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 jangka jitu kandungan salutan dan kadar pengendapan pada kadar aliran \( N_2 \) di atas \( f_{N_2}^c \). Kandungan salutan jangka 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 jangka disebabkan penumpuan salutan. Ujikaji dirancang dengan menggunakan kaedah permukaan gerak balas (RSM) dan dilaksanakan dengan menggunakan percikan magnetron dalam pengendapan salutan TiAIN pada sisip WC. Kandungan dan ketebalan salutan diperoleh dengan SEM/EDX. Struktur dan morfologi salutan masing-masing diperoleh dengan XRD dan AFM. Kekerasan dan lekatan salutan masing-masing diperoleh 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 diperoleh dengan menggunakan mikroskop optik dan ujian kekasaran permukaan. Hasil kajian menunjukan bahwa pada umumnya kandungan salutan substrat terpincang (-100, -150, -200 V) adalah tekan 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 halbuh. 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.
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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 : ..................................................
Date : ..................................................
DEDICATION

To my beloved father, mother, wife and children:
Sumarna (alm.), Komariah, Pepi, Giga and Tera
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SEM of TiAlN coating on WC insert at I = 3 A, V_b = -100 V, T = 350 °C, substrate rotation = 5 rpm, t = 90 min, Ar flow rate = 123 sccm, N2 flow rate of:
(a) 20 sccm; (b) 10 sccm

EDX of TiAlN coating on WC insert at I = 3 A, V_b = -100 V, T = 350 °C, substrate rotation = 5 rpm, t = 90 min, Ar flow rate = 123 sccm, N2 flow rate of:
(a) 20 sccm, (b) 10 sccm

SEM of TiAlN coating on WC insert at I = 5 A, V_b = -100 V, T = 350 °C, substrate rotation = 5 rpm, t = 90 min, Ar flow rate = 123 sccm, N2 flow rate = 60 sccm
Model calculated (solid line) and measured (experimental result) $\theta_s$ of TiAlN coating at $I = 5$ A, $S = 2050$ l/s and various substrate bias and nitrogen flow rate

Model calculated (solid lines) and measured (experimental result) $\theta_s$ of TiAlN coating at unbiased substrate ($V_b = 0$) and various nitrogen flow rate and its comparison with biased substrate of: (a) $V_b = -100$ V; (b) $V_b = -150$ V; (c) $V_b = -200$ V

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Interaction effect on Ti/Al ratio of TiAlN coating: (a) Ti/Al ratio vs nitrogen flow rate: triangle line curve is at high negatively substrate bias and the square line curve is at low negatively substrate bias; (b) Ti/Al ratio vs substrate bias: triangle line curve is at high nitrogen flow rate and the square line curve is at low nitrogen flow rate

Three dimension graph of Ti/Al ratio as function of substrate bias and nitrogen flow rate

Interaction effect on Ti/(Ti+Al+N) ratio of TiAlN coating: (a) Ti/(Ti+Al+N) ratio vs nitrogen flow rate: triangle line curve is at high negatively substrate bias and the square line curve is at low negatively substrate bias; (b) Ti/(Ti+Al+N) ratio vs substrate bias: triangle line curve is at high nitrogen flow rate and the square line curve is at low nitrogen flow rate

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