Faculty of Manufacturing Engineering

DEVELOPMENT AND PERFORMANCE ANALYSIS OF ALUMINA-YTTRIA STABILIZED ZIRCONIA-CHROMIA CUTTING TOOL FOR HIGH WEAR PERFORMANCE

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DECLARATION

I declare that this thesis entitled "Development and Performance Analysis of Alumina-Yttria Stabilized Zirconia-Chromia Cutting Tool for High Wear Performance" 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 : .....

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

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Date : 3/12/2020

DEDICATION

This project is dedicated to my beloved mother, father, wife and children for being great pillars of support.

ABSTRACT

Alumina based cutting tool have gradually garnered huge applications in refractory process especially in machining industries. This is due to their excellent hot hardness and abrasion resistance that could shear the workpiece material efficiently especially in dry condition. However, their inherent properties such as brittleness, low thermal shock resistance and sensitive to the cutting load have led to difficulty in providing longer tool life which limit their applications. This study presents the improvement of alumina (Al_2O_3) based cutting tool by addition of zirconia (ZrO_2) and chromia (Cr_2O_3) content. The development of these cutting tools were divided into four parts. The first part focused to determine the effective processing parameters with variations of polyethylene glycol (PEG) content (0.6-1.25 wt.%) as binder, sintering temperature (1200°C-1400°C) and cold isostatic pressing (CIP) pressure (200-400 MPa). The second part focused on the formulation of Al_2O_3, ZrO_2 and Cr_2O_3 compositions to produce effective cutting tool based on the hardness, density, flexural strength and coefficient of friction (COF). Various content of ZrO_2 (0, 5, 10, 15, 20 and 25 wt.%) and Cr_2O_3 (0, 0.2, 0.4, 0.6 and 0.8 wt.%) were added into dominant Al_2O_3 powders and consistently processed by using parameters determined from the first part of study. The third part focused on the comparison of machining performance for the fabricated cutting tools based on the tool life and wear mechanism. The fourth part focused on the optimization of machining parameters based on the response surface methodology (RSM) and analysis of variance (ANOVA). The results from the first part highlighted that the effective content of PEG binder recorded at 0.6 wt%. The samples recorded maximum hardness and density at 62.5 HRc and 3.692 g/cm^3 when CIP pressure was set at 300 MPa and 60-second dwell time and the sintering temperature was set at 1400°C and 9 hours soaking time. For the second part of the study, Al_2O_3-ZrO_2 with ratio 80-20 wt% produced hardness, relative density and bending strength of 70.07 HRc, 97% and 1449.33 MPa respectively. This value was changed to 71.03 HRc, 95.8% and 856.02 MPa when 0.6 wt% Cr_2O_3 were added into the 80-20 wt% Al_2O_3-ZrO_2. Al_2O_3-ZrO_2 mixed Cr_2O_3 presented lower COF (0.23) as compared to Al_2O_3-ZrO_2 (0.28) and Al_2O_3 (0.34). At the third part of the study, cutting tool fabricated from Al_2O_3-ZrO_2 mixed Cr_2O_3 with ratio 80-20-0.6 wt.% recorded highest tool life of 360-second with 33.33% improvement of tool life as compared to 80-20 wt.% ZTA (240-second) and 75% improvement of pure Al_2O_3 (90-second). The optimization of cutting parameters on the final part of the study proposed that the cutting speed of 200 m/min, feed rate of 0.125 mm/rev and depth of cut 0.50 mm obtained 99% desirability to produce minimum wear rate. Overall, the addition of 0.6 wt.% Cr_2O_3 into Al_2O_3-ZrO_2 matrix adequately enough to evaporate and reacted with the Al_2O_3 to generate anisotropy-oriented particles at the upper surface of the product. Such structure enabled stronger particle compact formed due to the interlocking grains at the affected area.

ABSTRAK

Alat pemotong berasaskan alumina secara beransur-ansur menghasilkan aplikasi yang sangat besar dalam proses refraktori terutamanya dalam industri pemesinan. Ini disebabkan kekerasan panas dan ketahanan lelasan yang sangat baik yang boleh memotong bahan kerja dengan cekap terutama dalam keadaan kering. Walau bagaimanapun, sifat-sifat yang wujud seperti kerapuhan, rintangan kejutan haba yang rendah dan sensitif terhadap beban pemotongan telah menyebabkan kesukaran dalam menyediakan hayat alat yang lebih lama yang membataskan aplikasi mereka. Kajian ini membentangkan fabrikasi dan prestasi pemesinan alat pemotong yang dibuat berasaskan alumina (Al_2O_3) dengan penambahan zirkonia (ZrO_2) dan chromia (Cr_2O_3). Pembangunan alat pemotong ini dibahagikan kepada empat bahagian. Bahagian pertama memberi tumpuan kepada penentuan parameter pemprosesan yang berkesan dengan variasi kandungan polyethylene glycol (PEG) (0.6-1.25% berat) sebagai pengikat, suhu persinteran (1200°C-1400°C) dan tekanan isostatik sejuk (CIP) (200-400 MPa). Bahagian kedua memberi tumpuan kepada penggubalan komposisi Al_2O_3, ZrO_2 dan Cr_2O_3 untuk menghasilkan alat pemotong yang berkesan berdasarkan kekerasan, kepadatan, kekuatan lenturan dan pekali geseran (COF). Bahagian ketiga memberi tumpuan kepada perbandingan prestasi pemesinan terhadap alat pemotong yang difabrikasi berdasarkan hayat alat dan mekanisma haus. Bahagian keempat memberi tumpuan kepada pengoptimuman parameter pemesinan berdasarkan kaedah tindak balas permukaan (RSM) dan variasi analisis (ANOVA). Keputusan daripada bahagian pertama menekankan bahawa kandungan pengikat PEG yang berkesan direkodkan pada 0.6% berat. Sampel telah mencatatkan kekerasan dan ketumpatan maksimum pada 62.5 HRc dan 3.692 g/cm^3 apabila tekanan CIP ditetapkan pada 300 MPa serta 60 saat masa tinggal dan suhu persinteran pula ditetapkan pada 1400°C dan 9 jam waktu perendaman. Pada bahagian kedua kajian, Al_2O_3-ZrO_2 dengan nisbah 80-20% berat menghasilkan kekerasan, ketumpatan relatif dan kekuatan lentur 70.07 HRc, 97% dan 1449.33 MPa masing-masing. Nilai ini telah berubah kepada 71.03 HRc, 95.8% dan 856.02 MPa apabila 0.6% berat Cr_2O_3 ditambah ke dalam 80-20% berat ZTA. ZTA dicampur Cr_2O_3 memperolehi nilai COF yang lebih rendah (0.23) berbanding ZTA (0.28) dan Al_2O_3 (0.34). Pada bahagian ketiga kajian, alat pemotong yang dibuat dari ZTA dicampur Cr_2O_3 dengan nisbah 80-20-0.6% berat mencatatkan hayat alat tertinggi iaitu 360 saat dengan peningkatan 33.33% berbanding 80-20% berat ZTA (240 saat) dan peningkatan 75% daripada Al_2O_3 tulen (90 saat). Pengoptimuman parameter pemotongan pada bahagian akhir kajian mencadangkan bahawa kelajuan pemotongan 200 m/min, kadar suapan 0.125 mm/rev dan kedalaman pemotongan 0.50 mm memperoleh 99% keinginan. Secara keseluruhannya, penambahan 0.6% berat Cr_2O_3 kepada matriks Al_2O_3-ZrO_2 sangat mencukupi untuk Cr_2O_3 menguap dan bertindak balas dengan struktur matrik Al_2O_3 bagi menghasilkan zarah berorientasikan anisotropi di permukaan atas produk. Struktur ini membolehkan zarah padat kuat terbentuk disebabkan oleh biji-bijian saling terkunci antara satu sama lain di kawasan yang terjejas.

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LIST OF ABBREVIATIONS

AISI	-	American iron and steel institute
Al	-	Aluminium
Al_2O_3	-	Aluminium oxide/ alumina
ASTM	-	American Society for Testing and Materials
BUE	-	Built-up edge
CBN	-	Cubic boron nitride
CeO_2	-	Cerium oxide
CIP	-	Cold isotactic press
CNC	-	Computer numerical control
CrN	-	Chromium nitride
Cr_2O_3	-	Chromium oxide
DOC	-	Depth of cut
EN	-	Euro norm
Ff	-	Load at fracture
Fr	-	Feed rate
HIP	-	Hot isotactic press
HSS	-	High speed steel
ISO	-	International standard organization
L	-	Distance