CUTTING PERFORMANCE AND WEAR OF ZTA-TiO_2-Cr_2O_3 MIXED CERAMIC CUTTING TOOLS WHEN TURNING STAINLESS STEEL 316L

BY

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A thesis submitted in fulfillment of the requirement for the degree of Master of Science (Manufacturing Engineering)

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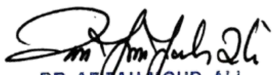
OCTOBER 2021

ABSTRACT

The ZTA-TiO_2-Cr_2O_3 ceramic cutting tool is a new cutting tool that possesses good hardness and fracture toughness. However, the performance of the ZTA-TiO_2-Cr_2O_3 cutting tool is still unknown and needs further study. In this research, the cutting performance and wear of the ZTA-TiO_2-Cr_2O_3 mixed ceramic cutting tools in turning stainless steel 316L are investigated. The tool wears of the ZTA-TiO_2-Cr_2O_3 cutting tool and the surface roughness of the machined surface of stainless steel 316L are investigated, and the empirical model for predicting the tool wear was generated. Finally, the comparison of the ZTA-TiO_2-Cr_2O_3 and Sandvik ceramic cutting tool is investigated. Preliminary experiments are conducted to set the range of machining where the spindle speeds are in the range of 1000 to 1450 rpm, feed rate from 0.1 to 0.15 mm/rev, and depth of cut of 0.2 mm. Measurements of wear were considered in the analysis before the final parameters were designed for machining. In the design of the experiment, the parameters used for the spindle speed are in the range of 907 to 1543 rpm, feed rate from 0.08 to 0.22 mm/rev, and depth of cut of 0.2 mm. Bridgeport ROMI PowerPath CNC lathe machine is utilized to conduct the turning operation for the experiment. Analysis of the flank wear and crater wear were performed by using an optical microscope (NIKON MM-4001L), while the chipping area was observed by scanning electron microscopy, SEM (JEOL JSM-IT100). The surface roughness of the machined surface is measured via portable surface roughness (Mahr MarSurf M3000C). In the preliminary experiment, the flank wear, crater wear, and surface roughness are decreasing when the spindle speed increased from 1000 to 1450 rpm and the feed rate increased from 0.10 to 0.15 mm/rev. The results obtained from the actual experiment are analyzed by using Design Expert 11 software. It is found that the spindle speed is a significant factor that affects the flank wear and the surface roughness of the machined surface, while the crater wear is more affected by the feed rate of the machining parameters. The optimum cutting parameters are when the spindle speed of 1421.38 rpm, and the feed rate of 0.10 mm/rev. It shows that the cutting tool has good potential in high-speed machining. The comparison between the cutting tool produced in this research and the commercial cutting tool shows that the wear performance of the ZTA-TiO_2-Cr_2O_3 ceramic cutting tool is lower than the Sandvik commercial ceramic cutting tool. Even though the commercial cutting tool has superior properties, the fabricated ceramic cutting tool shows some promising aspects such as cutting at a higher speed.



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خلاصة البحث

أداة قطع السراميك $ZTA-TiO_2-Cr_2O_3$ هي أداة قطع جديدة تمتلك صلابة جيّدة وصلابة الكسر. ومع ذلك، لا يزال أداء أداة قطع $ZTA-TiO_2-Cr_2O_3$ مجهولا ويحتاج إلى المزيد من الدراسة. وفي هذا البحث، يجري التحقيق في أداء القطع وارتداء أدوات قطع السيراميك المختلطة $ZTA-TiO_2-Cr_2O_3$ في تحويل 316L الفولاذ التي لا تصدأ. ويتم التحقيق في الأداة الخاصة بأداة القطع $ZTA-TiO_2-Cr_2O_3$ وخشونة سطح 316L الفولاذية التي لا تصدأ ، وتم توليد النموذج التجريبي للتنبؤ بارتداء الأداة. وأخيرا، تعرض المقارنة بين أداة قطع $ZTA-TiO_2-Cr_2O_3$ و أداة قطع الخزف الرملي. التجارب الأوّلية تجرى في وضع نطاق الآلة حيث تتراوح سرعان الاندفاع بين 1000 إلى 1450 rpm، معدل التغذية من 0.1 إلى 0.15 مم/إنش ، وعمق القطع من 0.2 مم. تم النظر في قياسات البلى في التحليل قبل البارامترات النهائية المصممة للماكينات. في تصميم التجربة ، تكون البارامترات المستخدمة لسرعة الاندفاع في حدود 907 إلى 1543 rpm، ومعدل التغذية من 0.08 إلى 0.22 ملم/إنش، وعمق القطع 0.2 ملم. وتستخدم آلة بريدجبورت ROMI PowerPath CNC لإجراء عملية تحويل التجربة. وقد أجري تحليل لبس الجناح وارتداء الحفرة باستخدام المجهر البصري (NIKON MM-4001L)، في حين لوحظت منطقة القص بواسطة مسح المجهر الإلكتروني ، (JEOL JSM-IT100) SEM. ويقاس خشونة السطح الماكنة من خلال خشونة السطح المحمولة (Mahr MarSurf M3000C). وفي التجبرية الأوّلية، حصلت على أنّ مقدار ارتداء الجناح وارتداء الحفرة والخشونة السطحية يقلل حينما زادت سرعة الدوران من 1000 إلى 1450 rpm وزاد معدل التغذية من 0.10 إلى 0.15 rev/mm. والنتائج استقرت من التجربة الحقيقية يتم تحليلها باستخدام برمجيات خبير التصميم 11. ووجد أن سرعة الدوران هي عامل هام يؤثر على ارتداء الجناح وخشونة سطح السطح الماكيني ، في حين أن ارتداء الحفرة يتأثر أكثر بمعدل تغذية بارامترات الماكينات. وبارامترات القطع المثلى هي عندما تكون سرعة الاندفاع 1421.38 rpm ، ومعدل التغذية 0.10 ملم/rev. وهو يعرض بأن أداة القطع لها إمكانات جيدة في استخدام الآلات العالية السرعة. وتبين المقارنة بين أداة القطع التي تم إنتاجها في هذا البحث وأداة القطع التجارية أن أداء أداة القطع السيراميكية $ZTA-TiO_2-Cr_2O_3$ أقل من أداة قطع السيراميك التجارية في ساندفيك. وعلى الرغم من أن أداة القطع التجارية لها خصائص متفوّقة، إلّا أنّ أداة مصنعة لقطع السراميك تظهر بعض الجوانب الواعدة مثل القدرة على القطع بسرعة أعلى.

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APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope, and quality, as a thesis for the degree of Master of Science (Manufacturing Engineering).

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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This thesis is dedicated to my beloved husband, parents, and family.

Thank you for the love, support, and encouragement.

ACKNOWLEDGMENTS

"In the name of Allah, The Most Gracious and The Most Merciful"

Alhamdulillah, all praises be to Allah, for the strength and His blessing, this research finally can be completed. First and foremost, special appreciation goes to my supervisor, Dr. Afifah binti Mohd. Ali for her supervision and support. Her patience, motivation, and immense knowledge helped me a lot throughout the master's journey. Besides that, I would like to express my gratitude to my beloved husband, Mohammad Ihsan bin Ibrahim, my father, Mudzaffar bin Mohd. Thalji, and my mom, Norlida binti Zaini, for their endless support, emotionally and financially.

My sincerest thank also goes to Br. Mohd. Syukor bin Md. Noh, Br. Ibrahim bin Razali @ Maarof, Br. Syed Mohammad Kamaruddin bin Syed Ali, Br, Husni Kamal bin Mohd. Said, and Br. Mohamad Faiz Izzat bin Bahaudin for assisting me throughout my time in the laboratory, doing the research. Lastly, I would like to say my gratitude to everyone who indirectly involves in my master's journey by giving me the trust to do the research and the time spent sharing the knowledge.

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LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
EDX	Energy Dispersive X-Ray
FESEM	Field Emission Scanning Electron Microscope
GPa	Giga Pascal
HV	Vickers Hardness
ICDD	International Centre for Diffraction Data
ISO	International Standards Organization
MPa	Mega Pascal
Ra	Average Roughness
SEM	Scanning Electron Microscope
XRD	X-Ray Diffractometer

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH BACKGROUND

In the machining of hard materials, ceramic cutting tools are common and widely used. This is due to their outstanding properties such as wear resistance, shock resistance, and high hot hardness as stated in Yin et al. (2015), Wang et al. (2016), Wang et al. (2017), Nandhakumar & Prakash (2017), Islam et al. (2017), Bakar et al. (2018), and Mohamad & Ratnam (2019).

Alumina, Al_2O_3 possesses good properties which are ideal for the cutting tool. According to Lee et al. (2016), alumina-based ceramic cutting tools have been a desirable choice for improving the quality of products, minimize the costs of manufacturing and production time. They are also known for operating the cutting process at a high speed and high temperature (Manshor et al., 2016). Despite their good properties, Tan et al. (2018) mentioned some problems are detected while machining with ceramic tools, such as chipping and fracture due to low toughness. Alumina-based cutting tools are also vulnerable to thermal cracking as stated in Varma et al. (2016). Due to that, researchers are performing studies to improve the properties of the tools by adding secondary material. One of the additives that show good potential is zirconia, ZrO_2 which is added to Al_2O_3 to form zirconia toughened alumina, ZTA (Manshor et al., 2016).

ZTA can be a great material for the cutting tool and can be expanded more for further improvement. Varma et al. (2016) mentioned that ZTA is known to be low in cost and ease the fabricating process. Due to their advantageous mechanical properties, Manshor et al. (2016) stated that it is commonly recognized as a tool material with high hardness, high-temperature strength, and able to sustain the shape of cutting edge at higher temperatures. However, in order to enhance ZTA's properties such as fracture toughness and hardness, the additives are introduced into the ceramic compositions (Ali et al., 2018). Researchers have made many efforts in their studies to develop the mechanical properties of the ZTA cutting tool (Rejab et al., 2016).

One of the additives used in this research is Titania, TiO_2. Manshor et al. (2015) mentioned that the sintering temperature of alumina can be reduced with the addition of TiO_2. Despite that, it also improved the mechanical properties of the sample. For instance, in the study by Dhar et al. (2015), the density value increased as Vickers hardness increased due to the addition of TiO_2 as an additive. However, further addition of TiO_2 resulted in a minor increment of the values mentioned. This data is supported by Manshor et al. (2015), where the value of the density is directly related to the Vickers hardness. Moreover, Manshor et al. (2016) stated that the properties of the sample are excellent for providing resistance to abrasive wear and high-temperature erosion with corresponding to high thermal shock resistance by using TiO_2 as an additive. It is also known for its low thermal conductivity and high toughness. Although the hardness decreases with the further addition of TiO_2 due to the reduction in density, adhesion strength and wears resistance improved.

Furthermore, chromia, Cr_2O_3 is also used as an additive as it has attracted attention due to its great ability to replace coated carbide or carbide itself (Singh et al., 2016). Due to the addition of Cr_2O_3, grain growth can be observed in the optimum state. Moreover, the density, fracture toughness, and Vickers hardness value of the sample also increased. The interaction between the crack and the matrix grains improved by the creation of large plate-like grains. The strength increased due to grain deflection caused by the inter-granular fracture mode where the cracks dispersed along the grain's borders. (Manshor et al., 2016).

Due to that, this research will be focusing on the newly developed cutting tool, ZTA added with TiO_2 and Cr_2O_3. Despite the fact the mentioned cutting tool has been improved, its performance and potential have yet to be fully realized, as the cutting tool's wear has not been thoroughly investigated, particularly in high-speed machining. Thus, this research aimed to further investigate the potential of the ZTA-TiO_2-Cr_2O_3 ceramic cutting tool developed from the previous work by Manshor et al. (2016).

1.2 PROBLEM STATEMENT

The great potential of ZTA as a cutting tool makes the researchers keep developing and making improvements to it. Therefore, some additives have been added for this purpose (Ali et al., 2015; Dhar et al., 2015; Manshor et al., 2016; Al Mahmood et al., 2017). As a prove, Manshor et al. (2016) in their work shows that by the addition of TiO_2 as an additive to the ZTA composition, the wear resistance and adhesion strength improved. Moreover, the study also showed that the effect of the Cr_2O_3 additive is bringing some improvements to the composition, such as the increase of fracture toughness. The addition of TiO_2 and Cr_2O_3 to the ZTA composition increased the hardness and fracture toughness.

In conjunction to determine the performance of the ceramic cutting tool, the machining process must be carried out. The tool wears, such as flank wear, crater wear, and chipping can be analyzed throughout the process (Ali et al., 2015; Lima et al., 2017; Tan et al., 2018). Additionally, the surface roughness of the machined surface (Das et al., 2015; Mir & Wani, 2018) and machining parameters (Singh et al., 2016; Ali et al., 2018) also has been the factors that affect the performance of the tool.

Although the good properties of ZTA-TiO_2-Cr_2O_3 have been achieved, the performance of the ZTA-TiO_2-Cr_2O_3 cutting tool is unknown and needs further study. A detailed study on the wear of this cutting tool is needed to prove the performance of the tool. As the solutions, tool wear of the ZTA-TiO_2-Cr_2O_3 cutting tool and the surface roughness on the workpiece surface will be studied in this research.

1.3 RESEARCH OBJECTIVES

The objectives of this research are:

1. To analyze the flank wear, crater wear, and chipping of ZTA-TiO_2-Cr_2O_3 ceramic cutting tool and surface roughness of the machined surface, stainless steel 316L at different parameters.
2. To develop an empirical model for predicting the tool wear of the ZTA-TiO_2-Cr_2O_3 ceramic cutting tool.
3. To compare the wears of the ZTA-TiO_2-Cr_2O_3 ceramic cutting tool to the Sandvik commercial ceramic cutting tool.

1.4 SCOPE OF THE STUDY

This project analyzes the new ceramic cutting tool, ZTA-TiO_2-Cr_2O_3 by turning stainless steel 316L. There are three types of wear that were analyzed from the tool, such as flank wear, crater wear, and chipping. The surface roughness of the machined surface, stainless steel 316L was determined by the value of roughness average, Ra.

The empirical model of the ZTA-TiO_2-Cr_2O_3 ceramic cutting tool was developed for predicting the tool wear of the tool by using the RSM model in Design Expert 11 software. The optimum cutting parameter can be chosen by getting the minimum value of the tool wear and the surface roughness of the machined surface, stainless steel 316L. This model was developed for the parameter of spindle speed range from 908 rpm to 1543 rpm, feed rate 0.08 mm/rev to 0.22 mm/rev, and depth of cut 0.2 mm.

The tool wears of the ZTA-TiO_2-Cr_2O_3 ceramic cutting tool and Sandvik commercial ceramic cutting tool were compared as a benchmark to improve the performance of the new cutting tool.

1.5 SIGNIFICANCE OF THE STUDY

Good potential on the ZTA-TiO_2-Cr_2O_3 ceramic cutting tool can be seen for commercialization due to the improved properties. The performance of the cutting tool has been investigated and compared with Sandvik commercial ceramic cutting tool. The optimum parameters were obtained based on the minimum tool wears and the surface roughness of the machined surface, stainless steel 316L. Therefore, this study could contribute to other researcher's studies by developing the ceramic cutting tool in the steel cutting industry.