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The Relationship of Cutting Chip Type, Length and Thickness to Wear of Zirconia Toughened Alumina Added with Magnesium Oxide (ZTA-MgO) Cutting Tool

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ABSTRACT. The effect of cutting chips on the performances of ZTA-MgO ceramic cutting tool investigated. The aim of this project is to discover the effect of cutting chip type, length and thickness on the wear of the ZTA-MgO cutting tool. CNC turning machining performed by using Rom-Bridgeport CNC turning machine at cutting speed range from 2250 to 3000 rpm, the feed rate 0.1, 0.3 and 0.5 mm/rev while the depth of cut is kept constant at 0.2 mm. The flank wear and crater wear were measured accordingly using optical microscope, Matlab programming and SEM. The chip type, length and thickness were classified and measured. The variation of cutting parameters influenced the chip geometry and it relation to tool wear were analysed. The chips were collected. The chip type, length and thickness analysed using optical microscope and SEM. Result shows chip started with tubular and ribbon form of chip. Increment of feed rate, make the chip break to smaller part. The chip length increase when cutting speed was increased. The chip is 2.49 cm length at cutting speed 2250 rpm increased up to 4.61 cm at 3000 rpm. The chip thickness was increased with increasing of feed rate where the average thickness is at lowest when the feedrate is at 0.1mm/rev and highest at 0.5 mm/rev all cutting speed. The increment of chip length caused the crater wear increased on cutting tool from 5.66 mm^2 at chip length of 2.49 cm and increased to 7.40 mm^2 when the length increased to 4.61 cm. The high chip thickness caused higher flank wear on the cutting tool. Based on the analysis, the chip type, length and thickness have influence on flank and crater wear of the ZTA-MgO cutting tool which may lead to failure of the cutting tool.

Keywords: *Chip formation, Chip morphology, Wear, ZTA, Turning;*

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1. INTRODUCTION

ZTA-MgO cutting tool can be described as additive yttria stabilized zirconia (YSZ) and magnesium oxide (MgO) introduced into alumina (Al_2O_3). The purpose of the additive addition is to toughen the brittle properties of the ceramic [1]. Addition of MgO into the ZTA composition improve the microstructure, hardness and fracture toughness of the cutting tool [2,3]. ZTA is an excellent cutting tool for machining due to their high melting temperature, excellent erosive wear, resistance toward corrosion and toughness. There are many studies relation to wear by using ZTA cutting tool, but no study involved on chip morphology by using various parameter. Generation of various types and forms of chip influences the contact zone between the tool and chip, i.e. the friction at tool-chip interface. Such changes generate various forms of tool vibrations, influence work surface quality, and intensify tool wear [7].

In high speed machining of steel by using the ceramic cutting tool, Dutta et al. [4] stated that continuous chips produced during the machining caused slow progressing of crater wear on the tools and continuous machining affect the flank wear progress greatly causing tool failure due to the tool-chip contact. Gatto and Iuliano [5] in their research observed the chips upon machining to analyse the wear mechanisms along the tool-chip contact length. They found that the chip segments size increase by increment of feedrate. Research results by Salem and Bayraktar [6] also agreed that feedrate significantly influence the chip morphology. While machining the hardened steel (62 HRC) at constant cutting speed, they found that continuous chip at low feedrate and the chip start to scallop approaching the saw-tooth chip shape when the feedrate is further increased. Other than that, chip formation also leave impact on the tool rake face surface which change the geometry of the tool [7]. Progressive crater wear will weaken the tool edge causing nose wear. Consequently, surface roughness of the workpiece will be affected. The effects of chips length and form leads to the study on the simulation of cutting chips and their effects on the wear as presented by Childs et al. [8]. Their research shows that length of the cutting chip significantly affect the contact time on the cutting zone. Long continuous chip causing wider and deeper crater wear. As the crater wear became wider and deeper, the tool nose became vulnerable and tool breakage might take place.

In this research, the relationship of cutting chip to wear of ZTA-MgO cutting tool will be investigated. The type, length and thickness of the cutting chips were analysed thoroughly in order to investigate their influence to the performance of the ZTA-MgO ceramic cutting tool.

2. MATERIALS AND METHODS

Alumina (Al_2O_3) and yttria stabilised zirconia (YSZ) were wet mixed with distilled water at the ratio of 80:20 with addition 1.1wt.% of 20 nm particle size magnesium oxide (MgO). The composition were dried before powdered and compacted into rhombus shape cutting insert. The X-Ray Diffraction analysis (XRD) performed on the ZTA-MgO cutting tool. Machining is then conducted by using ROMI Bridgeport CNC turning. Cutting speed are varied in range of 2250-3000 rpm, feedrate 0.1-0.5 mm/rev and constant depth of cut of 0.2 mm as shown in Table 1. Workpiece stainless steel 316L with diameter 50mm used for the machining process. The cutting chip produced during machining were collected and analysed. Optical microscope (Olympus BX41M) was used to observed the chip type while chip length measured by using thread and ruler. Chip thickness were analysed by using the SEM. The photo of wear on the cutting tool were captured using the optical microscope and the wear area was measured using the Matlab software.

Table 1 Cutting parameters of ZTA-Mgo cutting tool

Parameter	Condition / Value
Cutting Speed	2250, 2500, 2750, 3000 rpm
Feed rate	0.1, 0.3, 0.5mm/rev
Depth of cut	0.2mm
Cutting length	20mm
Cutting Condition	Dry

3. RESULTS AND DISCUSSION

3.1 Materials Characterization. Characterization on ZTA-MgO after sintering performed and presented in Fig. 1. In this XRD graph, it can be seen that presence of both tetragonal and monoclinic phase of ZrO_2 can be detected where tetragonal phase matches the (ICDD 81-1544) and monoclinic (ICDD 65-1023). The corundum presented as (ICDD 10-1073). Apart from that, presence of MgO identified in $MgAl_2O_4$ phase (ICDD 73-1959).

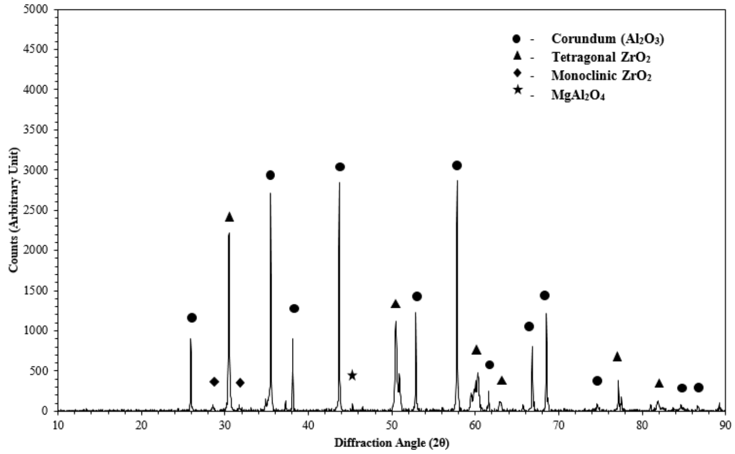
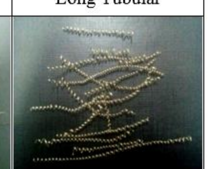


Fig. 1 XRD graph of ZTA-MgO cutting tool

3.2 Type, Length and Thickness of Cutting Chip. Observation on the chip form, length and thickness at different machining parameters for ZTA-MgO ceramic cutting inserts presented. The chip forms are compared to the standard chip form (ISO 3685:1993). The result presented in Table 2. From this table, it can be observed that at 0.1 mm/rev, the chip start with short tubular and turns to long tubular with increasing of cutting speed. Changing of feed rate to 0.3 mm/rev, make the chip turns snarled ribbon with increasing of cutting speed. At 0.5 mm/rev, the chip form a short tubular due to high feed rate and cutting speed which is 3000 rpm. The short tubular chip also can be related to the chipping at the cutting tool at high feedrate that act as chip breaker causing long tubular chip to be cut into short tubular chip.

Table 2 Chip type with changes of parameters

Cutting Speed (rpm) / Feed Rate (mm/rev)	2250	2500	2750	3000
0.1	 Short Tubular	 Long Tubular	 Long Tubular	 Long Tubular
0.3	 Snarled Ribbon	 Snarled Ribbon	 Snarled Ribbon	 Short Tubular
0.5	 Snarled Ribbon	 Snarled Ribbon	 Snarled Ribbon	 Short Tubular

The chip length in the other hand change due to the changes of cutting speed. It is found that the chip length increased with increment of the cutting speed as preented in Fig. 2. There is no significant change of chip length when the feedrate is increased.

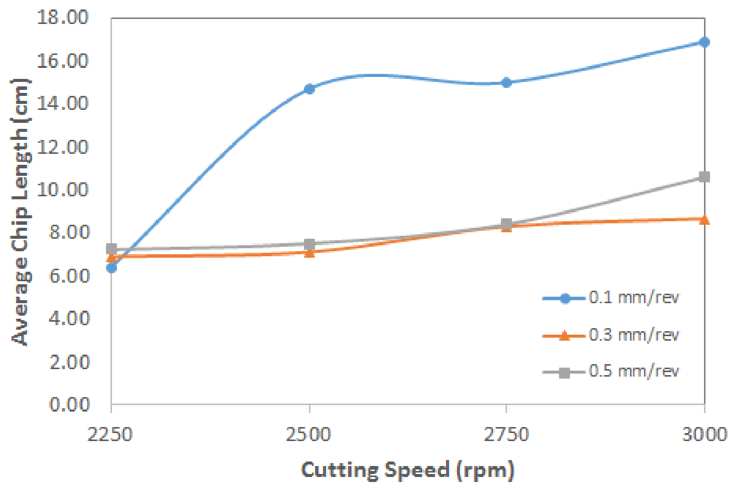


Fig. 2 Effect of cutting speed to chip length

Feedrate affect the thickness of the chip where the chip thickness increase with increment of feedrate from 0.1 to 0.5 mm/rev for all cutting speed. It can be seen also higher thickness of chip when the cutting speed is increased. This result is parallel to the explaination of George et al. [9] where the feedrate is the determining factor to chip thickness.

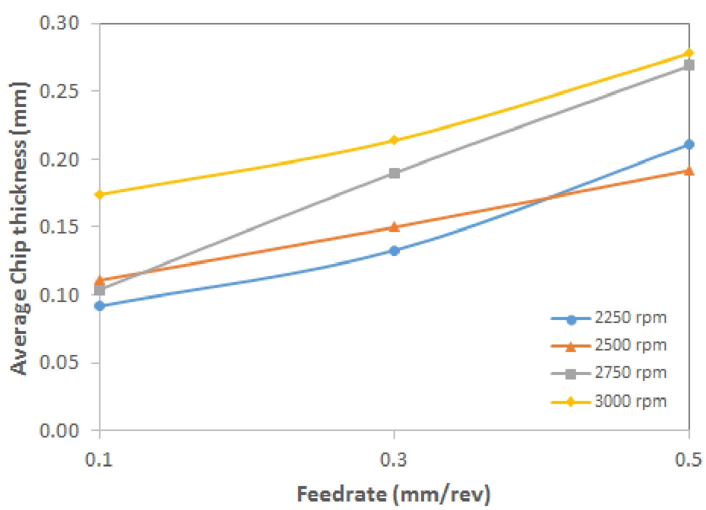


Fig. 3 Effect of feedrate to chip thickness

3.3 Effect of Chip Type, Length and Thickness to Wear. Chip type also have contribution to the performance of the cutting tool. In this reseach, it is found that long tubular chip have a great impact on the crater wear as crater wear area is bigger when long tubular chip present compared to other type of chip. The crater wear area also increased when the length of the long tubular chip increased as presented in Fig. 4. This condition is related to the tool-chip interface where long tubular chip has grater contact area to the tool rake face compared to the ribbon type (straight type) chip. The curle of the tubular chip also able to plough the rake face causing bigger area to abrade compared to other type of chip.

The effects of chip length can be seen on the crater wear. Based on the analysis as presented in Fig. 5. As the chip become longer, the crater wear area also become bigger. Long cutting chips will interact with the tool surface longer and abrade the cutting tool surface while shorter chip indicates shorter time contact between chip and rake angle because the chip leave the cutting tip faster thus reduce the crater wear. In order to reduce the crater wear at high cutting speed, it is suggested for chip breaker to be used during the machining process. The crater wear is not affected at high feedrate as the chip break to shorter length when the feedrate is increased [9].

The effect of chip thickness observed to be affecting the flank wear compared to the crater wear. As the chip thickness increased due to increment of feedrate and cutting speed, the flank wear also start to increased. Fig. 6 illustrate the effect of the chip thickness to the flank wear.

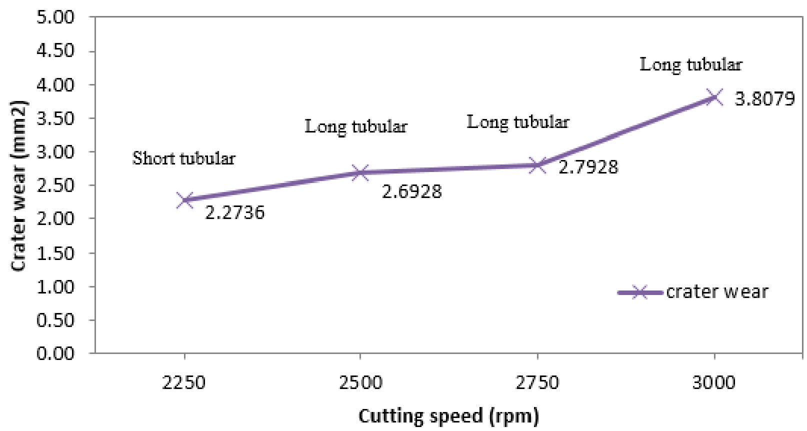


Fig. 4 Effect of chip type to wear

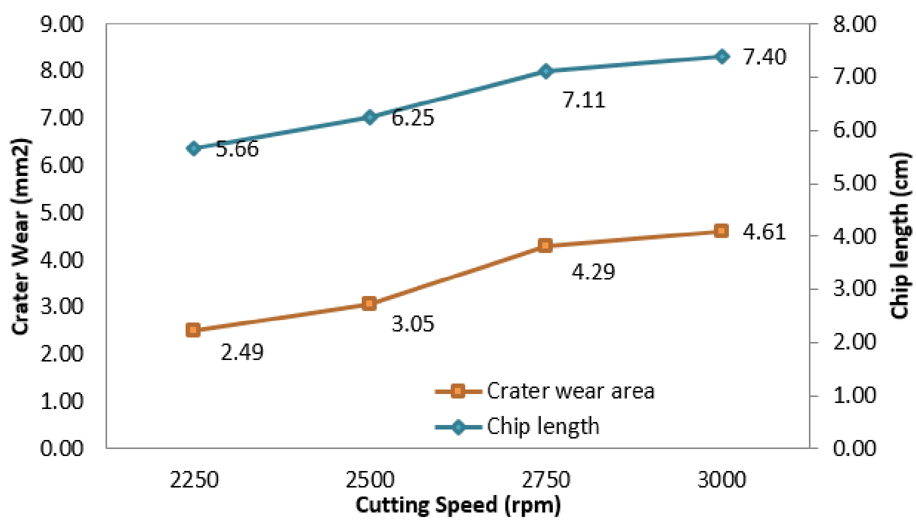


Fig. 5 The effect of chip length to the crater wear

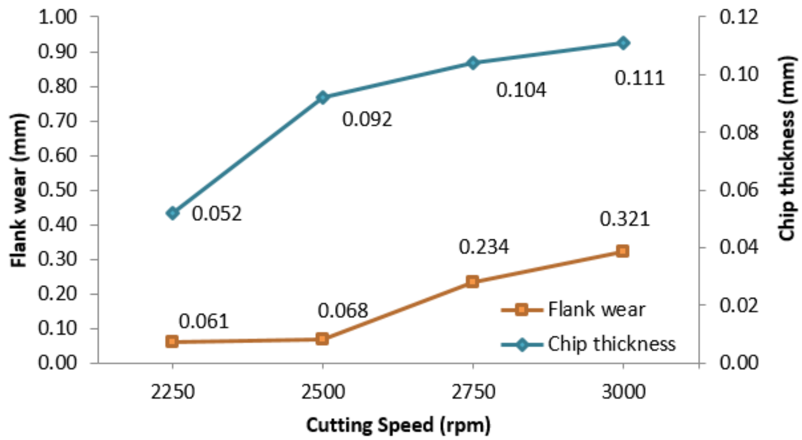


Fig. 6 The effect of chip thickness to the flank wear

4. SUMMARY

The conclusion that can be made from the results are cutting speed increase the length of the cutting chip while feedrate increment increase the thickness of chip. As the length of the chip increase, the crater wear increased. Frank wear increase with increment of chip thickness. Chip type also influence the wear as long tubular cutting chip CAUSED INCREMENT OF CRATER WEAR.

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