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The effect of cutting parameters on the performance of ZTA-MgO cutting tool

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Abstract. The effect of cutting parameters on the performances of ZTA-MgO ceramic cutting tool investigated. The aim of this project is to discover the effect of cutting speed and feedrate on the performance of the ZTA-MgO cutting tool via wear and surface roughness measurement. CNC turning machining performed using the cutting speed, *Vc* range from 354 to 471 m/min and the feed rate, *f* 0.1, 0.3 and 0.5 mm/rev while the depth of cut, *d* is kept constant at 0.2 mm. The flank wear, crater wear, and chipping were measured accordingly using optical microscope, Matlab programming and SEM. Surface roughness of machined stainless steel 316L surface were measured using the surface roughness tester (Mitutoyo MTR097-8. The result showing the increment trend of flank wear with increment of cutting speed and feed rate with the lowest value of flank wear, 0.061 mm achieved at *Vc* = 354 m/min and *f* = 0.1 mm/rev while the highest flank wear is 0.480 mm at *Vc* = 471 m/min and *f* = 0.5 mm/rev. The increasing pattern also observed in the crater wear results. The lowest area of crater wear is 2.2736 mm^2 at *Vc* = 354 m/min and *f* = 0.1 mm/rev while the highest value is 4.8524 mm^2 at *Vc* = 471 m/min and *f* = 0.5 mm/rev. As for the surface roughness, the higher the cutting speed, the lower the average roughness (*Ra*) value. Cutting speed, *Vc* = 471 m/min with *f* = 0.1 mm/rev has the lowest value of *Ra* which is 0.72µm.

1. Introduction

Zirconia toughened alumina (ZTA) is one of the ceramic cutting tool that has been commercialised and well accepted in the industry. Due to their great potential as cutting tool, the scholars have prioritized improvement on the properties of ZTA based ceramic cutting tool especially on the hardness and fracture toughness. One of the methods to improve the properties of ZTA is via introduction of additives into the ceramic compositions. Many additives discovered by the researchers that may improve the properties of the cutting tool. The example of the additives are chromium oxide, (Cr_2O_3)[1][2], ceria (CeO_2)[3]–[5], titanium carbide (TiC)[6]–[8] and many more. One of the additives is nano particle magnesium oxide (MgO) shows a promising result in improvement of properties. Studies by [9] [10] showing great improvement of the ZTA-MgO properties where the hardness hav been increased to 1740 HV and fracture toughness, 4.32 MPa√m compared to without the additives at 1650 HV and 3.40 MPa√m.

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Although the improvement have been made on the ZTA cutting tool, the potential of the cutting tool has not been fully discovered, as the wear of the cutting tool has not been thoroughly studied especially in high speed machining. Previous study [11], [12] showing a good result of wear on ZTA-MgO cutting tools in machining process especially when the cutting speed is increased to high value. Due to that, the investigation on the tool wear of the ZTA-MgO cutting tool with enhancement of parameters selection at higher value will be conducted. Flank wear, crater wear, chipping condition of the ZTA-MgO cutting tool and surface roughness of the machined surface will be presented in this research paper.

2. Experimental procedures

In order to achieve the objectives, the experiments were conducted by using the fabricated ZTA-MgO cutting tool with hardness 1568.69 HV and fracture toughness 8.60 MPa.√m as shown in figure 1. Turning process conducted by using CNC lathe machine (ROM-Bridgeport) with ZTA- MgO cutting tool mounted on Sandvik Coromant (Coro turn CCLNR 164D-4) tool holder. The machining performed on stainless steel 316L at parameter presented in table 1. The wears on the cutting tool were measured accordingly. Flank wear is measured by using the optical microscope (Nikon measuring microscope MM400/L) while the crater wear is measured by capturing the image of the wear on the optical camera (OLYMPUS BX41M) before measured by using the Matlab programming. Chipping analysis performed on the scanning electron microscope (SEM). Surface roughness of machined surface measured by using the surface roughness tester (Mitutoyo - MTR097-8). Five readings were taken and the average value was calculated and analysed.

Figure 1. Fabricated ZTA-MgO ceramic cutting tools.

Table 1. Parameter and cutting condition used in the experiment.

Parameter	Condition / Value
Cutting Speed, V_c	354, 393, 432, 471 m/min
Feed rate, f	0.1, 0.3, 0.5 mm/rev
Depth of cut, d	0.2 mm
Cutting length, l	20 mm
Cutting Condition	Dry

3. Results and Discussion

3.1. Flank Wear

Flank wear is the most common wear that discovered on the cutting tool during the turning process. The flank wear occurs on the relief face of the cutting tool and it occurs as a result of friction on the tool flank between the workpiece and machined surface. From this experiment, the data on the flank wear were gathered and tabulated into graph in figure 2. From this graph, an increasing trend of flank wear with increment of cutting speed, (*Vc)* and feedrate, (*f*) can be observed. This result is expected as the higher the cutting speed and feedrate, thus higher friction between the flank surface and the workpiece. Among all of the causes, abrasion is the main cause to the flank wear due to rubbing at lower temperature on the flank surfaces. However, due to some conditions, the mechanism that cause crater wear which is increased of the V_C and cutting temperature also contribute to the flank wear development [13].

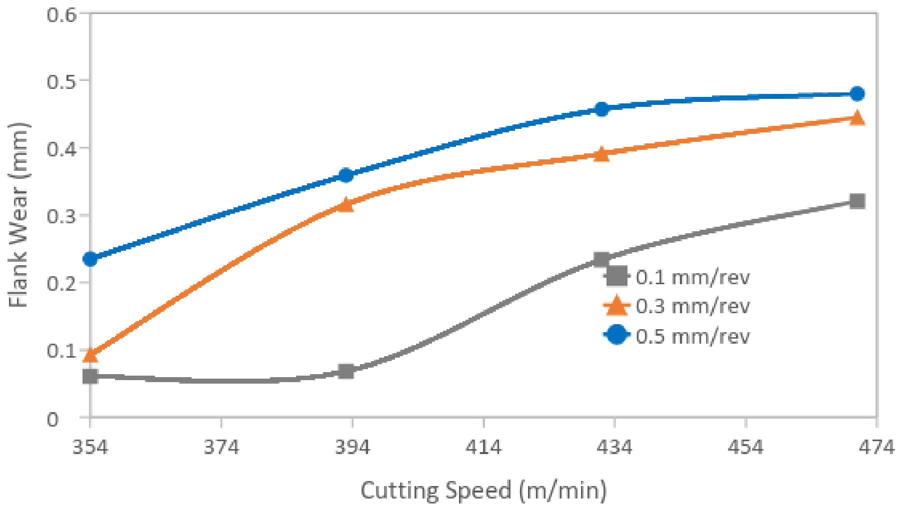

Figure 2. Flank wear at different cutting speed and federate.

The lowest flank wear measured at *Vc*= 354 m/min and feedrate 0.1 mm/rev at 0.06 mm value while the highest flank wear is at *Vc* = 471 m/min and feedrate 0.5 mm/rev at 0.48 mm. This value is close to the allowable V_B value, which is 0.5-0.6 mm. If the amount of flank wear is more than its critical value ($V_B > 0.5 \sim 0.6$ mm), then it will cause tool failure due to the excessive cutting force [13]. It can also be seen that the flank wear start at higher value when machining perform at *f* =0.5 mm/rev and *Vc* = 354 m/min with the value 0.36 mm compared to *f* = 0.1 and 0.3 mm/rev which are at 0.06 and 0.09 mm respectively. Therefore, it is recommended for machining to be performed at low feedrate for ZTA-MgO cutting tool.

3.2. Crater wear

Crater wear occurs on the rake face of the cutting tool and it consists of a concave section on the tool face caused by the action of the chip pass through the machined surface [14]. Result of crater wear were tabulated into graph presented in figure 3. Similar to the flank wear trend, the crater wear also showing an increment of wear area when the cutting speed and feedrate is being increased.

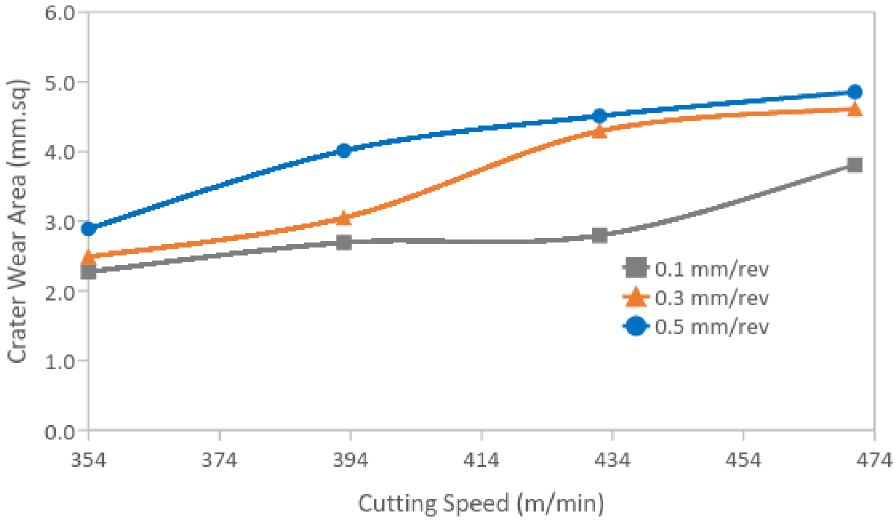

Figure 3. Crater wear at different cutting speed and federate.

The lowest reading of crater wear is at parameter Vc = 354 m/min and f= 0.1 mm/rev while the highest at Vc = 471 m/min and f= 0.5 mm/rev with the value 2.2736 and 4.8524 mm^2 respectively. Kumar et al. [15] stated that common cause of crater wear is due to the action of chip flow over the face at high temperature and short distance. Other than that, the factors that are influenced the flank wear may influence the crater wear too.

3.3. Chipping

Chipping always associated to brittle cutting tool and ceramic cutting tool can severely affected by chipping during the machining process. The analysis of chipping on ZTA-MgO ceramic cutting tool presented in figure 4 shows that there is no significant changes of chipping area when the *Vc* is being increased from 354 to 471 m/min. However, the chipping area found to be increased when the feedrate is increased from 0.1 to 0.5 mm/rev. This condition can be visualize from figure 4 where the increment of chipping can be seen as the feedrate is increased from 0.1 mm/rev as shown in figure 4(a) to 0.3 mm/rev in figure 4(b).

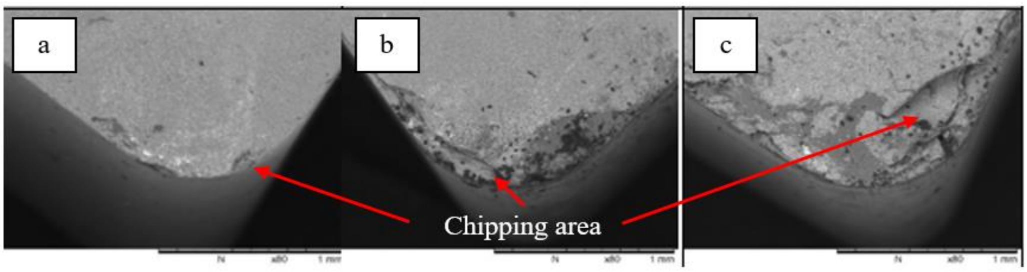

Figure 4. SEM micrograph of the chipping area at different feedrate a) 0.1 mm/rev, b) 0.3 mm/rev and c) 0.5 mm/rev at Vc = 471 m/min.

Further increment of the feedrate to 0.5 mm/rev increase the chipping area to the largest area as shown in figure 4(c). According to Deng et al. [16], chipping occur as a result of an overload of mechanical shock due to interruption during machining process such as very high depth of cut or feed rate and excessive wear on the insert. Chipping started with the crack initiation on defect surface and due to excessive load to the cutting tips and higher feed rate, the crack network spread wider until the chipping occurred. It also may cause by the high temperature that oxidize the wear, and the alternate and impact stress [17].

3.4. Surface roughness
Surface roughness is one of the methods to evaluate the quality and performance of machining. The result of surface roughness versus the cutting speed at three level of feedrate presented in figure 5.

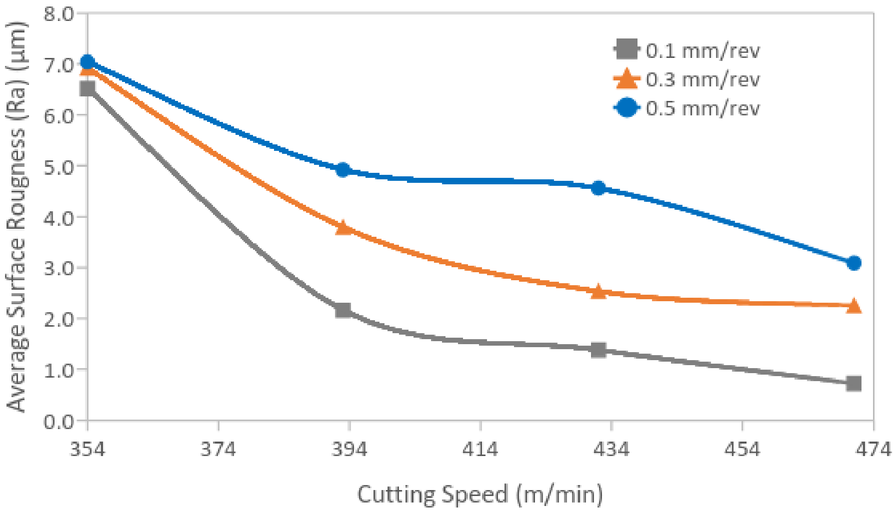

Figure 5. Surface roughness of Stainless Steel 316L at different parameters.

Although the wears are showing the increment pattern when the cutting speed is being increased, surface roughness (Ra) showing the inverse pattern where the Ra value decreased when the cutting speed is increased. The increment pattern of Ra occur when the feedrate is increased. The lowest Ra value is 0.72 µm at Vc=471 m/min and f =0.1 mm/rev while the highest value of Ra is 7.04 µm at Vc=354 m/min and f = 0.5 mm/rev. During high speed machining, high friction between the cutting tool and the workpiece is higher causing the temperature on the cutting tip of the cutting tool and the workpiece to be higher. At this moment, the surface of workpiece will become softer and making the chip formation process to be smoother. This result in better surface roughness but in the same time causing higher wear as the cutting tip also affected with the temperature increment. As the temperature rises, the abrasion and oxidation on the tool surface also raised causing higher flank and crater wear. The poor surface roughness at high feedrate related to the chipping on the cutting insert as excessive chipping give poor surface finish which streaked the machine surface cause by the fractured tool [16][18].

4. Conclusion
From this research, as conclusion both cutting speed and feedrate give influence to the wear of ZTA-MgO cutting tool where increment of both parameter increased the flank and crater wear on ZTA-MgO cutting tool. Chipping mainly caused by the excessive load on the cutting edge when the feedrate is increased. Higher feedrate will give higher chipping area. Surface roughness decreased with increment of cutting speed but increased with increment of feedrate. The best parameter combination when machining by using the ZTA-MgO cutting tool is at high cutting speed (471 m/min) and low feedrate (0.1 mm/rev).

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