COMPARISON OF WEAR PERFORMANCE BETWEEN ALUMINA AND ALUMINA-ZIRCONIA CUTTING TOOLS AT HIGHER CUTTING SPEED

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ABSTRACT: This study presented the comparison of alumina and alumina-zirconia cutting tools in machining with high feed rate application in terms of tool life and wear mechanism. Both cutting tools were prepared by the powder metallurgy processes including ball mill, cold isostatic press and sintering at the elevated temperature. These cutting tools were fabricated in the form of RNGN 120600 insert and machined with AISI 1045. The cutting parameters employed were 200-350 m/min cutting speeds with constant 0.175 mm/rev feed rate and 0.5 mm depth of cut. The results show that the alumina-zirconia cutting tool capable to machine AISI 1045 up to 164 seconds cutting time, which is almost five folds improvement as compared to alumina cutting tool which is at 36 seconds tool life. For alumina cutting tool, the wear mechanism demonstrated severe wear development at the concentrated area in the flank zone. This is due to the brittleness of material that makes it unable to resist load from the high feed rate impact. Whereas, alumina-zirconia cutting tool consistently demonstrated uniform wear development at the flank zone. The addition of zirconia enables the structure to be integrated strongly to resist high cutting load from the engagement of the cutting tool at the higher cutting speed.

KEYWORDS: *Ceramic Cutting Tool; Turning; Alumina; Zirconia; Tool Wear*

1.0 INTRODUCTION

Ceramic cutting tool generally prepared from the mixed ceramic powders that being pressed and sintered at elevated temperature. This cutting tool possess very high hardness and are suitable for high speed machining because of their ability to maintain their structures at high temperature without any coolant needed [1-2]. In fact, ceramic cutting tools can operate at temperatures up to 1000°C where at that temperature, some carbides and HSS tools are unable to maintain the grain structure and cause deformation in tool geometry [3-4]. The use of high cutting speed enable better productivity with low cutting force, chip load and surface finish. Some examples of ceramic cutting tools are silicon nitride, Sialon, cubic boron nitride and aluminium oxide or alumina [4].

One of the promising ceramic material that being engineered into cutting tool is alumina. Alumina can be applied as refractory and abrasive composite if the compaction, usage of binder and sintering processes were controlled effectively [5-6]. In fact, alumina is chemically stable which would be added advantage in high temperature and oxidative application [7]. Previous studies of application of alumina cutting tool in machining various steels showing that the wear performance of alumina based cutting tool not only depended on the mechanical properties such as hardness, fracture toughness and microstructure but also surface and cutting edge condition. In addition, the ability of alumina cutting tools in terms of tool life and mechanical properties also can be enhanced by adding reinforced material such as SiC, TiC, Zr or coated with high performance adhesive layer such as TiN, TiCN and TiBr2 [8-10].

During machining, the stability of cutting tool edge strongly dependent on the cutting parameters [11-12]. Generally, cutting speed, feed rate and depth of cut is dominant primary parameters that feasible for most of machining facilities. Selection of cutting parameters depended on the properties, especially hardness and hardening characteristics of the workpiece material [13]. In the case high material removal rate, the use of high cutting speed and feed rate is necessary in order to shear the materials quickly in traverse direction. Therefore, the cutting tools need to be able to resist load from the material engagement. In addition, the nose radius of cutting tool should also need to be bigger to avoid stress concentration at the cutting edge [14]. In this study, two type of ceramic cutting tools, namely alumina and alumina-zirconia have been fabricated. Both cutting tools were processed in similar condition and sintered at the constant temperature. These cutting tool were pressed in the form of 12 mm round shape to make it ready in high feed rate application. These cutting tools then were machined with AISI 1045 to compare their wear performance at the higher feed rate.

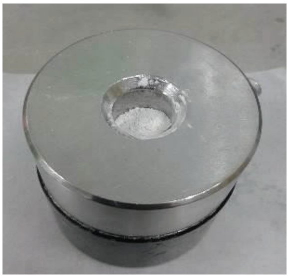
2.0 METHODOLOGY

2.1 Fabrication of Cutting Tool

Figure 1 shows the sequence of process flow used to fabricate the cutting tool. To fabricate alumina cutting tool, 2.5 g of alumina was weighted and ball milled for 12 hours. This powder then was compacted using hydraulic press and further compacted using Cold Isostatic Press at the 350 MPa pressure in the form of RNGN 120600. The compacted powder then was sintered at 1400^{o}C with 9 hours soaking time. For alumina-zirconia cutting tool, similar processing stages to alumina were held. However, the composition ratio was set at 80 wt% alumina and 20wt% zirconia. Table 1 shows the processing parameter used for preparation of alumina-zirconia cutting tool. The methodology is reported elsewhere in [5].

Table 1: Processing parameters to fabricate Al_2O_3-ZrO_2 cutting tool

Composition	80-90 wt% Al_2O_3 and 10-20 wt%
Ball Mill	12 hours
Sintering Temperature	1400^{o}C with 9 hours soaking time
CIP Pressure	300 MPa



(a) (b)

(c) (d)

(e) (f)

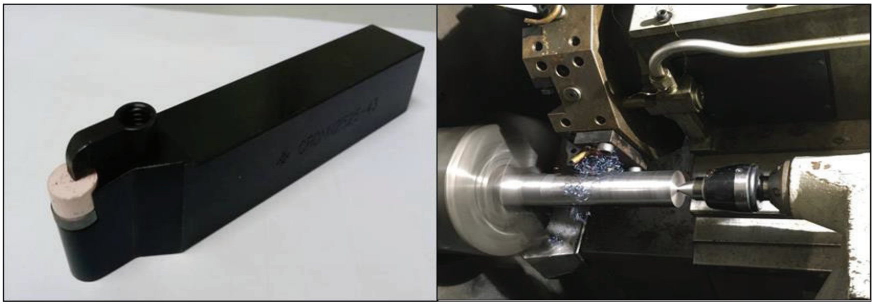
Figure 1: Procedure to fabricate alumina-zirconia cutting tool started with (a) blending alumina and zirconia powders, (b) inserting the powders into the mould, (c) pressing the mould by hydraulic, (d) pressing the mould by using cold isostatic press, (e) sintering the compacted powders to obtain ceramic cutting tool and (f) solid sintered of ceramic cutting tool

2.2 Machining Performance

As both cutting tools sintered, these cutting tool were machined with AISI 1045. Figure 2(a) shows the cutting tool and tool holder used in this study. Machining test were held by CNC Turning with the cutting parameters according to the Table 2. Tool wear for each trial were measured by using optical microscope until it reached 0.3 mm, according to guidance ISO 3685. For each measurement, the images of worn cutting tool were captured using optical microscope to observe the wear mechanism.

Table 2: Cutting parameter for machining test

Cutting Speed (m/min)	200, 250, 300, 350
Feed Rate (mm/rev)	0.175
Depth of Cut (mm)	0.5



(a) (b)

Figure 2: (a) Cutting tool with the design of RNGN120600 clamped in CRDN252543 tool holder and (b) machining setup with AISI 1045 workpiece

3.0 RESULTS AND DISCUSSION

The formation of flank wear on alumina cutting tool at feed rate 0.175 mm/rev can be seen in Figure 3. The alumina cutting tool has a short time at cutting speed of 200 m/min which about 7 seconds as the cutting tool break tremendously when engaged with the workpiece. At cutting speed of 250 m/min, 36 seconds has been taken by alumina cutting tool to form minimum flank wear. Time recorded by alumina cutting tool at cutting speed of 300 and 350 m/min is about 16 seconds and 25 seconds, respectively. Since alumina presented fragile when engaged with the workpiece, the pattern of tool wear appeared with inconsistence condition. The higher cutting speed somehow presenting higher tool life while lower cutting speed presenting lower tool life, not as expected according to the theory.

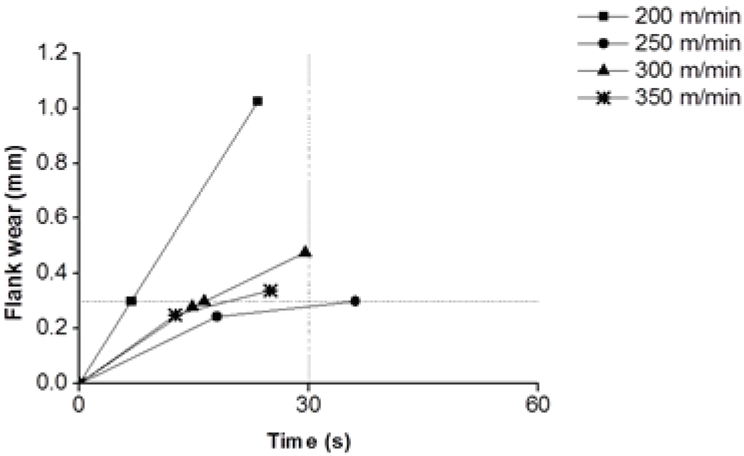


Figure 3: Effect of cutting speed when machining alumina cutting tool with AISI 1045 at the feed rate of 0.175 mm/rev

Figure 4 shows the pattern of flank wear for the alumina-zirconia cutting tool. The time that has been recorded at 200 m/min cutting speed is about 164 seconds. At cutting speed of 250 and 300 m/min, the time recorded was about 42 and 49 seconds, respectively. But at cutting speed of 350 m/min, machining time is about 62 seconds to form minimum flank wear. The flank wear for 250, 300 and 350 m/min became abruptly increased for the first 15 seconds of machining before it steadily increased as the machining prolonged.

The alumina cutting tool spends less than 60 seconds to form minimum flank wear compared to the alumina-zirconia cutting tool. The flank wear pattern for the alumina cutting tool also increased drastically in a very short time as compared to alumina-zirconia cutting tool. It is noted that increment of feed rate boosts the formation flank wear of the alumina cutting tool. Then, the average time for alumina and alumina-zirconia cutting tools is 21 seconds and 79 seconds, respectively. Once again, the average time taken by the alumina-zirconia cutting tool is longer than the alumina cutting tool.

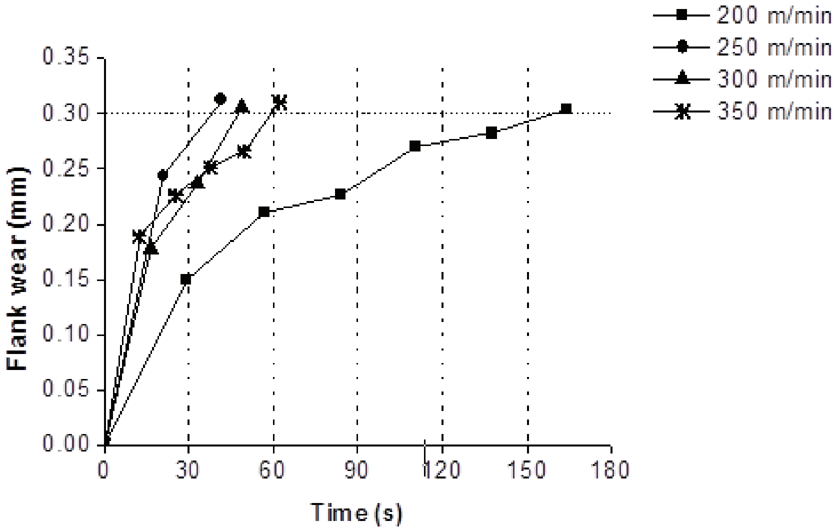


Figure 4: Effect of cutting speed when machining alumina-zirconia cutting tool with AISI 1045 at the feed rate of 0.175 mm/rev

Figure 5 shows the wear development for alumina based cutting tool. At the 13 seconds of machining period, there are significant wear development at the concentrated area of cutting tool where the wear already recorded high value of 0.25 mm. There is a sign of shiny surfaces on the wear area reflected the appearance of molten layer attachment of AISI 1045. This is shows that the temperature is high enough to melt the steel even though the machining just last only 13 seconds.

When the cutting process further prolonged into 25 seconds, the value of wear already reached 0.34 mm, reflected the tool life failure for the cutting tool. At this condition, the edge of cutting tool demonstrated severe molten metal attachment that would result higher cutting force to shear the metal. As a result, the cutting edge unable to resist the high cutting load and high temperature resulting detachment of particles and chipping at the edge of cutting tool. However, the cutting edge still demonstrated solid structural integrity showing that the alumina has good ability to maintain in the good shape even though high cutting speed and feed rate applied.

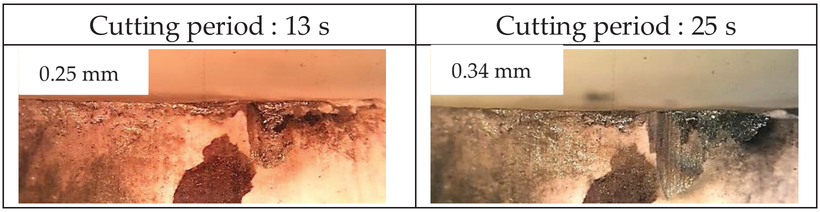


Figure 5: Wear development for alumina based cutting tool at the cutting speed of 350 m/min and 0.175 mm/rev feed rate

On the other hand, the cutting tool fabricated with alumina-zirconia demonstrated different characteristics when machined at high feed rate. As shown in Figure 6, the wear development started with the slight edge chipping at the concentrated area on 13 seconds machining time. When the machining prolonged to 38 seconds, the wear started to develop to the 0.25 mm. Further wear development can be seen when the machining period increased to 50 seconds, there are some sign of minor notch wear development at the concentrated area of flank wear. When the machining time increased to 62 seconds, the tool wear reached 0.31 mm. There a sign of molten metal attached on the flank face reflected the formation of adhesive wear or built up adage dominate the wear region.

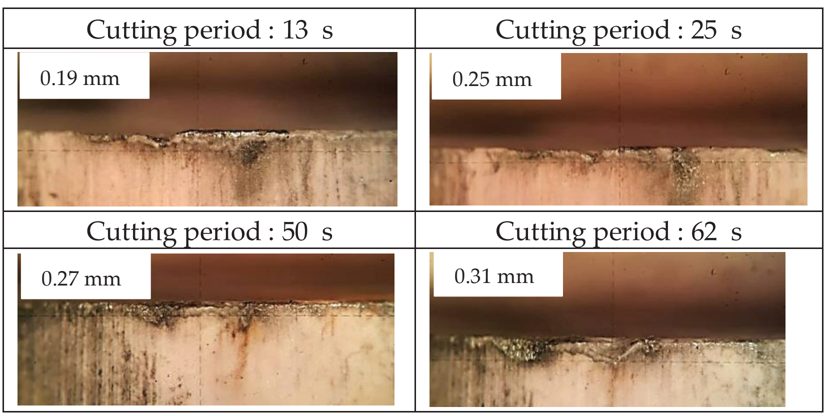


Figure 6: Wear development for alumina-zirconia based cutting tool at the cutting speed of 350 m/min and 0.175 mm/rev feed rate

It should be summarized that the wear resistance of alumina-zirconia consumed almost 5 fold improvement as compared to a cutting tool. This shows that the addition of zirconia into alumina matrix significantly improve the structural integrity. In this study, cutting tool fabricated by the single alumina was formed by the larger particle size of 109.646 μm as compared to zirconia at 9.773 μm. During powder compaction, the large particles could leave empty spaces between grains boundaries as a result of mismatch between particle sizes. This empty space could induce porosity that yield stress concentration whenever the load applied [8, 15]. Since alumina possesses brittle characteristics, tremendous cutting load could resulting significant notch wear at the cutting region. In addition, heat generated during machining could invoke grains spallation since alumina has high thermal expansion. As machining prolonged, these spelled grains being removed to abrade the surrounding particles to detach along shearing path, resulting material lost at the slip region [16].

When zirconia added into the alumina matrix, the small particle size of zirconia could entrap between large alumina particles. The entrapment of ZrO_2 improved the slip resistance of the Al_2O_3 sample as ZrO_2 particles inhibit the grain growth of Al_2O_3 as it reduces in grain size while expand evenly through the sintered body [17]. In addition, the diffusion between particles facilitate interlocking mechanism at the grain boundaries that could increase the barrier of grain dislocation when the force is applied [18]. This not only can enhance the ability of the particles to hold strong their surrounding matrix but also resist deformation whenever the load applied.

4.0 CONCLUSION

This paper presents the comparison of cutting tool performance between alumina and alumina-zirconia at the high feed rate. Both cutting tools were fabricated with similar processing parameters with alumina-zirconia contained of 80-20 wt% ratio. These cutting tools were machined with AISI 1045 to assess their wear performance. Based on the experimental finding, the following conclusions can be drawn:

i. Alumina-zirconia cutting tool outperformed alumina cutting tool with almost 5 folds improvement. Alumina-zirconia recorded 164 s tool life while alumina only recorded 36 s tool life.
ii. Wear mechanism of alumina cutting tool dominated by the brittle fracture at the concentrated region of flank zone. The formation of severe wear inducing high temperature to melt the steel and deteriorate cutting edge.

iii. For alumina-zirconia cutting tool, the wear formation developed with the slight chipping at the concentrated area at the flank zone. The chipped area progressed into minor notch wear as the machining prolonged. The wear development still demonstrated uniform wear regime until the cutting tool reach tool life condition.
iv. The improvement of alumina-zirconia related to the infiltrated of small zirconia particles between spaces of alumina particles. The grains interlock the alumina boundaries to resist slippage when exposed to the cutting load.

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