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MACHINING PERFORMANCE OF ZIRCONIA CUTfING TOOLS

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ABSTRAcr

Grain boundary phases can control the properties and performance of the engineering ceramics. It is well documented that the presence of the grain boundary phases in zirconia plays an important role in microstructural development as well as influencing the electrical and mechanical properties. The present paper deals with the techniques of fabricating and evaluating the performances of newly developed hybrid zirconia cutting tool containing ceria stabilized zirconia and yttria stabilized zirconia.

INTRODUCI'ION

Zirconia (ZrOJ is a remarkable material, which has attracted a great deal of attention from scientists, technologists and users. The progress in our understanding of this material and in exploiting it has been substantial[l]. The phenomenon of phase transformation of zirconia is utilized in the development of tougher grades of alumina-zirconia cutting tools[2]. The increased toughness is due to the stress-induced transformation of zirconia particles at the vicinity of a propagating crack (by absorbing the energy at the crack front), or due to the volume change from phase transformation. Ceria and Yttria are the two materials most frequently us~d in partially stabilized zirconia (PSZ). Recent machining trials on yttria-stabilized zirconia cutting tools and ceria-stabilized zirconia cutting tool have evaluated the performance characteristics[2,3]. However such materials have certain basic drawbacks.

The disadvantage of Y-PSZ is that it loses its strength (degrades) when annealed in the temperature range of 200 -3000C in humid air or at lower temperatures in water[4]. Such problems are not present in Ce-PSZ, because it has a very good resistance to transformation during low temperature annealing[5]. One noted disadvantage of Ce-PSZ is its lower

hardness. This property has led to the concept of adding Ce-PSZ to y -PSZ in an alumina matrix[6J. Thus, the thermal stability of y .:.PSZ could he improved without losing its mechanical properties, by homogeneous mixillg with Ce-PSZ. The present paper deals with the techniques of fabricating and evaluating the performance of a newly developed hybrid zircqnia cutting tool containing ceria stabilized zirconia and yttria stabilized zirconia.

FABRICATION

The main criteria for transformation toughening to occur is the subrnicron size of the tetragonal phase particles. Transformation toughening can be operative only, if the tetragonal phase particle is smaller than a particular critical size diameter. For 3Y -TZP the critical grain size is about O.3.um[7], whereas, for 12 Ce- TZP , the critical grain size is about 3 *.urn*, about ten times larger[8] .

Carefully weighed quantities of 3Y -PSZ and 12Ce-PSZ powders were mixed with alumina powder. Thus, hybrid agglomerates will facilitate grain boundary characteristics and consequently phase stability. The fabrication details is given in Table 1.

The nose radius of the insert was made by grinding. From the knowledge gained from the previous research[9], conditions optimal for inducing completer cyclic (t-m-t) transformation were used to grind the nose radius in an optical profile grindin~ machine.

Table I fabricati()11 Details

Ceramic-Composite **(wt** %)	**85** % **AI2O3** **10** % **12Ce-PSZ** 5 % **3Y -PSZ**
Binder used	Poly Vinyl Alcohol
Compacting Pressure	200 MPa
Sintering Temperature	**15000** C
Sintering Time	2 **hours**
HIPing Temperature	**1470°** C
HIPing Pressure	200 **MPa**
HIPing Time	2 **hours**
Insert Designation	ISO 120416
Insert Hardness HvlO	1350 **GPa**

For evaluating the phases present after grinding, the ground inserts of ceramic-composites was subjected to X-ray Diffraction. Typical XRD profiles for ceramic-composites for as sintered, HIPed and ground conditions are presented in Figure I.

Referring to Figure 1, it can be seen that HIPing and grinding, have resulted in stress-induced transformation of tetragona! to monoclinic phase. This will facilitate cyclic transformation of t-m-t during subsequent service of the ceramic inserts as a cutting tool.

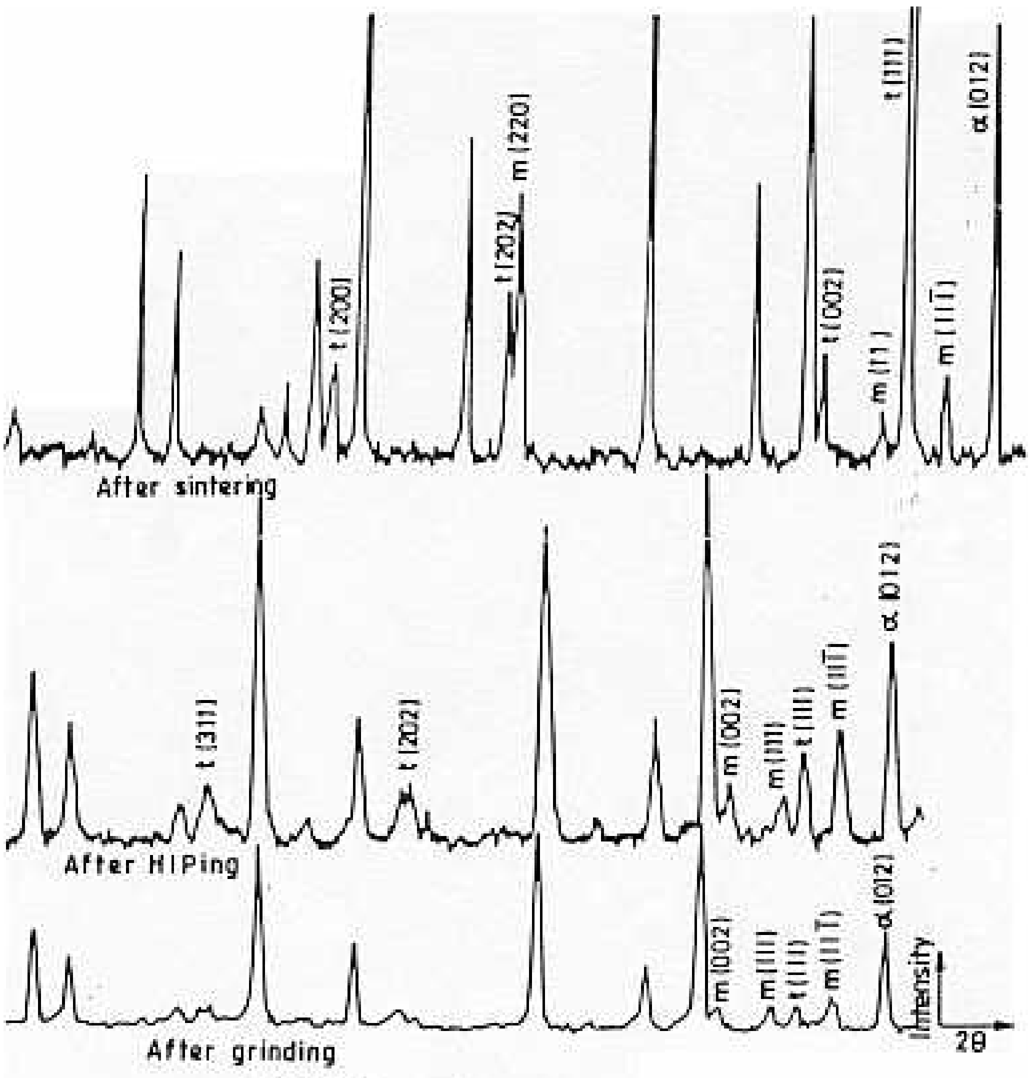

FIGURE 1 XRD Profiles

From the fig 1 it can be calculated that the ceramic inserts contains 66 vol% m phase and 34 vol% t phase. From the Ref{10] it has been proved that for 15 wt % ZrO2-A12O) an optimum resistance to fracture during high-speed turning of steel is obtained. Most likely, all three mechanisms of toughening contribute to the toughening in this case, namely transformation to increase volume phase, absorbing of crack tip energy by phase transformation and diffusion of crack tip by deflection .[11].

EXPERIMENTAL PROCEDURE

These inserts have been tried out for machining of steel workpiece of hardness 275 Hv; The performance of the inserts has been evaluated by measuring cutting forces, surface finish and observation on tool-wear. The data are presented in the following section. Machining tests have been conducted in a **high speed precision VDF lathe with the conditions presented in Table** 2. As **stated earlier the components of cutting forces were measured using** a **Kistler type dynamometer. The surface finish of the turned workpieces was measured using** a **Perthon type profilometer** . **Observation on nose wear of cutting tools was carried out using optical**
.I **mIcroscopy.** ;;1

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c'.':r.~
J..'J.a ,,1 1\,

Power

Speed Feed

Depth of Cut

Tool Geometry Approach Angle

Side rake angle

Clearance an,gle

Back rake angle

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Dr ., **..'**
h- ***V'*** 1 **1.AL** C

18 kw

100- 300 m/min

0.063 -0.1 mm/rev

0.1 -0.5 mm

45°

.6°

6°

00

Table **II** Machining Conditions

RESULTS AND DISCUSSIONS

Cutting Forces

Typical variations of cutting forces as a **function of cutting speed are presented in Figure** 2.

It is seen that with an increase in cutting speed there is a reduction in cutting force components. Referring to Figure 2 one can visualize two distinct zones in the trend of variations of cutting forces with cutting speed.

There is a zone of higher order of cutting forces with lower cutting speed. This is attributed to the ploughing of the cutting tool on the work surface. As the speed increases the cutting force component decreases, indicating steady cutti.ng. This is over a region of 150- 200 m/min. Beyond 200 m.min the nature of variation further changes. In this region the slope changes, where cutting force component tends to increase. This can be attributed to an increase in the nose radius/or deformation of nose associated with phase transformation of t -m phase.

This observations clearly indicates the occurrence of certain critical velocity for nose deformation, which is around 200 -250 m/min. The reduction in the cutting force with increasing speed can also be due to the softening of work material at temperatures associated with high cutting speeds and consequent reduction in shear strength. This facilitates easy chip removal without much chip strain and consequent reduction in cutting force.

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:J **200.00**
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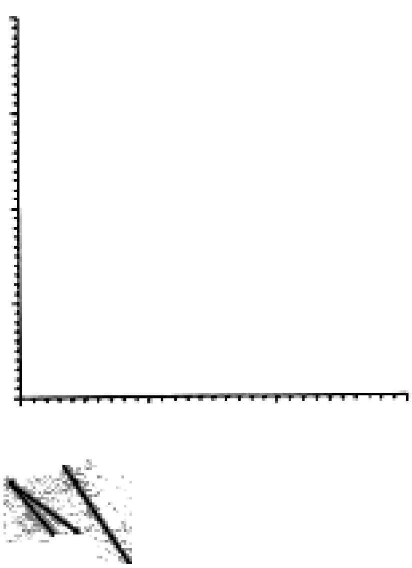

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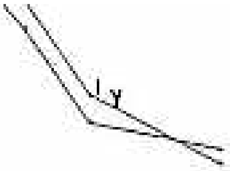

Workplec. 275 f+- OOC 0.5 mm
F..d 0.1 mm/r... Tool **~'e** 5 m,n

~.., 100.00 200.00 300.00 **Cutting speed *mi* min**

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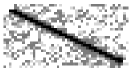

FIGURE 2 **Cutting forces vs Cutting speed**

Materials Processing and Design **II**

FIGURE 3 **Surface finish Ra vs** ***Cutting*** **speed**

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Surface finish

The influence of cutting speed on surface finish is illustrated in Figure 3.

It is seen that in the lower cutting speed range the machined surface was relatively rougher which is mostly attributed to the ploughing trend. As the speed increases the cutting becomes steady with easy chip removal, resulting in an -improvement of surface finish in the range of 150 -200 m/min. An increase in cutting speed produces an increase in temperature in the primary deformation zone, which softens the workpiece and the increase in the real area of contact at the tool-workpiece interface. Relative motion between the tool edge and workpiece produces plastic deformation within the surface, resulting in a better surface finish[12].

Beyond the critical velocity of 200 m/min the nose experiences a deformation with consequent roughening of surface. The variation of surface finish with cutting feed is presented in Figure 4. In turning the surface texture is obtained by replication of the cutting nose on the work surface. The accuracy of the replication is largely dependent on the form stability of the cutting tool and the feed rate. It is known that surface finish Rt is simply related to the above parameters by the relationship.[13]

Rt = K **.(52/8R)**

where

(1)

s = **feed rate**
P. '"= **nose rarJiu'.**
K = **stiffness constant**

This shows the significance of the ge'neratrix motion (feed) on the surface finish. As **the feed increases the surface texture becomes rougher**
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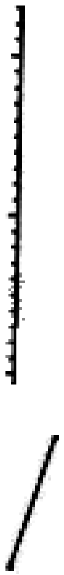
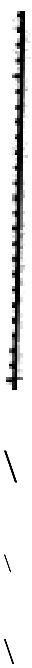


0.00 .'.: J-, 0.00 ***OoS*** 0.10 0.f5 **Feed Rote mm/rev**
FIGURE It **SURFACE FINISH**
vs Feed rute



000 ~ :_.~, ~."."".", 000 10000 200.00 300.00
Cutting speed m/min FIGURE 5 FlANK WEAR
vs Cutting speed

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Wo~piece 275 f+- DOC ***O.~*** mm
reed 0. , **mm/rev Tool .,. ~ m~**

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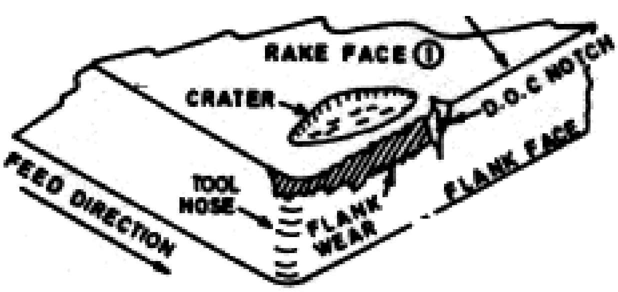
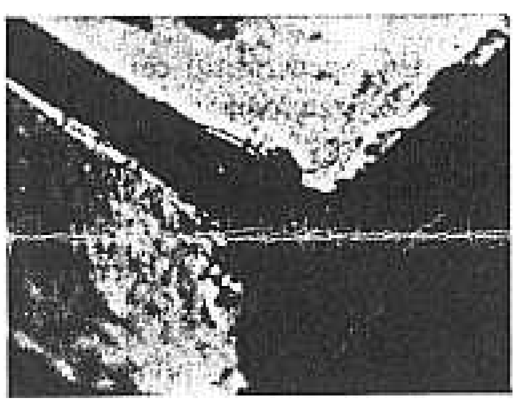
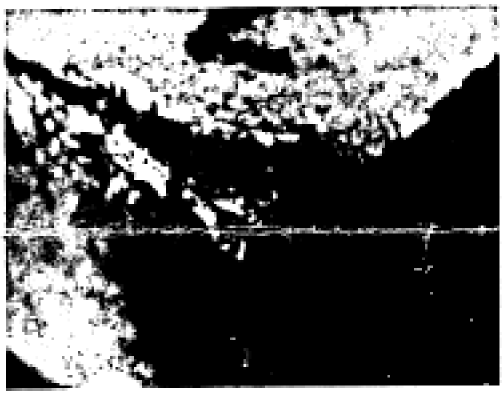
Flank Wear

The performance of cutting tools in turning is evaluated by measuring the st,ability to maintain dimensional tolerances, as well as the surface finish. The dimensional tolerance in turning is largely influenced by the flank wear of the cutting tool. During machining the just machined work surface slides past the flank surface of the cutting tool establishing an increase in adhesion contact wear .During this period of adhesion the material on the flank surfaces may undergo smoother flank wear due to deformation at the contacting asperities or exhibit abrasion wear due to rubbing of the strain hardened work surface. PRI~ARY
CUTTiNG EDGE



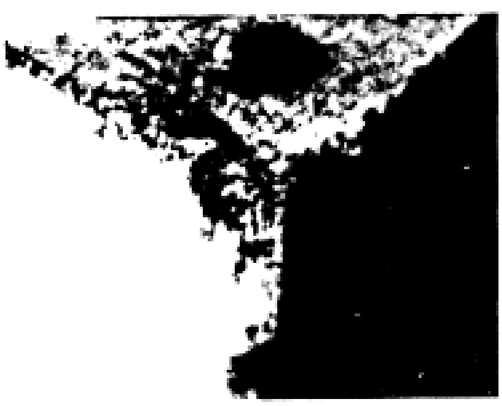


la) 100m/min



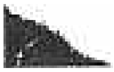
(b) 150 m/min

Ic) 200 mlmin



,,.-. Idl300m/min

FIGURE 6 **MICROGRAPHS**



250}J m

All this results in removal of material from the flank resuJting in occurrence of flank wear.The variation of flank wear with cutting speed is illustrated in Figure 5. It is seen that, as the cutting speed increases the flank wear decreases indicating steady cutting. Beyond the critica! velocity of 200 m/min there is a small increase in flank wear. During machining the material over the fiaI'.k surface will exhibit monoclinic to tetragonal transformation due to heating and subsequent tetragonal to monoclinic transformation due to contact stress. The occurrence of the cyclic tetragonal to monoclinic transformation results in softening of the tool material and a small increase in flank wear .

The optical micrographs of the worn portion of the cutting tool .ire presented in Figure 6. Referring to Figure 6 the occurrence of the critical velocity of 200 m/rnin can be visualized in that the cuiiing tool exhibited minimum wear on, the cutting nose. With lower velocities, namely 100 m/min and 150 m/min the tool portion exhibited chipping and triangular nose wear. With an increase in velocity severe primary grooving on the Depth of Cut Line (DCL) zone was observed. This is attributed to the cutting of tool material due to continuous rubbing of the unmachined diameter of the work surface.

CONCLUSIONS

The machining performance of newly-developed hybrid ceramic composite cutting tools containing ceria stabilized zirconia and yttria stabilized zirconia has been evaluated. The following conclusion were made.

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lnere is a **reduction in cutting forces with an increase in cutting speed in the range of 100 -300 m/min.**

There is a critical velocity of 200 m/rnin beyond which the nose deforms with consequent roughening of the surface. The flank wear is minimum at this velocity.

Beyond the critical velocity the increase in flank wear is attributed to the cyclic transformation of tetragonal to monoclinic phase.

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