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CBN Wheel Grinding of Alumina and Partially Stabilized Zirconia Ceramic–Ceramic Composites

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Abstract: Composites of alumina and partially stabilized zirconia have good functional properties such as high hardness. high strength, high thermal resistance, good chemical inertness, low thermal conductivity and high fracture toughness value. These properties make it a prospective material for tribo- logical applications and metal cutting. This requires critical dimensional tolerance and surface finish. To meet this efficient and precision machining technologies are needed. CBN wheel grinding of this ceramic-ceramic composite has resulted in a surface with good texture and finish.

INTRODUCTION

Research and development on engineering cera- mics has resulted in the generation of toughened ceramics and ceramic-ceramic composites having a high reliability. The main field of application of engineering ceramics and ceramic-ceramic com- posites are in tribological applications and cutting tools. The other applications include sliding bear- ings. axial face seals, sealing washers, wear parts in paper-making machines, textile machines, wire drawing machines, automobile parts and machine tools parts.

The mechanical performance of brittle cera- mics can be improved by increasing their fracture toughness/resistance. This is reflected in the increase in resistance to strength degradation from in-service thermal stresses, improved slow crack growth resistance and contact or impact damage when the fracture toughness is enhanced. The mechanisms which can result in improved fracture toughness are: phase transformation and associated stress-induced transformation tough- ening and microcrack toughening; ductile re-

inforcement; twinning; and fibre/whisker reinforcement.[1,2] This has resulted in thedevelop- ment of ceramic-ceramic composites.

The composites of alumina and partially stabi- lized zirconia like any other ceramics or cera- mic-ceramic composites are normally fabricated from fine powders through powder processing techniques like compacting, sintering and hot iso- static pressing (HIPing). The sintered or HIPed specimen surfaces are rough and sometimes warped requiring further machining operations to attain the near nett shape and the desired level of surface finish. Diamond wheel grinding has been well established as an effective method for grind- ing ceramics.[3-6] The CBN (cubic boron nitride) wheel grinding of such ceramic-ceramic com- posites is reported in this present study.

The ceramic-ceramic composites/ceramics are hard, brittle and mostly electrically non-con- ductive materials and they have necessarily to be machined only by traditional techniques. Among the techniques, abrasive machining is most suited to achieve the required precision in dimensional tolerance and surface texture. Some physical properties of the most important abrasive materials are presented in Table 1 !

Referring to Table 1, providing sufficient gradient in hardness, CBN and diamond are most suited to abrasive machining of ceramics. In comparison with diamond, one important advantage of CBN is its thermal stability. Both diamond and CBN are stable in vacuum up to temperatures in excess of 1400°C. In normal atmosphere a B2OJ protective layer on CBN prevents oxidation up to 1300°C and no conversion from cubic to hexagonal form occurs up to 1400°C. Diamond is thermally stable only up to a much lower tempera- ture of about 800°C in normal atmosphere.8

The material removal in the grInding of cera- mics or ceramic-ceramic composites is the sum of micro-plastic deformation and micro-brittle fracture at the point of contact of the abrasive grain with the ceramic. The material removal also depends on the type of abrasive, the grinding conditions, the stiffness of the abrasive-ceramic inter- face, the fracture toughness and hardness of the ceramic being ground.9 Malkin and Ritterlo have also reported that flow and fracture appear to be important factors for grinding of ceramics. Higher fracture toughness should favour flow mech- anisms. Indentation of ceramics even at room temperature was reported to be associated with dislocation pile-up on the indenting zone, leading to deformation of material and subsequent crack- ing if the threshold stress is attained. Among the oxide ceramics, zirconia and related systems have greater fracture toughness due to a possible stress-induced *t- m* phase transformation.ll This facilitates grinding of zirconia systems with more micro-plastic deformation than micro-brittle frac- ture, resulting in reduced cracking and better surface texture due to folding of surface asperities.

Table I. Properties of abrasive materials

Aluminium
oxide
(AI1OJ

Silicon carbide
(SiC)

Crystal structure Density
{gcm-3) **Melting point**
{OC)
Knoop hardness {kgmm-Z)

Hexagonal
3'98

2040

2100

Hexagonal
3.22

-2830

2400

TP- Triple point

EXPERIMENT AL PROCEDURE

Composite powders of 20% wt alumina and 80% wt partially stabilized zirconia (3 mol% y 203- Zr02) were cold compacted into square shapes at 200 MPa and sintered at 1500°C for 2 h. Some of the samples sintered were also subsequently HIPed at 1450°C for 1 hat 190 MPa. The properties of the composites of alumina and partially stabilised zirconia are summarized in Table 2.12.13

After sintering and HIPing, to eliminate the form error and also to obtain a near nett shape, all the specimens were ground with cubic boron nitride (CBN) wheels with conditions shown in Table 3.

The grinding chips were collected on double sided adhesive tapes pasted onto glass plates. The surface finish values of the ground surfaces were measured with the help of a Perthometer. The ground surfaces were analysed using an optical microscope and a scanning electron microscope (SEM). The grinding chips were analysed using an optical microscope.

RESUL TS AND DISCUSSIONS

Microscopy

The optical microscopy pattern of the ground surface presented in Fig. 1 reveals an orderly lay, i.e. the ground surface is uniformly serrated with an unidirectional lay. Figure 2 presents the optical microscopy of the chips produced during grind- ing. **It** is seen that the toughened ceramics have yielded short segmental chips, unlike the case of brittle materials where powdery chips are pro- duced.

!vlaterial

Cubic boron
nitride
(ENJ

Diamond
rrJ

Cubic
3'48

-3200
(at 105 kbar-TP) 4700

Cubic
3.52

-3700
(at **130 kbar-TP) ROOO**

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Table 2. The properties of the composites of alumina and partially stabilized zirconia

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PropertY

Notation

As-sintered and silltered HIPed

Young's modulus Poisson's ratio Thermal conductivity Thermal expo coeffo Thermal diffusivity Fracture toughness Bending strength Hardness Density
Phase at surface

E y *K* a *D* ***K/,.*** *a H p*

250
0.3
5-4355 9-6
2.0
5.28
426
1350
5-10 *a-AI10J+t+c*

260
0.3 5.6486 9.4
2.0
8.28
593
1500
5.30 a-A12O3 + *t* + *C*

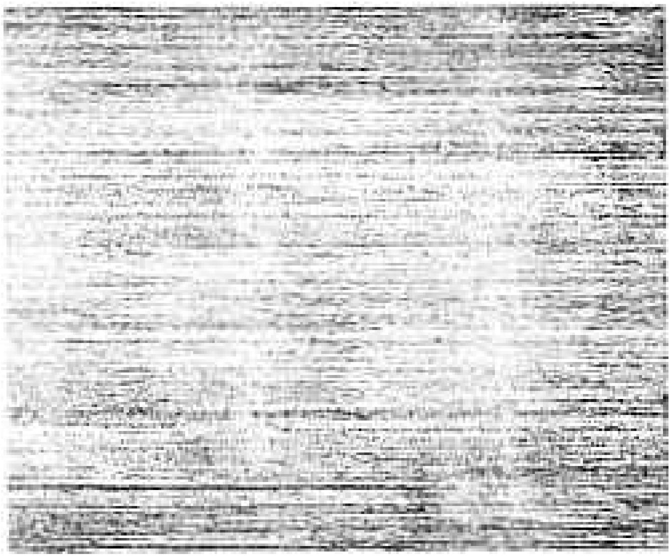
Units

GPa

\- **Wm-1oC-1 xlO-ti°C-1**
x **IO-tim2S-1 MPam"2**
MPa
HV
9 **cm** -.'

Table 3. Grinding conditions

I. Machine Tool and cutter grinder
2. Operation Surface grinding
3. Grinding wheel
CBN -B 120 RR 100 D
(152 rnrn diameter: 6.4 rnrn width: grit size 120)
4. Wheel speeds 1100, 2200, 3000 and 6000 5. Depths of cut 10, 20, 30 and 40 .urn
6. Work fced rate 27.5 rnrn rnin -I
7. Coolant No coolant (dry grinding)



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The scanning electron microscope (SEM) photograph of the ground surface is presented in Fig. 3. The ground surface texture of the cera- mic-ceramic composite revealed zones of surface material with folding of asperities. This is due to the higher order transformation toughening of the material. This has resulted in better surface tex- ture of the ceramic-ceramic composite.

Fig. 2. Optical micrograph of the chips produced during CBN \vh.:.:1 grinding of the as-sintered ceramic-ceramic compo,it\:, at II()() rpm and dcpth (Jfcut 4() ,llm at IOOOx magnification.

Sulface roughness

The grind ability was evaluated in terms of the surface roughness of the ground surfaces. The influence of depth of cut on surface roughness parameter *R"* is presented in Fig. 4. The variation of *R"* value with grinding speed for a constant depth of grinding of 40 *.urn* is presented in Fig. 5.

Influence of HIPing on surface finish

It is seen that the sintered and HIPed ceramic-ceramic composite exhibited better sur- face finish than the as-sintered cerarnic-cerarnic composite with CBN wheel grinding. The HIPing results in densification facilitating sharper cutting and hence better finish. Further HIPing after sin-

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Fig.3.

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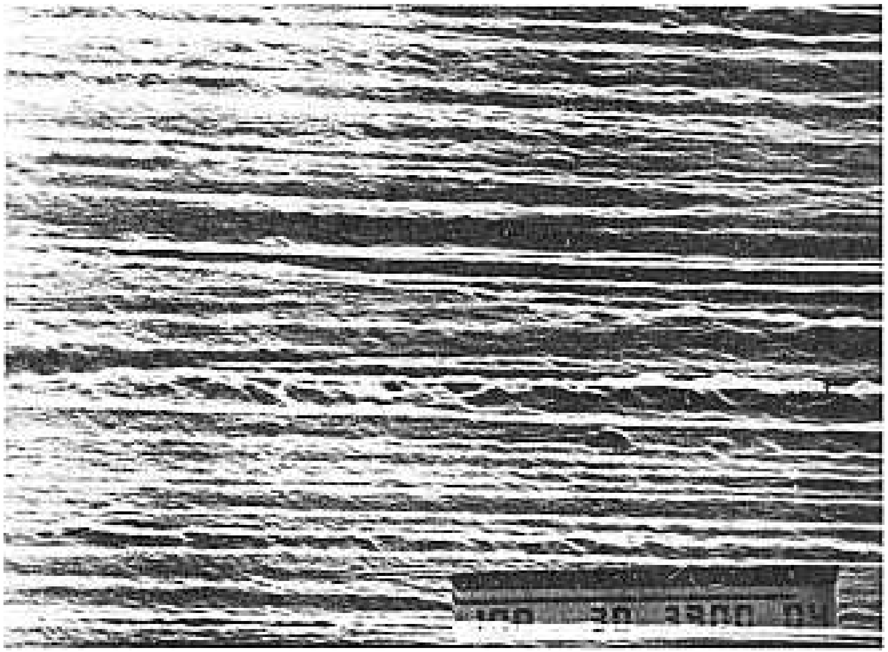


he scanning electron microscope (SEM) photograph of the ground-surface-as-sintered ceramic-ceramic composite in CBN wheel grinding at 3000 rpm and depth of cut 40 *,um* at 500 x magnification.

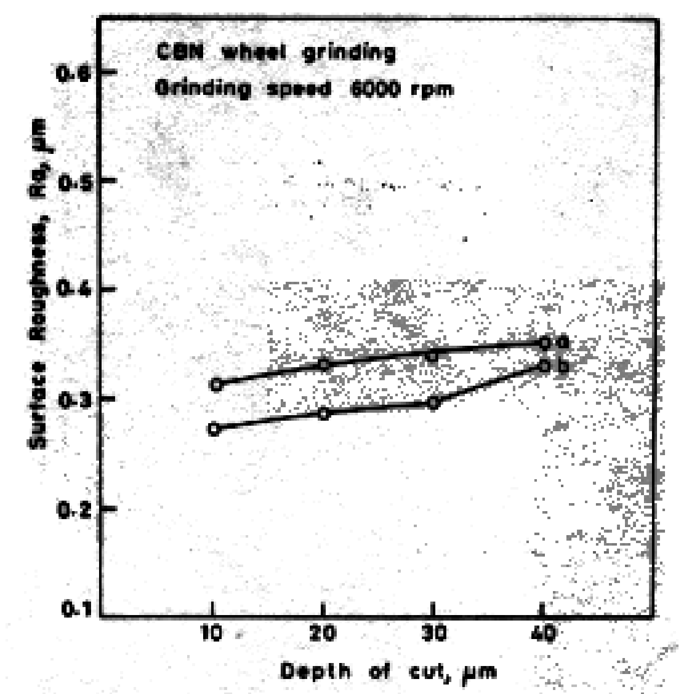
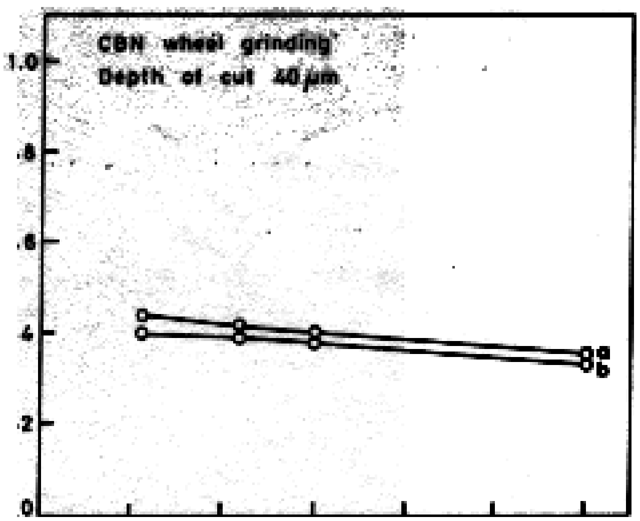


Fig. 4. **The variation of surface roughness with depth of grinding for: (a) sintered ceramic–ceramic composite; and (b) sintered and HIPed ceramic–ceramic composite.**

tering leaves a higher amount of residual strain energy in the material. This energy will be used by the ZrO_2 in the ceramic-ceramic composite for transforming the kinetically stabilized *t*-+ *m* phase. Thus, during grinding of the sintered and HIPed ceramic-ceramic composite samples more (-+ *m*-+ (transformation toughening takes place

E **~O c~**
a:
I/I~
1/1 O a.
c:
.c
01
"
o
a: O
a- u C
~ 0 (/)



-" .." 0 1000 2000 3000 4000 5000 6000 Grinding speed, rpm

Fig. S. The variation of surface roughness with grinding speed for: i.a) sintered ceramic-ceramic composite; and (b) sintered and HlPed ceramic-ceramic composite.

which can promote better surface finish due to folding of the asperity, minilnising the *Ra* value.

Influence of depth of cut on surface finish

Referring to Fig. 4 which presents the variation of surface roughness with the depth of grinding, it is seen that the surface finish marginally deteriorates with increasing depth of grinding. As the depth of cut increases the material removal mechanism changes from ductile- to brittle-regime. This

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explains the deterioration in surface finish as the depth of cut increases.14

Infuence of grinding speed on surface finish

It is seen that the surface finish improves as the grinding speed is increased. As the grinding speed increases the tendency to plough decreases, resulting in a steady grinding action and hence better surface finish.

CONCLUSIONS

Composites of alumina and partially stabilized zirconia have been ground with CBN grinding wheel, producing a good surface finish. The sur- face finish of ground surfaces of sintered and HIPed ceramic-ceramic composite is better than that of the as-sintered ceramic-ceramic com- posite.

The surface finish improves marginally with increase in grinding speed and decrease in depth of cut and the improvement in surface finish is observed to be associated with the deformation of the surface asperity; hence the improvement in surface texture could b'e largely attributed to toughening due to phase transformations during grinding.

REFERENCES

1. Ruhle, M. & Evans, A. G., High-toughness ceramics and ceramic composites. *Prog. Mater. Sci.,* **33** (1989) R5-167.

2. Becher, P. F., Advances in the design of toughened cera- mics. *The Centennial Memorial Issue of the Ceramic Society of Japan*, 99(10) (1991) 993-1001.
3. Inasaki, I. & Nakayama, K., High efficiency grinding of advanced ceramics. *Annals of the CIRP*, 35(1) (1986) 211-14.
4. Kitajima, K., Cai, C. Q., Kumagai, N., Tanaka, Y. & Zhing, H. W., Study of mechanism of ceramics grinding. *AlIIlals of the CIRP*, 41(1) (1992) 367-71.
5. Sornakumar, T., Annamalai, V. E., Gokularathnam, C. V. & Krishnamurthy, R., Grindability of zirconia tQughened alumina. *J. Matli'r. Sci. Lett.*, **11** (1992) 1049-50.
6. Sornakumar, T., Annamalai, V. E., Krishnamurthy, R. & Gokularathnam, C. V., Lapping of composites of alumina and partially stabilized zirconia. *Int. J. Refr. Ivletals* & *Hard Mater.*, **12** (1993-1994) 207-10.
7. Malkin, S., In *Grinding Technology, Theory and Applica- tions of Machining with Abrasives.* Ellis Horwood Ltd, Chichester, UK, 1989, p. 25.
8. Malkin, S., Current trends in CBN grinding technology. *Annals of the CIRP*, 34(2) (1985) 557-63.
9. Inasaki, I., Grinding of hard and brittle materials. *Annals of the CIRP*, 36(2) (1987) 463-71.
10. Malkin, S. & Ritter, *I.* E., Grinding mechanism and strength degradation for ceramics. *ASME J. Eng. Ind.*, 111(1989)167-74.
11. Annamalai, V. E., Sornakumar, T., Gokularathnam, C. V. & Kirshnamurthy, R., Transformations during grinding of ceria-stabilized tetragonal zirconia polycrystals. *J. Amer. Ceram. Soc.*, 75 (1992) 2559-64.
12. Sornakumar, T., Annamalai, V. E., Kirshnamurthy, R. & Gokularathnam, C. V., Mechanical properties of com- posites of alumina and partially stabilized zirconia. *J. Mater. Sci. Lett.*, **12** (1993) 1283-5.
13. Sornakumar, T., Annamalai, V. E., Krishnamurthy, R. & Gokularathnam, C. V., Thermal shock resistance of composites of alumina and partially stabilized zirconia. *J. Mater. Sci. Lett.*, **12** (1993) 1253-4.
14. Bifano, T. G. & Yi, Y., Acoustic emission as an indicator of material removal regime in glass micro-machining. *Precis. Eng.,* 14(4)(1992)219-28.