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Production of Titania Stabilized Alumina Ceramic Cutting Tool

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ABSTRACT

Cutting being an important fabrication route enables fast and easy manufacturing of different product. In this research, ceramic cutting tool samples based on Al_2O_3 with different amounts of TiO_2 (4%, 8% and 12%) additions were prepared by uniaxial pressing at about 170-180 MPa and sintering them at different temperatures (1350°C, 1400°C, 1450°C & 1500°C) for different soaking times (0 hr, 2 hr) depending upon the type of sintering schedule chosen. Initial single stage sintering data was utilized to find appropriate activation and soaking temperature for two stage sintering processes. Later two stage sintering was carried out. The sintered bodies were tested to determine the physical and mechanical properties such as density, hardness, grain size, wear and cutting property. The Scanning Electron Microscope was used to observe microstructure and co-relate it with the measured properties. And finally the major findings are reported in the conclusion section.

Keywords: Alumina, Titania, density, hardness, wear property, cutting property.

1. Introduction

The recent advancements in cutting tool technology is moving towards high speed, dry cutting processes together with focusing on increased durability and lower tool cost. The application of nano-ceramic materials with their superior physical, mechanical and chemical properties [1] has enabled to accomplish new heights in cutting tool industry. As engineering ceramics like alumina (Al_2O_3), silicon nitride (Si_3N_4), titanium carbide (TiC), titanium carbonitride (TiCN), cubic boron nitride (cBN), etc. possess high hardness, low thermal expansion, high thermal conductivity, chemical inertness, hot strength; they are undergoing increased utilization in tribological [2] applications.

Among all the ceramics Aluminum Oxide (Al_2O_3) or Alumina is readily available and cheaper than others. It possesses good hardness and wear resistance, but lacks toughness. The deficiency in toughness may cause premature failure which would render alumina unsuitable for demanding applications. In order to enhance to properties of alumina and other ceramics incorporation of small quantities of additives like ZrO_2, MgO, CaO, WC, SiO_2, TiO_2, TiC, etc. has been considered as standard practice [3,5]. Titanium Oxide (TiO_2) or Titania is a prospective additive in case of alumina. Among the other techniques application of various tool shapes, cutting angle, tool alignment, tool holder geometry, etc. have significant effects in improving cutting tool performance [4].

In the Department of Materials and Metallurgical Engineering (MME) of BUET, some attempts have already been made to develop cost-effective cutting tool inserts with titania as additive. Among them, Syed Md. Zakaria conducted research to develop cutting tools by slip casting. Later Md. Al Hossani Shuva, Abu Naser Reza and Tasneem Ara Islam made successful attempts by applying cold uniaxial pressing.

2. Experimental Procedure

2.1 Raw materials

The raw materials with following specification were used:

Table 1 Raw materials' specification

Attributes	Alpha Al_2O_3	TiO_2 (Anatase)
Purity	99.85%	99.9%
Particle size	150 nm	40nm
SSA	10m²/g	40m²/g
ρ	3.97 g/cc	3.89 g/cc
M_p	2045°C,	1830-1850°C
B_p	2980°C	2500-3000°C

In this current research compositions of 4% TiO_2- 96% Al_2O_3, 8% TiO_2- 92% Al_2O_3 and 12% TiO_2- 88% Al_2O_3 were used for producing cutting tool inserts.

2.2 Slurry preparation

First, appropriate amounts of Al_2O_3 and TiO_2 powders were weighed (30gm batch) and poured into an ultrasonically cleaned HDPE bottle containing zirconia balls. Two third of height of the bottle was filled with acetone as milling media. Then it was ball milled at 150 rpm form 18 hours. After that, prepared slurry was extracted using small amounts of acetone for proper cleaning purposes. The extracted slurry was kept in beaker and marked with permanent markers for easy identification.

2.3 Drying and binder addition

The slurry was dried for minimum 24 hours at 110-120°C. A stirrer was used to first crush dried cake, to add PVA binder (3-4 drops with a 2 minute interval) and then dry for another 24 hours.

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2.4 Forming

Dies with 13mm internal diameter from Pike Tools was used for uniaxial compaction into cylindrical forms. The applied pressure was 2 tons (170 MPa) and holding time was 2 minutes. Formed green bodies are then dried at 110-120°C for at least 24 hours.

2.5 Sintering

The green bodies were pressure-less sintered under the ambient condition using an electrically heated furnace. First, they were heated slowly (3-5°C/min) to 500°C and held there for 1 hour to remove binder and other volatile matter. Then they were heated to desired temperatures for different soaking times. Compacts were sintered at 1450°C for 0 hour to determine activation temperature and at 1400°C, 2 hour & 1450°C, 2 hour to find soaking temperature. After performing preliminary steps, trail two stage sintering schedules were chosen to be 1450°C, 0 hour ; 1350°C, 2 hour. The final sintering cycles chosen were 1500°C, 0 hour; 1350°C, 2 hour & 1500°C, 0 hour; 1450°C, 2 hour. The cooling rate was kept within 3-5°C/min.

3. Results and discussion

3.1 % Theoretical Density

In order to attain bulk density as close as possible to the theoretical density different composition, temperature and soaking time were used. The % theoretical densities of samples are given below:

Table 2 % theoretical densities of different composition

Sintering cycles	4% TiO_2-96% Al_2O_3	8% TiO_2-92% Al_2O_3	12% TiO_2-88% Al_2O_3
1400°C, 2 hr	90.95%	89.80%	88.49%
1450°C, 0 hr	91.58%	89.32%	88.82%
1450°C, 2 hr	92.1%	91.97%	87.8%
1500°C, 0 hr 1350°C, 2 hr	92.56%	91.29%	89.7%
1500°C, 0 hr 1450°C, 2 hr	93.02%	93.01%	90.21%

The following figure 1 illustrates the effect of temperature and composition on %theoretical density.

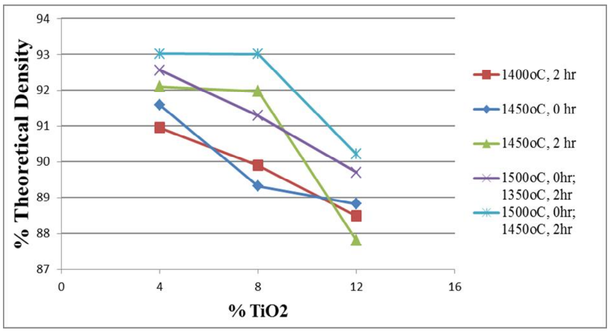

Fig.1 Variation of % theoretical density with temperature and composition.

3.2 Hardness

The hardness of the samples was measured by Vickers Micro-hardness Testing Machine using the following formula:

$$H.V = 1.854\ P * g / d^2 \ \text{GPa}$$

Table 3 Hardness of different composition

Sintering cycles	4% TiO_2-96% Al_2O_3	8% TiO_2-92% Al_2O_3	12% TiO_2-88% Al_2O_3
1400°C, 2 hr	14.19 GPa	16.55 GPa	18.79 GPa
1450°C, 0 hr	14.03 GPa	13.21 GPa	15.64 GPa
1450°C, 2 hr	12.14 GPa	17.32 GPa	18.86 GPa
1500°C, 0 hr 1350°C, 2 hr	17.11 GPa	14.47 GPa	13.02 GPa
1500°C, 0 hr 1450°C, 2 hr	19.48 GPa	23.44 GPa	---

The following figure 2 illustrates the effect of temperature and composition on hardness.

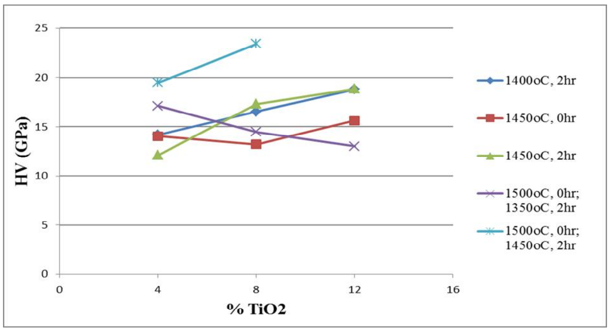

Fig.2 Variation of hardness with temperature and composition.

Addition of TiO_2 in alumina facilitates not only, reduction of the sintering temperature of alumina, but also influences its properties. It is clearly evident that, increase in the TiO_2 content increases hardness. It is because of the fact that, there are more sites of pinning the grain boundary, thus grain size is reduced and hardness is improved. We also know that density is an important factor in determining hardness. The denser the material the higher is the hardness.

3.3 Wear property

Pin – on – Disc apparatus was used to measure the wear property of the samples. The speed was 1150 rpm, dwell time was 30 minutes and applied load was 3 kg. The wear property was measured in gm/m unit. Only the final two compositions with two stage sintering were used in this case.

Table 4 Wear property of different composition (10^{-6})

Sintering cycles	4% TiO_2-96% Al_2O_3	8% TiO_2-92% Al_2O_3
1500°C, 0 hr 1350°C, 2 hr	1.41 gm/m	1.03 gm/m
1500°C, 0 hr 1450°C, 2 hr	0.981 gm/m	0.646 gm/m

The effect of sintering temperature and composition on wear property is illustrated in the following figure 3:

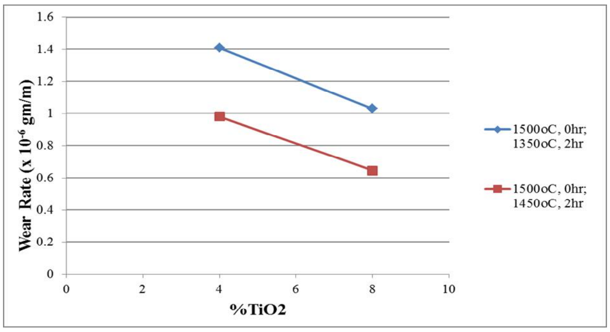

Fig.3 Variation of hardness with temperature and composition

With increase in density and hardness, wear rate decreases. This has been found throughout the project. But there were another variable such as temperature. With increase in sintering temperature it was found that, density further increased. Hardness also increased in the same manner. So the wear rate decreased.

3.4 Cutting property

The cutting specimen was mild steel (60HRC) with parameters cutting speed 465 rpm, depth of cut around 0.2 mm and cutting time of 2 minutes. After each operation, the removal of metal was measured by weighing out the chips in every cut. The tools were weighed after cutting, by the difference of initial and final weight, the tool weight loss was determined.

Table 5 Cutting property of different composition

Sintering cycles	Composition	% weight loss of insert	Weight of chips (gm)	Status
1500°C, 0hr 1350°C, 2hr	4% TiO_2-96% Al_2O_3	2.35	1.6516	Sustain
	8% TiO_2-92% Al_2O_3	4.74	3.3848	Sustain
1500°C, 0hr 1450°C, 2hr	4% TiO_2-96% Al_2O_3	2.75	3.5595	Sustain
	8% TiO_2-92% Al_2O_3	1.27	3.0515	Sustain

With increase in sintering temperature cutting property gradually improves for all composition except 8% TiO_2. The inconsistency may arise from sudden coarsening at higher temperature.

The effect of sintering temperature and composition on cutting property is illustrated in the following figure 4:

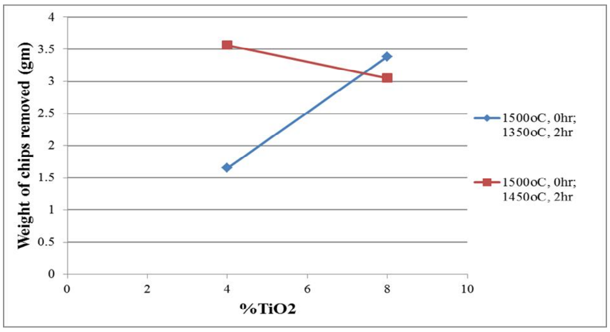

Fig. 4 Variation of cutting property with temperature and composition

3.5 Microstructural study

The SEM photographs show, bimodal type grain distribution. The microstructure mostly consists of fine grains together with some irregularly shaped large grains. It means that, the sintering temperature was high and the material was not allowed to attain homogeneity because of lack of time. In some cases, TiO_2 particles were not homogeneously distributed in the matrix meaning insufficient or inappropriate milling practice.

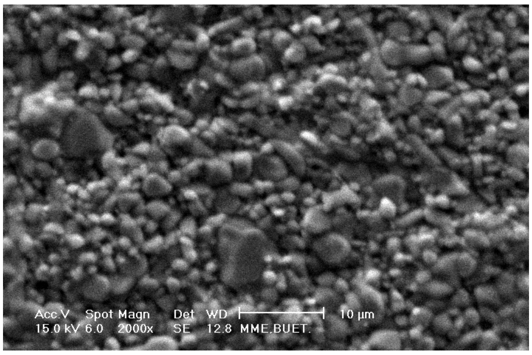

Fig. 9 SEM photograph of 4% TiO_2 -96% Al_2O_3 sample at 1500°C, 0 hr; 1350°C, 2 hr at 2000x

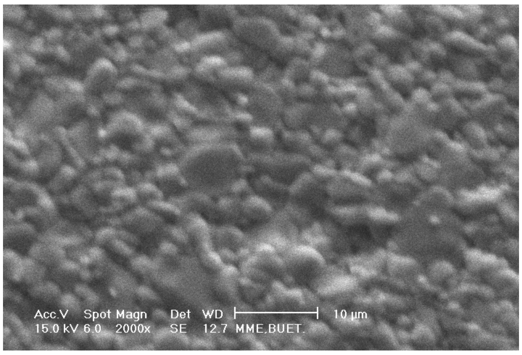

Fig. 10 SEM photograph of 8% TiO_2 -92% Al_2O_3 sample at 1500°C, 0 hr; 1350°C, 2 hr at 2000x

Conclusion

The following conclusions can be drawn from the present work:

i. The % theoretical density has gradually increased for cutting tools having composition until 12% TiO_2-88% Al_2O_3.

ii. The maximum % theoretical density of has obtained for 4% TiO_2 stabilized alumina during two stage sintering schedule of 1500^oC, 0 hr; 1450^oC, 2 hr.

iii. The hardness of 4% TiO_2 and 8 % TiO_2 stabilized alumina cutting tools increased consistently with increase in sintering temperature. Maximum hardness value was obtained for 8% TiO2 sintered at 1500^oC, 0 hr ; 1450^0C, 2 hr.

iv. As the sintering temperature and % TiO_2 increases the wear rate of cutting tools decrease. Wear rate of 4% TiO_2 stabilized alumina sintered at 1500^oC, 0 hr; 1350^0C is the lowest of all.

v. Cutting properties have also improved consistently with increasing sintering temperature and % of TiO_2.

vi. At lower temperature fine grain microstructure has been obtained and with increase in TiO_2 content relatively fine grain microstructures has been obtained even at higher temperature.

vii. Best combination of all properties has been obtained with 8% TiO_2 sintered at 14500C for 2 hours.

NOMENCLATURE

SSA : Specific surface area, m^2/g
ρ : Density, gm/cc
M_p : Melting point, ^oC
B_p : Boiling point, ^oC

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