Surface Finish Studies of a Dense Alumina Ceramic Material

Using 3 - AXIS CNC Grinding Machine

Prabaha Das, Pranab Das, Probal Kumar Das [(a)] and Gurumoorthy Hebbar

Department Of Mechanical Engineering, Christ University, Kumbalgadu, Bangalore-560 060

(a) Non-Oxide and Composite Division, Central Glass and Ceramic Research Institute, Jadavpur,Kolkata- 700 032

ABSTRACT

High Alumina Ceramics (95%-99% Alumina) materials are widely used as substrates in electronic industries and also as Bio-Ceramic material.In both these applications surface finish characteristics of the material plays a very important role for its successful application. In the present study a dense alumina ceramics (>95% T.D) was studied for its surface finish characteristics.To evaluate the effect of machining parameters on the surface finish of the sintered alumina using the surface grinding machine, samples were ground using different spindle rpm, depth of cuts and x-stage movement. After each machining stage, surface roughness values of the ground specimens were measured using either non-contact type or contact type surface profilometer.The machining operation indicated that the best set of input parameters for surface grinding of sintered Al_2O_3 ceramics is

- 2000 rpm spindle speed
- 0.3 μm depth of cut and
- 5,000 mm/min X-stage movement.

(Key Words – High Alumina Ceramics, CNC Grinding machine, surface finish)

1. Introduction

99.5% Aluminum oxide substrates are most often used in thin film applications in electronic industries and are commonly referred to as thin film Ceramic substrates. In the as-fired condition, flatness, surface imperfections, thickness tolerances and surface finish may not meet required conditions for sensitive applications. Lapping provides the desired flatness and thickness tolerance, with a surface finish typically in the 8 to 12 microinch range. Polishing will make the surface defect-free and improve the finish to 0.5 microinch with good flatness and thickness tolerances Thinning can bring the substrate thickness down to 0.001" with either a lapped or polished finish. 96% Aluminum oxide substrates,on the other hand known also as thick film substrates, have similar thickness and flatness characteristics as 99.6% Alumina in the as-fired state. However, the surface finish for 96% Alumina may be as rough as 30 micron inches. Lapping process will give desired thickness tolerance and good flatness. The thicker the finished substrate, the better flatness canbe achieved. Most thick film applications do not require polished substrates. 96% Alumina can be polished, although not as highly as 99.6% Alumina.

High Alumina (95%-99.% Alumina) ceramics moreover has been widely recognized as a bio ceramic implant materials in medical applications Since early seventies more than 2.5 million

femoral heads were implanted in animal bodies worldwide. Alumina-on-alumina implants have been monitoredand over 3000 implants have been found successfully implemented since 1987

As regards the properties of these ceramic materials, smaller grain size and porosity, higher strength(E = 380 GPa,stress shielding may be a problem),high hardness,low friction(surface finish of < 0.05 µm),low wear (no wear particles generated and bio compactible) and low corrosion resistance are some of the prime requirements of alumina bio ceramics materials. More over Bio- inertness (results in bio compatibility, immune response) is an important criteria for prolonged service condition .However alumina bio ceramics suffer from the following disadvantages (1) minimal bone ingrowth (2) non-adherent fibrous membrane and (3) interfacial failure and loss of implant may occur . Despite all these controversial properties they find wide applications in orthopaedics (femoral head, bone screws and plates, porous coatings and femoral stems and porous spacers (specifically in revision surgery and knee prosthesis). In dental applications they are used in crowns and bridges

1(a)Designof Bio Ceramics Materials

The performance of the artificial ceramics depends on its composition and end use application. Careful selection of the right material with suitable properties is thus important. Computer-aided design software is also used now a daysfor optimizing the shape and for simulating the mechanical behavior of the implant with the surrounding bone tissue. A mathematical technique called finite element analysis is used to determine the stress distribution on both the implant and biological structure. Prototypes are then fabricated that undergo testing of properties, as well as clinical tests, before final production.

1(b)Raw Materials

The major raw material is usually a high Alumina ceramic powder of specific composition.. Additives include binders, lubricants, and other chemicals to assist in the shape forming process. The powder may also contain a sintering aid, which helps the ceramic material to densify properly during firing and sometimes at a lower temperature. If a chemical-based process is used, organic precursors and solvents are combined into a solution to make the final product.

1(c)The Manufacturing Process

Depending on its composition, artificial shapes are made using various processes, the traditional ceramic process and a chemical-based method called sol- gel process. The traditional process involves consolidation of the powers in the desired shapes in a die and press method to obtain the green shape and thereafter in an iso-static press to have uniform density of the green shape . In the sol - gel method, two approaches can be used. In one, a suspension of extremely small particles is allowed to gel inside a mold, followed by aging at 77-176° F (25-80° C) for several hours, drying, and several thermal treatments to chemically stabilize and densify the material. The other approach uses a solution of chemical precursors as the starting material followed by the same process.

1(d)Raw material preparation

The ceramic powder is manufactured elsewhere from mined or processed raw materials. Additional crushing and grinding steps may be necessary to achieve the desired particle size. The ceramic powder plus additives are carefully weighed in the appropriate amounts and then mixed in some type of mixing machine equipped with blades or revolving rolls. Sometimes mixing and particle size reduction takes place at the same time, using a milling machine. A ball mill uses rotating cylinders filled with the mixture and spherical media to disperse the material and reduce its particle size. An attrition mill uses tiny beads and rotating agitators to accomplish the same objective..

1(e)Forming

After mixing, the ceramic material is of plastic consistency and ready for forming into the desired shape. A variety of methods can be used, including injection molding, extrusion, or pressing. In injection molding, the mix is loaded into a heated cylinder, where it softens. A steel piston forces the hot mixture into a cooled metal mold. Extrusion compacts the material in a high-pressure cylinder and then forces the material out through a specially shaped die orifice. Pressing involves compaction of the material in steel dies or the material is placed in a rubber mold inside a high-pressure oil or water cylinder, with uniform pressure applied. Another variation of pressing called hot pressing combines forming and firing in one step using heated dies.

1(f)Drying and firing

After forming, the ceramic shape must undergo several thermal treatments. The first dries the material to remove moisture using a drying oven or chamber. After drying, a kiln or furnace is used to heat the material at high temperatures in order to remove organics and densify the material. The firing cycle will depend on the material composition and must be designed at the appropriate heating rates to prevent cracking.

1(g)Finishing

After firing, one or more finishing processes may be required depending on application. To achieve the desired dimensional and surface finish specifications, grinding and/or polishing is conducted. Grinding and polishing of the harder materials usually requires diamond tooling or abrasives. Drilling may be needed to form holes of various shapes. If the application requires joining of two or more components, a brazing or cementing method is used.

1(h)Quality Control

During the manufacture of the artificial bone material or component, control of each processing step is required to control the properties that affect performance.

1(i)TheBioceramic applications. (1). Cranial repair. (2). Eye lens. (3). Ear implants. (4). Facial reconstruction. (5). Dental implants. (6). Jaw augmentation. (7). Periodontal pockets.(8) H.

Percutaneous devices. (9). Spinal surgery. (11). Iliac crest repair. (12). Space fillers. (13) Orthopedic support purposes. (14). Orthopedic fillers(15)N. Artificial tendons. (16). Joints.

Properties of interest for most implant applications are mechanical performance and surface chemical behavior. These in turn depend on the chemical composition (type and amount of impurities), the particle size, shape and surface characteristics of the starting powder, crystalline structure, microstructure (grain size, type and content of each phase), and surface behavior (measured by comparing the chemical composition of the surface before and after it is tested in a simulated environment relevant to the application). Some of these properties may be more important than others, depending on the type of artificial bone material and its application.

Since artificial bone can sometimes be considered a medical device or at least part of a medical device, it must meet national and international standards for such devices and materials, as well as regulations established.

The present work was undertaken to study the effect of machining a dense High Alumina Ceramics using 3-axis CNC Grinding Machine (.**Model:** N6 KGT 840D**Make:** *M/s ELB*, Germany). This machine is used for grinding and cutting of different ceramic materials. There are three motors in X, Y, Z axis and they can move along their axis and used as desired. The X-axis motor is fixed at the bottom and the Z-axis motor is fixed at the top. There are a couple of small motors also provided for other works. The machine is driven by *Siemens 840 D Sinumeric*controller**.**

2.Experimental:

The raw materials used are polycrystalline alumina powder (A-16-SG, *Almatis Alumina Pvt. Ltd*, India) and MgO powder (*Merck*, India). 0.5 wt.%MgO was mixed with Al_2O_3 powder in deionized water using attrition milling in the 2.5 kg attritor for 3 hours using 3 mm alumina balls. After milling the mixture was dried overnight in the air oven at 120^oC for moisture removal. Finally, the dried powder mixture was sieved through 60 mesh B.S. screen in the sieve shaker for granulation and collected. Circular pellets of nearly 35 mm diameter were uniaxially pressed at 4000 kg/cm^2 followed by cold isostatic pressing at 150 MPa for 1 minute. Green dimensions were taken to calculate respective shrinkage values. Samples were then sintered at 1650^oC with a dwell of 2 hours in ambient. The heating and cooling rate was maintained at 5^oC/min. Density and apparent porosity values of the sintered circular discs were measured by *Archimedes* water immersion technique using deionised water. Dimensions of the sintered specimens were also measured using a digital vernier calliper to calculate the shrinkage values.

To evaluate the effect of machining parameters on the surface finish of the sintered alumina using the 3 axis ELB surface grinding machine, samples were ground using different spindle rpm, depth of cuts and x-stage movement. After each machining stage, surface roughness values of the ground specimens were measured using either non-contact type or contact type surface profilometer.

3.Results and discussions:

As can be seen from **Table 1**, that irrespective of measuring direction, the green shrinkage value after CIP was ranged in between 3.4 to 4.7% while after sintering it was close to 15.5%. Density values of the sintered specimens indicated that that after sintering at 1650^oC for

2 hours, the average relative density reached to ~99%. This suggested that 1650°C was sufficient for achieving desired level of densification in the studied alumina ceramics.

Table 1: Physical properties of sintered Al_2O_3

Sample	UT[a] (mm)	CT[b] (mm)	GST[c] (%)	UD[d] (mm)	CD[e] (mm)	GSD[f] (%)	FT[g] (mm)	FST[h] (%)	FD[i] (mm)	FSD[j] (%)
1	12.84	12.79	0.39	34.50	33.38	3.25	10.63	16.89	28.17	15.61
2	12.96	12.60	2.78	34.50	33.36	3.30	10.59	15.95	28.18	15.53
3	13.05	12.45	4.60	34.50	33.30	3.48	10.64	14.54	28.14	15.50
4	13.16	12.53	4.79	34.50	33.26	3.59	10.69	14.68	28.10	15.51
Average			**4.69**			**3.41**		**15.52**		**15.54**

Sample	FW[k] (gm)	IW[l] (gm)	SW[m] (gm)	BD[n] (g/cc)	RD[o] (%)	AP[p] (%)
1	25.24	18.85	25.34	3.95	99.49	1.56
2	25.61	19.06	25.69	3.91	98.49	1.22
3	25.39	18.93	25.50	3.93	99.00	1.70
4	25.51	19.05	25.60	3.95	99.47	1.39
Average				**3.93**	**99.11**	**1.47**

[a] = Thickness after uniaxial pressing at 4000 kg.cm^2 for 1 minute/ [b] = Thickness after CIP at 150 MPa for 1 minute/ [c] = Green shrinkage after CIP w.r.t. thickness/ [d] = Diameter after uniaxial pressing at 4000 kg.cm^2 for 1 minute/ [e] = Diameter after CIP at 150 MPa for 1 minute/ f = Green shrinkage after CIP w.r.t. diameter/ [g] = Thickness after firing at 1650°C for 2 hrs. in ambient/ [h] = Firing shrinkage w.r.t. thickness/ [i] = Diameter after firing at 1650°C for 2 hrs. in ambient/ [j] = Firing shrinkage w.r.t. diameter/ [k] = Fired weight/ [l] = Immersed weight/ [m] = Soaked weight/ [n] = Bulk density/ [o] = Relative density/ [p] = Apparent porosity

The roughness data as obtained after grinding of the specimens at different spindle RPMs (Table 2) indicated that the lowest R_a (average surface roughness) was obtained for sample # 2 i.e. 0.579 µm. Therefore, in the subsequent stages, spindle RPM was set at 2000. Further, it may be noted from **Table 2** that decreasing RPM resulted in increased R_a values suggesting higher frictional force build-up at the wheel/specimen interface during grinding at lower spindle RPM.

Table 2: Roughness data of sintered alumina after grinding at different spindle RPM

Parameters	1st Sample	2nd Sample	3rd Sample	4th Sample
Wheel speed (RPM)	2200	2000	1800	1600
Depth of cut (µm)	1	1	1	1
X-axis speed (mm/min)	10,000	10,000	10,000	10,000
R_a (µm)	0.621	**0.579**	0.620	0.686
R_p (µm)	8.097	1.850	10.649	2.816
R_v (µm)	-15.348	-19.152	-19.465	-15.016
R_t (µm)	23.445	21.002	30.114	17.826

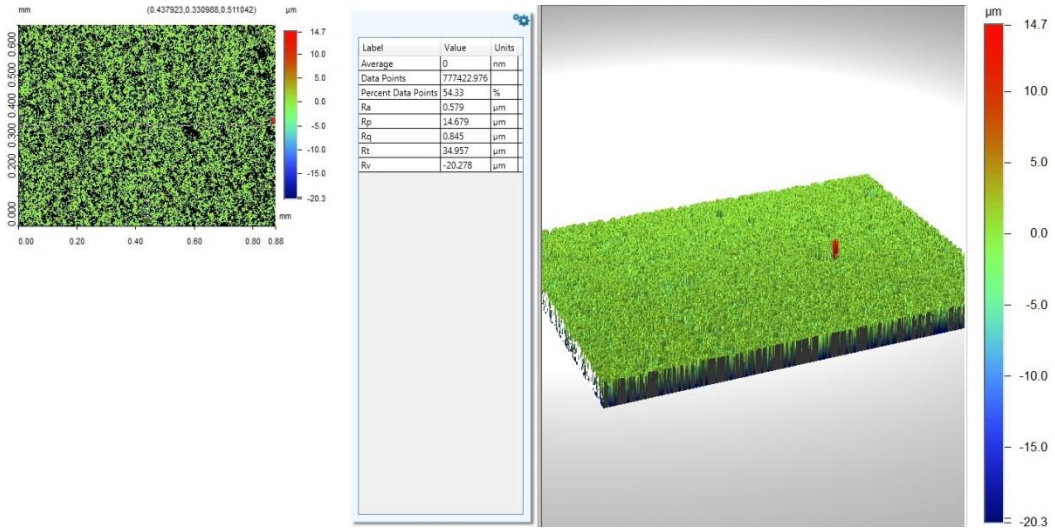

Fig. 1.: Surface finish of sintered Al_2O_3 at 2000 RPM using Non-contact profilometer

In the next stage, the specimens were ground at different depth of cuts ranging from 1 to 7 mm at a constant spindle RPM i.e. 2000 and X-stage movement i.e. 10,000 mm/min. The R_a values obtained after grinding at this stage indicated a set of 2000 RPM spindle speed and 7 µm depth of cut resulted in the highest surface smoothness followed by 3 µm depth of cut (**Table 3**). Since, at 7 µm depth of cut the power consumed by the machine and load on the grinding wheel were too high, the optimum depth of cut was set at 3 µm.

Table 3: Roughness data of sintered alumina after grinding at different depth of cut

Parameters	1st Sample	2nd Sample	3rd Sample	4th Sample
Wheel speed (RPM)	2000	2000	2000	2000
Depth of cut (µm)	1	3	5	7
X-axis speed (mm/min)	10,000	10,000	10,000	10,000
R_a (µm)	0.569	**0.553**	0.558	0.546
R_p (µm)	8.532	10.935	13.047	7.555
R_v (µm)	-16.062	-15.229	-12.716	-17.877
R_t (µm)	24.594	26.164	25.764	25.432

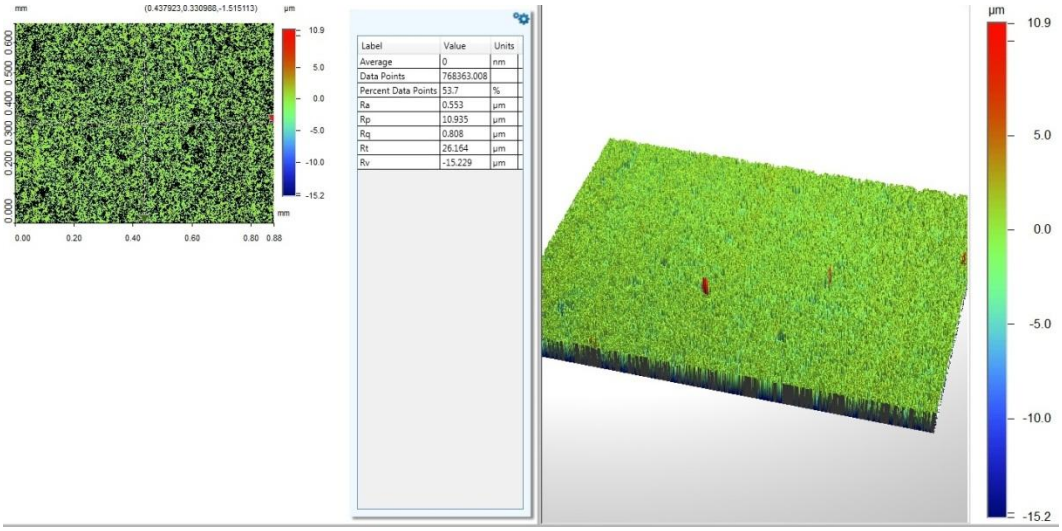

Fig. 2.: Surface finish of sintered Al_2O_3 at 3 µm depth of cut using Non-contact profilometer

Finally, keeping the spindle RPM and depth of cut fixed at 2000 and 3 µm, respectively, the X-stage movement varied in between 10000 and 2500 mm/min. It was noticed that the VSI mode in Non-contact surface profilometer was giving erratic results during measurement of the roughness data of the ground surfaces. Therefore, after the final stage of grinding, the contact type surface profilometer was used and results indicated that the best surface finish was obtained at 5000 mm/min X-stage speed (**Table 4**). However, above that i.e. at 7500 and 10000 mm/min X-stage speed roughness values was also found to be close that of specimen #3 (**Table 4**).

Table 4: Roughness data of sintered alumina after grinding at different X-stage speed

Parameters	1st Sample	2nd Sample	3rd Sample	4th Sample
Wheel speed (RPM)	2000	2000	2000	2000
Depth of cut (µm)	3	3	3	3
X-axis speed (mm/min)	10,000	7,500	5,000	2,500
R_a (µm)	0.173	0.171	**0.165**	0.183
R_p (µm)	0.3866	0.3830	0.3811	0.3971
R_v (µm)	0.6692	0.6573	0.6251	0.7060
R_t (µm)	2.8941	2.5281	3.3136	6.3047

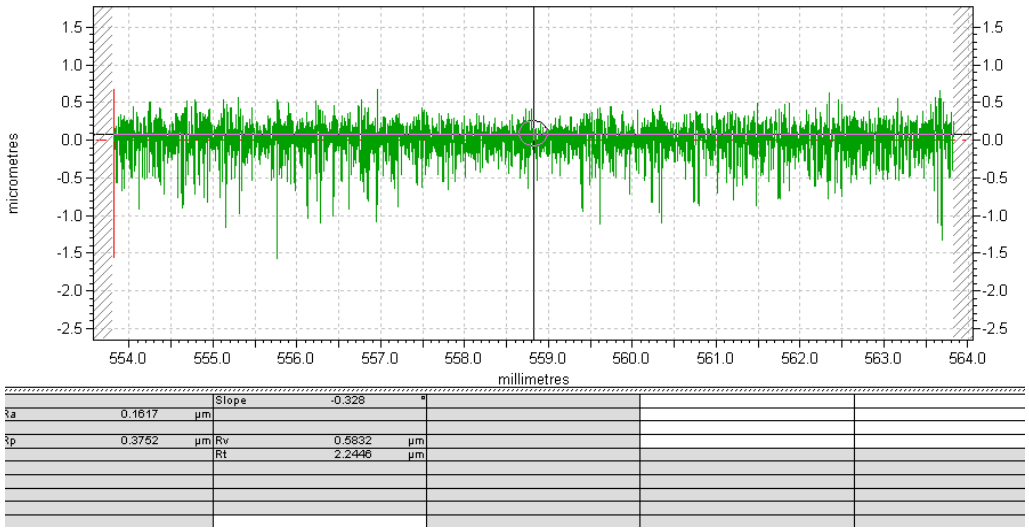

Fig. 3. Surface finish of sintered Al_2O_3 at 5000 mm/min X-stage speed using contact profilometer

4.Conclusion:

After sintering at 1650^{o}C in ambient condition for 2 hours, the Al_2O_3 samples were nearly theoretically dense having negligible open porosity. The machining operation indicated that the best set of input parameters for surface grinding of sintered Al_2O_3 ceramics is

- 2000 rpm spindle speed
- 0.3 µm depth of cut and
- 5,000 mm/min X-stage movement.

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