Micro-Drilling of ZTA and ATZ Ceramic Composit: Effect of Cutting Parameters on Surface Roughness

MICRO-DRILLING OF ZTA AND ATZ CERAMIC COMPOSITE: EFFECT OF CUTTING PARAMETERS ON SURFACE ROUGHNESS

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ABSTRACT: Ceramics are a class of materials widely used during last fifteen years for orthopaedic applications. It is well known that they are characterized by low wear rate, and friction coefficient. However, these materials are very difficult to machine into complex shapes because of their brittleness and high hardness. The most effective method to increase the crack resistance is the formation of a composite structure. This class of materials, composed by two or more different ceramics, can present higher characteristic respect to the single component, like fracture toughness and flexural strength. This paper presents a study of the influence of cutting parameters (cutting speed, feed rate and step number) onto the hole surface roughness and deformation due to the drill operation. The ceramic composite materials AZT (alumina toughened zirconia) and ZTA (zirconia toughened alumina) were first characterized in terms of hardness and roughness. After the drilling test, the holes were analyzed using scanning electron microscope (SEM) and an advanced 3-dimensional non-contact optical profilometer.

KEYWORDS: Ceramic composite, Micromachining, Roughness

1 INTRODUCTION

In the last years there was an increasing use for oxidic materials within biomedical fields, especially in dentistry and prosthetic. However the results have not always met the expectations because of their fragility, causing sometimes the prosthesis failure. For example, Linkevicius et al. [1] have shown how particular ceramic materials exhibit a tendency to fracture when subjected to high compression conditions. For this reason, the need for ceramics showing a good balance between hardness and toughness has increased.

This balance can be achieved by using zirconia-based ceramic, as the tetragonal form of zirconia which has excellent mechanical properties. A good compromise is to use the alumina-zirconia composites as an alternative to pure zirconia.

Two types of ceramic composites can be prepared: the first consisting of a matrix of ZrO_2 reinforced with alumina particles, called AZT (developed for its excellent value hardness-toughness), and the second consisting of a matrix of Al_2O_3 reinforced with particles of zirconium oxide, known as ZTA (developed to substitute alumina ceramics in applications where a higher fracture resistance was required). [2-3]. Despite there is a trend today to develop alumina–zirconia composites as an alternative to monolithic alumina and zirconia, the literature contains few formal investigations of the machining of alumina–zirconia composites ceramic materials as well as no systematic studies on their machining are present.

The paper experimentally investigates the micromachining of green and pre-sintered alumina–zirconia composites. In particular micro-drilling of AZT and ZTA ceramics is investigated making use of a high precision machining centre and micro-drills in hard metal.

In the last years there has been an increasing tendency to the down-scaling of components and systems in different industrial fields (mechanics, biotechnology, electronics, energetics, fluidics, optics, etc…); the miniaturization is needed, first of all, for functional purposes, but it also driven from the necessity of saving materials and energy and, this way, making costs decrease.

As shown in [4] and [5], micro components or features can be produced by means of several process, such as mechanical machining, laser machining, EDM, ECM, ultrasonic machining, injection moulding; among these different process, mechanical micromachining is one of the most widespread since it is very versatile in terms of workpiece material and geometry, it allows to produce objects with a good quality and, at the same time, it has a high productivity.

As confirmed by Masuzawa, microholes are the simplest products of micromachining. Holes with diameter of 200-300 μm can be commonly found in several products (printed boards, fuel injection nozzles, moulds, filters) and recently the challenge has shifted to performing holes with even smaller diameters.

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2 EXPERIMENTAL

2.1 MATERIALS

Two kinds of ceramic composites were considered:

- an yttria stabilized zirconia matrix reinforced with alumina particles, alumina toughened zirconia (AZT);
- an alumina matrix reinforced with zirconia particles, zirconia toughened alumina (ZTA).

The following raw powders "ready to press" were used:

- for ZTA the granulated powder was an Alumina composite (pure at 99.99%), (84% in weight of Alumina, 16% of Zirconia);
- for AZT the powder was a composite of Zirconia with 20% in weight of Alumina (Tosoh Corporation: ZrO_2-20%Al_2O_3, TZ-3Y20AB).

In both cases, the zirconia powders contain 3 mol% of Yttria (~ 4 wt %), required to stabilize the tetragonal zirconia during the sintering, and traces of other compounds.

Green samples were produced utilizing an Uniaxial Pressing at low pressure, around 49 MPa; afterwards, the samples were subjected to Cold Isostatic Pressing (CIP) at a pressure of 245 MPa for 1-2 minutes in order to obtain the presintered one.

The forming phase was carried out in moulds of proper dimensions to obtain final green compacts of 33x33 mm, thickness 11 mm with parallel surfaces.

Before the drilling operation, the surface were levelled with a 6 mm diameter mill. Cutting conditions: n = 3978 rev/min; V_f = 300 mm/min; V_c = 75 m/min.

The composite materials were analyzed by means of SEM ZEISS EVO 50xvp equipped with source LaB_6 in order to evaluate the microstructure surface. The specimens were mirror polished with diamond suspensions and proper disks, in order to progressively reduce the roughness up to 0.025 µm, so that the roughness sample surface is suitable for the microhardness tests.

Vickers microhardness, for the presintered composite materials, was determined by a FISCHERSCOPE HM 2000 XYm (Fischer, NIS-University of Turin, Turin, Italy) with WIN-HCU software. It's a computer-controlled measuring system for microhardness testing and determination of material parameters according to the standard ISO 14577 [6].

Ten indentations were made to account for the scatter caused by residual porosity or foreign particles. Each test was performed to give a cycle with the same rates on loading and unloading, using the following conditions: Peak load of 1000 mN, loading rate of 50 $mN\cdot s^{-1}$.

2.2 MICRODRILLING

The drilling experiments were carried out on the KERN Evo 5 axis high precision machining centre available at the "MI_crolab" of the Dipartimento di Meccanica of Politecnico di Milano, whose main characteristics are listed below.

Micro drills made of hard metal, with a diameter of D = 0.5 mm, were used.

Surface roughness was measured with a non contact profilometer Talysurf CCI 3000Å using a metered cut-off length of 0.8 mm. Surface roughness readings were taken in three different positions inside the hole and the average was taken for the analysis. After data collection the image data was levelled to remove slope caused by tilting of the tablet surface using a data-analysis programme Talymap. From the three-dimensional analysis, the roughness parameters Sa, Ssk and Sku were extrapolated.

The skewness parameter Ssk is a measure of the asymmetry of surface deviations about the mean plane. It can be a good indicator of the presence of peaks or pits of a surface, while Sku, (*Kurtosis)* is a measure of the "spikiness" of the surface, or the distribution of spikes above and below the mean line. For spiky surfaces, Sku > 3; for bumpy surfaces, Sku < 3; perfectly random surfaces have kurtosis of 3. Kurtosis is also a measure of the randomness of surface heights. [7]. Two parallel series of holes have been produced. One was necessary in order to evaluate the hole circularity, while the other one has been milled to half in order to estimate the internal roughness.

The holes deformation has been evaluated by means of the "noncircularity" parameter, which has been calculated measuring by the SEM the holes diameter 4 times every 45° and then subtracting the minimum value from the maximum one.

2.3 DESIGN OF EXPERIMENT

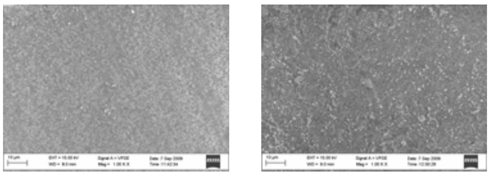
The factors whose effect is intended to be studied are the cutting speed V_c , the feed rate f and the number of steps (named "step") which are necessary to complete the hole depth with the "peck drilling" strategy; in order to reduce the number of tests to be done and, at the same time, to be able to estimate the data variance, a 2^{3-1} factorial plan with 4 central points has been chosen. The following table shows the experimental design, used both for the tests on ZTA and for those on AZT.

Table 1: *Experimental design.*

Run order	V_c [m/min]	f [mm/rev]	step
1	50	0,02	2
2	50	0,02	2
3	25	0,03	1
4	75	0,01	1
5	25	0,01	3
6	75	0,03	3
7	50	0,02	2
8	50	0,02	2

3 RESULT AND DISCUSSION

For sake of brevity only the morphologies of the AZT composite are shown in Fig. 1 (a) and (b), referred to green and presintered respectively. The SEM images show that the alumina and zirconia particles were uniformly distributed and closely packed in the green and presintered body without surface defects, such as crack, void and particles pull-out.



a) b)

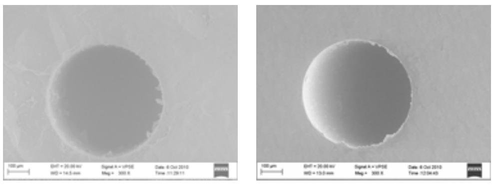
Figure 1: *SEM image of a) AZT green and b) presintered*

Tables 2 shows the micro hardness and young modulus of AZT and ZTA presintered samples.
Analysing the hardness of the composite materials can be seen that ZTA presintered sample has a high hardness respect to AZT.

Table 2 *- Microhardness and Young's modulus for ZTA and AZT*

	AZT	ZTA
HV_{L-D} [N/mm^2]	1744± 27	2241± 15
E_{IT} [GPa]	266± 2,5	348± 2,5

Fig. 2 shows the ZTA green and presintered sample holes performed with *Vc* = 75 m/min, f = 0,01 mm/rev, step = 1 (test n°4). The others hole images are not reported for sake of brevity. As can be seen from the SEM images, the holes shape is regular, in both case, with some debris material left inside the hole. Debris mainly consists of small drops of AZT and ZTA composite material. Considering the area around the hole periphery, a little chip was found for the presintered composite material, which was not found around the green one. This phenomena depends on the type of chip. In fact for the green samples only powder was found, while for the presintered one, the microdrilling operation causes the production of flakes.

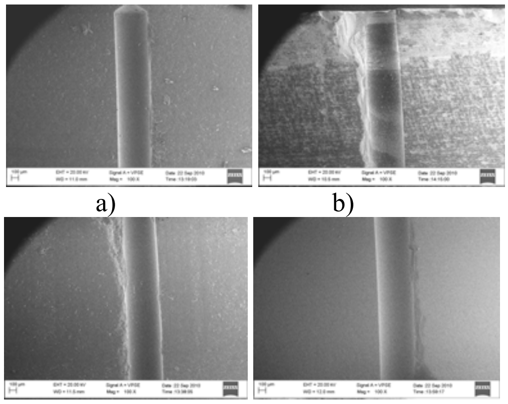


a) b)

Figure 2: *SEM image of a) ZTA presintered and b) green area 4*

Figure 3 shows the cross-sections of a) green and b) presintered ZTA and c) green and d) presintered AZT holes for the area 4. As can be noticed from the picture below, a barrelling phenomenon, which defines how parallel-sided is the hole, was not found for the cross section of all the ceramic composite.

As can be notice from the picture below, the ZTA presintered and AZT green and presintered, show a split along all the cross sections. This phenomena was due to milling operation necessary to investigate the internal roughness.



a) b) c) d)

Figure 3*: Cross-sections of the ZTA a) green and b) presintered, and c) green and b) presintered of AZT holes of the condition n°4.*

Figure 3 shows a three-dimensional analysis of the ZTA composite hole.

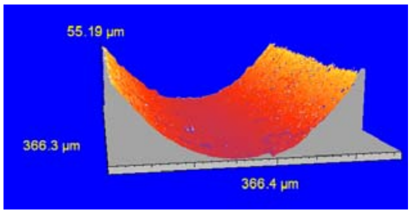


Figure 4: *3D surface roughness profiles of AZT green hole*

In order to study the influence of cutting parameters on the hole roughness and circularity, the ANalysis Of VAriance (ANOVA) has been performed on Sa, Sku, Ssk and noncircularity data for both ZTA and AZT, green and presintered. For sake of brevity the whole analysis and its verifications are not shown and only results are presented.
As concerning both green and presintered ZTA, there is no statistic evidence that any cutting parameter influences all roughness parameters Sa, Ssk, Sku; as regarding noncircularity, only in presintered ZTA it is influenced by *f*.
As regarding green AZT, Sa is influenced by “step” factor while Ssk, Sku and noncircularity are not influenced by any cutting parameters. On presintered AZT there is no statistical evidence of an influence of cutting parameters on Sa and noncircularity while Ssk and Sku are both influenced by “step” factor.

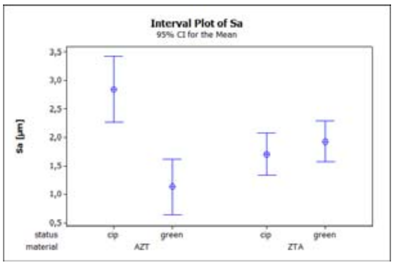


Figure 4: *Sa measurement results.*

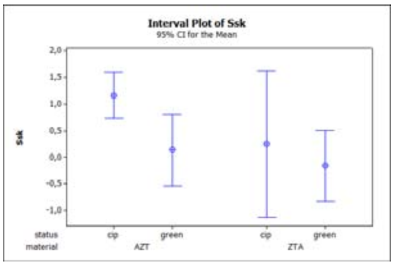


Figure 5: *Ssk measurement results.*

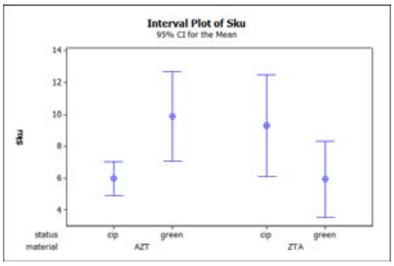


Figure 6: *Sku measurement results.*

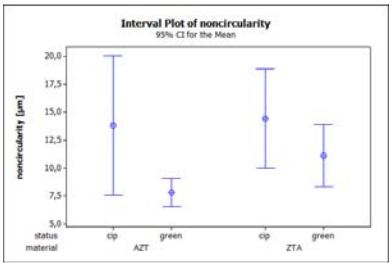


Figure 7: *Noncircularity measurement results.*

An ANOVA carried out on Sa, Sku, Ssk and noncircularity data respect to material type (AZT or ZTA) and status (green or presintered by means of CIP) points out that Sa is statistically influenced by the material status and its interaction with the material type, Sku is only influenced by the interaction between material type and status, no factor has an influence on Ssk while material status has an influence on the noncircularity.

4 CONCLUSIONS

An investigative analysis of parametric influence on surface roughness in micro drilling operation of AZT and ZTA green and presintered ceramic composite has been presented in this paper. The influence of drilling parameters was validated through analysis of variance (ANOVA).

As a result of drilling test the following points have been noted:

- Damage around the hole caused by microdrilling operation are less for the green ceramic composite respect to the presintered one.
- Comparing the Sa parameter, a lower value for green AZT composite was found.
- The Kurtosis (Sku) parameter is for all the materials higher than 3, means that is representative of a surface with valleys and less peaks.
- Also for skewness value (Ssk), the surface is characterized by high valleys. In fact the values are higher than zero. Only ZTA green presents negative value.
- Comparing the micro hole roundness of all the ceramic samples, a lower value for the green one was found and in particular for the AZT one.
- As for the ANOVA analysis, only the AZT green sample presents an evident influence of machining operation onto the roughness parameters. In fact drilling with one step, the surface roughness presents lower value.

REFERENCES

[1] T. Linkevicius, E. Vladimirovas, S. Gybauskas, A. Puisys, V. Rutkunas, 'Venner Fracture in Implant-Supported Metal-Ceramic Restorations: Part I: Overall Success Rate and Impact of Occlusal Guidance', Stomatologija - Baltic Dental Maxillofacial J. 10 (2008) 133-139

[2] S. Martorana, A. Fedele, M. Mazzocchi, A. Bellosi, Surface coatings of bioactive glasses on high strength ceramic composites, Applied Surface Science 255 (2009) 6679–6685

[3] A. Nevarez-Rascon, A. Aguilar-Elguezabal, E. Orrantia, M.H. Bocanegra-Bernal,' On the wide range of mechanical properties of ZTA and ATZ based dental ceramic composites by varying the Al2O3 and ZrO2 content, Int. Journal of Refractory Metals & Hard Materials, 27 (2009) 962–970

[4] L. Alting, F. Kimura, H.N. Hansen, G. Bissacco. "Micro engineering". CIRP Annals - Manufacturing Technology. 52 (2003) 635-657

[5] T. Masuzawa. "State of the art of micromachining". CIRP Annals - Manufacturing Technology. 49 (2000) 473-488

[6] ISO 14577, Metallic materials – Instrumented indentation test for hardness and materials parameters, Switzerland: International Organization for Standardization, Geneva; 2002

[7] E.S.Gadelmawla, M.M.Koura, T.M.A. Maksoud, I.M.Elewa, H.H.Soliman, ' Roughness parameters' Journal of Material Processing Technology, 123(2002)133-145.