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MACHINING OF QUARTZ SINGLE CRYSTAL USING MICRO GRINDING TOOL.

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Abstract. *The single crystals are attractive materials due mechanical characteristics. Comparing to steels, it has a regular atomic arrangement, dimensional stability at high temperatures and low weight. The challenges related to this material are the machinning process. It is a anisotropic material, with high surface hardness and brittleness, demanding specific cutting conditions and parameters. Piezoelectric single crystals are mainly represented by Quartz (SiO2), which currently has two major applications: resonators for electronics and sensors (load and inertial sensors). The Quartz single crystal is traditionally machined by abrasive (blade or belt/wire) and ultrasonic machining. This study aims to investigate the surface finish of Quartz single crystal plane X, using a micro grinding tool (a micro milling tip). It is not a common application for machining the Quartz, but it has advantages when applied in the construction of micro prototype piezo sensors or actuators, mostly due to the cost, because it is not necessary to invest in a ultrasonic process. In addition, the grinding tip enables the fabrication of more complex geometries when compared to other abrasive processes. The methodology to evaluate surface finish in this study starts on three process parameters: tool rotation speed, tool feed rate over the workpiece and depth of cut. The grinding tool will generate channels on the Quartz and the surface average roughness and crack dimension will be aim of the analysis. Preliminary results indicates it is not a high productivity technique. Tool cleaning and cutting lubrication play an extremely important role in tool life application for hard materiais.*

Keywords: *micro grinding tool; Quartz; machining.*

1. INTRODUCTION

The machining of hard and brittle materials is a very commom subject in micro electromechanic industry and micro machining research. Silicon and Germanium were the materials with main application in microprocessors. It is a very well developed segment, with a high production (Madou, 2011).

But from 2000s, different materials, compositions and design were getting place. The main reason is the massive application of micro sensors in mobiles, medical monitoring patients, wearing sensors, vehicle applications and power transformation. The development of more reliable manufacturing processes contribute directly to the development of new micro components and applications (Carazo, 2016).

The single crystals are attractive materials due mechanical characteristics. Comparing to steels, it has a regular atomic arrangement, dimensional stability at high temperatures and low weight. The challenges related to this material are the machinning process. It is a anisotropic material, with high surface hardness and brittleness, demanding specific cutting conditions and parameters. Piezoelectric single crystals are mainly represented by Quartz (SiO2), which currently has two major applications: resonators for electronics and sensors (load and inertial sensors). The Quartz Single Crystal is traditionally machined by abrasive (blade or belt/wire) or ultrasonic machining, as described by Kirsch *et al.* (2017) and Sharma *et al.* (2022). The micro abrasive milling and drilling are getting evidence with the miniaturization of products. The products, previously manufactured by a macro scale abrasive process, move to the micro scale, bringing the process together. Aurich *et al.* (2019) explains there is a demand for an investigation of the abrasive mechanisms in a small scale material removal processes. The abrasive machining is not scalable to a reduced scale.

The main objective of this study is follow the investigation of different abrasive tool applyed in the machining of Quartz Single Crystal, presenting preliminar results from abrasive milling.

The process of dicing using abrasive blades were investigated by Araujo *et al.* (2018). The next step of this investigation, a precision machine was constructed, combining the process manfacturing of dicing, milling and drilling. The project was funded by CNPQ. The results presented in this article are from this new equipment.

2. METHODOLOGY

In this segment, it is presented materials and methodology applied in this experimentation of abrasive milling applied in Quartz Single Crustal.

2.1 The Machine and tool.

The machine applied in this process was developed at the Departamento de Engenharia Mecânica (DEMec), from Universidade Federal de São Carlos (UFScar), funded by a CNPQ Universal research fund 2018-2022 (CNPQ process: 434480/2018-5). The equipment, named as C3L version 01, is a combination of three different process in only one system: dicing, milling and drilling (Figure 1). The machine consiste in a X, Y, Z table and a Theta in the spindle. Exactly in the Toll Center Point (TCP),

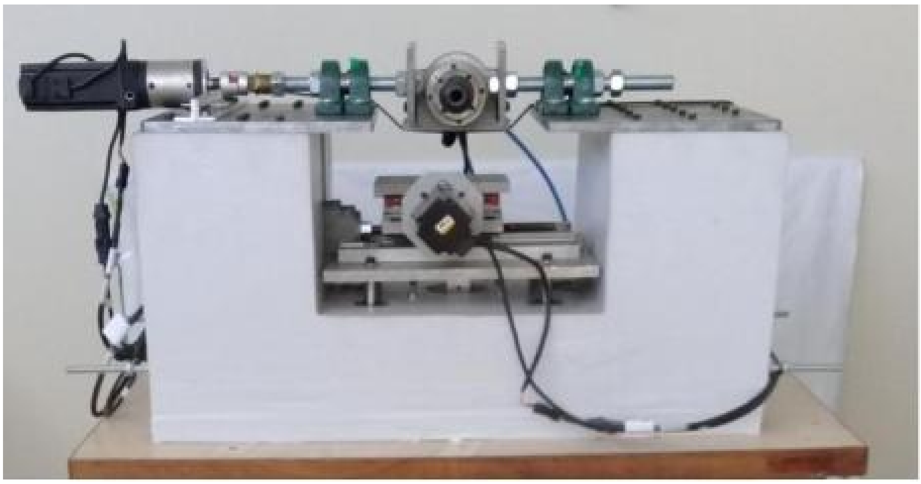


Figure 1. Picture of the machine C3L. CNPQ Universal research funding 2018-2022.

The spindle is a 24.000 RPM, maximum (TECMAF, model TLO-80-2,2-20, power: 3CV). The general theorycal resolution of X, Y, Z table is 0,00056 mm, using a DELTA INC., as servo motor system.

The tool (an micro abrasive griding) applied was manufactured in Brazil, by OSG Dental Division, model: OSG AG AD2 Diamond Diameter 1,4mm. Figure 2a rings an visual example of the apperance. Figure 2b is a micro perfilometry of an OSG dental model OSG AG AD2, diameter 1,4 mm. The perfilometry was made in a Alicona Infinite Focus SL. The idea was to characterization of the tool according with grain size. The perfilometry indicates a range of grain size, from 80 - 180 μm.

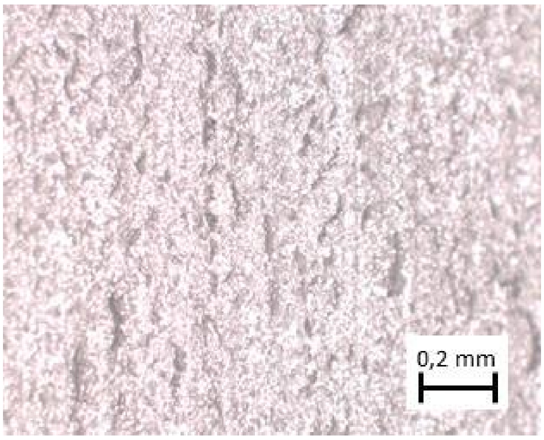
a) b)

Figure 2. In a) picture of the OSG dental model OSG AG AD2, diameter 1,0 and 1,8 mm. In b) a micro perfilometry of an OSG dental model OSG AG AD2, diameter 1,4 mm.

2.2 The Specimen: Quartz Single Crystal.

The specimen to be machined was a Natural Quartz Single Crystal obtained by the process of abrasive tape, (EXAKT 300) according with the Figure 3a. The piece obtained did not receive any extra process to change surface riughness. The surface was analysed in a optical microscope 20x (Figure 3 b) and a perfilometry, made in a Veeco, Wyco NT110, brought the roughness (Ra) of 0,91μm (Figure 3c). The Figure 3c is the specimen attached in a glass by a ThermoPlastic Quartz Cement, modelo Lakeside n° 70. The glass plays the role of a machining surface. It is a sacrificial surface, because tool can also machine it. The aim is just use a surface that could keep the specimen in positiob during machining.

a)



b)

c)

d)

Figure 3. En a) the abrasive tape process of cutting Natural Quartz Single Crystal. In b) an optical evaluation of surface irregularities. In c) a perfilometry to quantify the surface roughness, and d) the specimen assembled in a machining surface, ready to be operated at C3L.

2.3 The plan of manufacturing and the method to evaluate chipping and cracking size.

The methodology to evaluate surface finish in this study starts on three process parameters: Tool Rotation Speed (TRS), Tool Feed Rate over the workpiece (TFR) and Depth of Cut (DC). The grinding tool will generate channels (named as Lines) on the Quartz specimen and, the surface average chipping and cracking dimension were the aim of the analysis.

As preliminar plan, two combinations of parameters were defined to reach a square geometry (Table 1). The objective is obtain an square with 3,65mm each side.

Table 1. Parameters defined for the experiment.

	Tool Rotation Speed (TRS)	Tool Feed Rate over the workpiece (TFR)	Depth of Cut (DC).
Line 0	18.000 RPM	0,5 μm/revolution	1,5 mm
Lines 1 and 2	18.000 RPM	0,5 μm/revolution	1,5 mm
Lines 3 and 4	18.000 RPM	50 μm/revolution	1,5 mm

The Figure 4 ilustrates the maching plan (strategy).

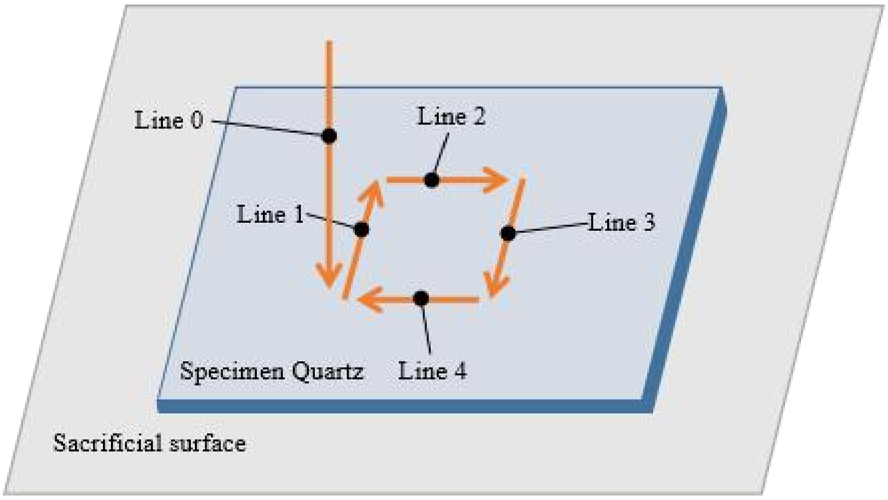


Figure 4. Machining plan (ilustration).

A specific methodology was developed and applied in the quantification of defects by Araujo (2015), from the abrasive dicing process. The main idea was quantify the chipping in a defined lenght and a standard magnify. In this study, the same method was applied (Figure 5).

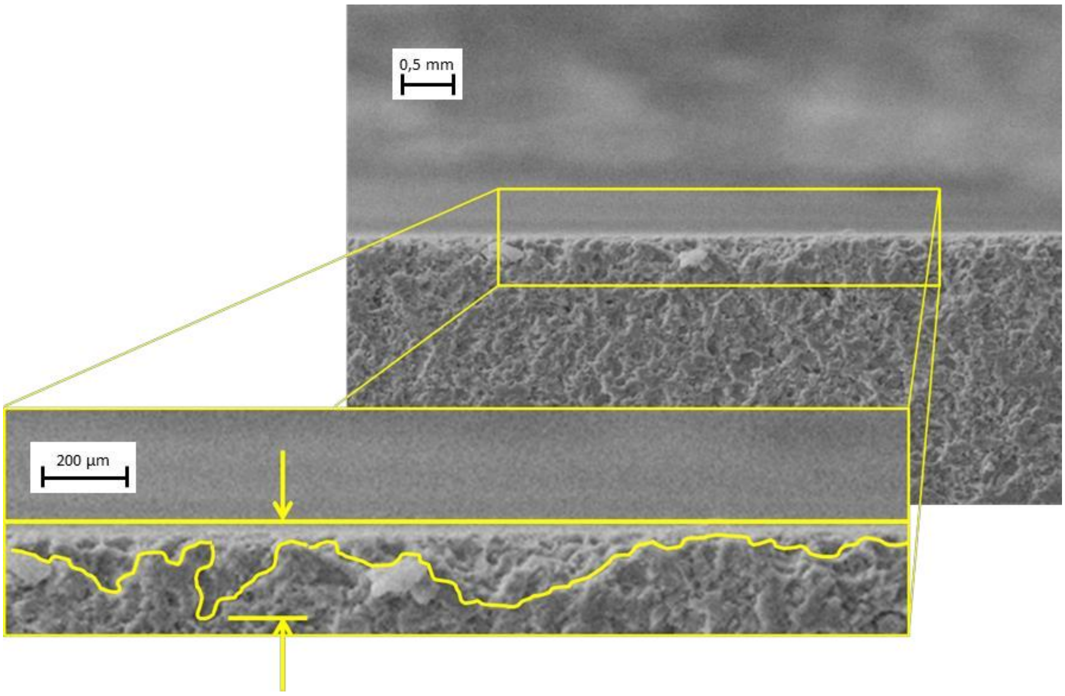


Figure 5. The method to evaluate chipping and cracking dimensions (Araujo, 2015).

After follow the strategy of machining, the expectation was obtain chipping in majority.

3. RESULTS

During the experimentation, two unexpected facts occured: first, the abrasive tool got impregnated by a mix of removed Quartz and the Tthermoplastic Quartz Cement used to attached the specimen to the machining surface. The Figure 6a ilustrates the apperance of the tool after initial drilling.

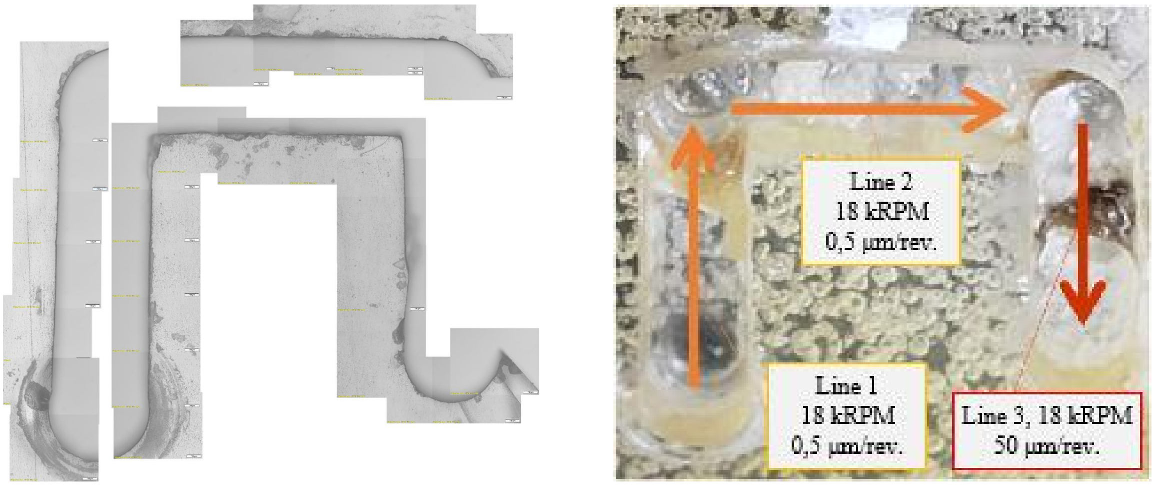
Second, the abrasive tool breacked during Line 3 (Figure 6b). There are some hypothesis to explain this fact. It is at the Conclusion section.

a) b)

Figure 6. The two unexpected facts: first, in a), the abrasive tool got impregnated by a mix of removed Quartz and the Tthermoplastic Quartz Cement. In b) the abrasive tool breackes during Line 3.

After experimentation, it was possible to find chipping and cracks. The chipping occurs in the majority, and in a large range of size. The cracking occur during Line 3. It was also possible to find distorsions of form, as straighteness and flatness of the channels generated by the abrasive tool.

The Figure 7a is a visual overview of the result from experimentation. The magnification was 10x in an optical microscope Olympus. The perfilomey using the Alicona Infinite Focus SL, didn´t bring good results because the specimen is translucid. In Figure 7b, it´s possible to see the specimen, after experimentation and still attached to the substrate.



a) b)

Figure 7. In a), an optical microscope imagem from the machined specimen. In b), a picture from the machined specimen.

The methodology of quantification the dimensions of chipping was applied in Lines 1, 2 and 3. The Lines 1 and 2 were analysed in 4 Sectors, as presented in Figure 8. The Line 3 was analysed in just one side of the channel.

An average of the 10 longest chips in each Sector were made and listed in Table 2.

Table 2. Medium chipping obtained from experimentation.

Line1.Sector1	99 μm	Line2.Sector1	32 μm	Line3.Sector1	28 μm
Line2.Sector2	16 μm	Line2.Sector2	41 μm	Line3.Sector2	17 μm
Line3.Sector3	19 μm	Line2.Sector3	100 μm	Line3.Sector3	---
Line4.Sector4	7 μm	Line2.Sector4	19 μm	Line3.Sector4	---

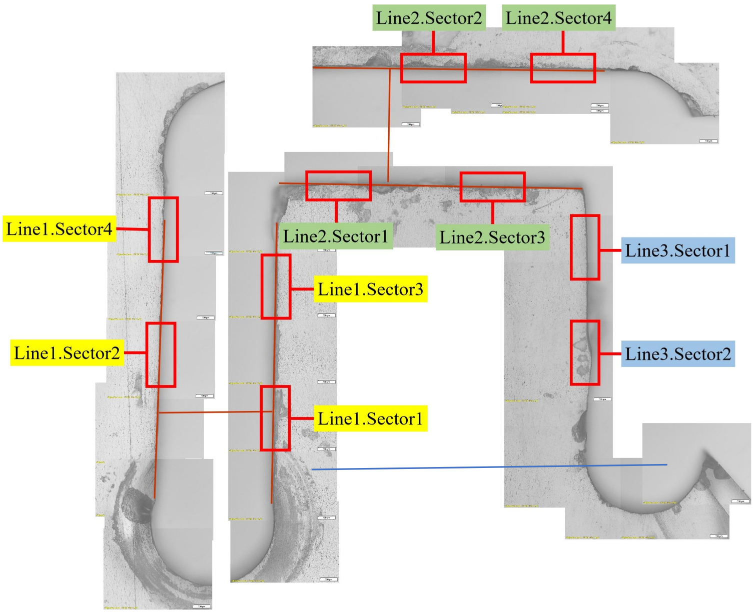


Figure 8. The Sectors analysed in each Line.

4. CONCLUSIONS

The main conclusion obtained from the experiment is: the methodology applied in the experimentation indicates higher chipping in Line 2. The Line 2 has results above 19 µm, but Line 1 has 3/4 of the results below 19 µm. The results are unexpected, if we consider the same parameters, just changing the cutting direction.

Based on this, there some hypothesis to explain this effect. First, there is a large possibility of the abrasive process removal mechanism did not work properlly. Probably because of saturated pockets with Quartz and also the adesive applyed to attache the specimen to the machining surface. The pockets are the empty space between abrasive grains. The abrasive process removal mechanism use those pockets to transport the removed material, from removal areal to discard area. A fluid must be applyed to clean the pockets and also, reduce temperature). Figure xxx ilustrates de saturation of the abrasive tool.

This hypothesis also explain the distorsions of form, as straighteness and flatness of the channels generated by the abrasive tool.

Second, the surface finishing of the Quartz could be better. The specimen was obtained by a abrasive tape cutting process, without later operations, as grinding or lapping to reduce roughness.

Third, the abrasive tool was too long and it could impact in flexural effect. According with the manufacturer (OSG), those tools are applied in the machining of Zirconia Implant Prosthesis. Those specimens are pre sinthered.

Aditional conclusions are: preliminary results indicates it is not a high productivity technique (abrasive milling of Quartz Single Crystal). The TRF=0,5µm/revolution means 10mm per minute (with a TRS=20.000 RPM).

Equipment must be improved in the operation of cleaning tool.

A better design of tool must be investigate to reduce flexural effect.

5. ACKNOWLEDGEMENTS

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