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Research paper

Study of Dental Zirconia Milling Using Rotary Ultrasonic Machining

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Abstract

The main objective of this study is to investigate the influence of spindle speed on the surface roughness (Ra) of dental zirconia during Rotary Ultrasonic Machining (RUM) and traditional milling. The spindle speed set at range 2000- 6000rpm, with constant feed rate, frequency, and depth of cut for both RUM and traditional milling. The results show that when the spindle speed at 6000rpm, frequency at 23 kHz, feed rate at 50mm/min and cutting depth of 0.025mm created the best outcome of Ra with value of 0.182 µm. The maximum differences in Ra value between RUM and traditional milling is 42% at spindle speed of 6000 rpm.

Keywords: *surface roughness, traditional milling, dental zirconia, spindle speed.*

1. Introduction

Zirconia dental implants presents a great stability in mechanical properties and a great biocompatibility because of their small electrical and thermal conductivity, without considering the biodegradation and negligible reaction with the surrounding biological environments [1].One of the main drawbacks of dental zirconia is its limited processing capability with respect to milling its surface roughness. It would be more desirable to prepare the surfaces of dental zirconia in micrometer scale of roughness, as well. The limitations in preparing such dental zirconia surfaces emanates from two prevalent challenges:

- The limited success of abrasive procedures.
- The probability of strength reduction of the roughened material [2].

On the other hand, preliminary adhesion ideally begins at spots where bacteria is shielded from shear forces thereby making transformation from reversible to permanent attachment much more easier. For irregularities on the surface, bacteria is able to survive for longer durations due to the shelter from natural removal forces and oral hygiene measures. Furthermore, action taken to make the surface more rough creates a larger surface area for bacterial adhesion [3].

To solve this problem a new strategy is applied for machining the dental zirconia with minimum surface roughness. RUM is regarded as an efficient and cheaper machining method applicable to several critical engineering applications. RUM is a hybrid machining process which is comprised of material removal mechanisms used in diamond grinding coupled with ultrasonic machining (USM) so as to improve material removal rates (MRR) more than those of diamond grinding and USM machining processes separately. Additional benefits of RUM involve exceptional surface finishing and minimal pressure of the tool [4]. The selection of the RUM parameters levels for machining dental zirconia ceramic established on the premise of the desirable attributes identified during the literature survey. The pioneers in using RUM for ultrasonic milling were Pei et al. [6] in 1994. In their study, they developed the implementation of RUM from its conventional application in drilling operations to face milling of ceramics. The parameters applied in the study fell in the following range: rotational speed of 1000 to 3000 rpm; vibration amplitude of 0.023 to 0.033 mm; cutting depth of 0.1 to 1 mm and the feed rate in range of 0.381, 0.762, 1.524, 3.048, 6.096 mm/min. An investigation of the RUM process by Hu, et al. [7] using diverse rotational speeds (ranging from 1000 to 3000 rpm) and witnessed there is no major effect of ranging rotational speed on MRR. The study by Hochengand Kuo, [8] of the process of ultrasonic drilling for zirconia ceramic was conducted by altering the amplitudes of vibration between 40%, 50%, 60%, and 70% culminating in the conclusion that vibration amplitude of 70% offers the greatest value of MRR. Diverse cutting depths from (10 to 50 µm) and the feed rates from100 to 500 mm/min were also explored by Lauwers et al. [9]. The outcome of the study led to drawing the conclusion that a 100mm/min of feed rate results in minimal cutting force when machining ZrO2 utilizing ultrasonic aided the grinding method.

In the light of the knowledge acquired amidst the literature surveyed, this study sets out to scrutinize the influence of spindle speed variation on the surface roughness using both RUM and traditional milling processes with the same cutting conditions.

2. Experiment details

Computer control machines are used in this experiment. HAAS VOP-C with maximum 7000 RPM. Although this machine is fully automated, for this experiment it only uses manual data entry. This is because these experiments require simple movements. The experiment was conducted using a ball nose end mill insert with a 16 mm diameter which had the following characteristics: WC-10%

Co with PVD of multilayer coating with TiAlN/AlCrN; radial rake angle 0°; relief angle 11°; axial rake angle -3°. Zirconia ceramic was the work piece material used in this study. It is a vital element in a great deal of industrial applications including mechanical components (e.g., cylinder head gaskets and high pressure pumps) in addition to molds and die inserts. The high fracture toughness property of Zirconia ceramic, its hardness, lower malleability and intensity also makes it characteristically one of the most difficult materials to cut. The properties of a 40×20×16 mm Zirconia ceramic work piece are depicted Table 1.

Table 1: properties of work piece material [5]

Property	Value
Tensile strength (MPa)	448
Melting point (K)	2973
Thermal conductivity W/(m×K)	18-3.0
Density (Kg/m3)	6000
Young's modulus (MPa)	205000
Vickers hardness (GPa)	12.5
Poisson's ratio	0.31

The machining parameters were selected to be cutting speed of 2000 – 6000 rpm, a feed rate of 50mm/min, depth of cut at 0.025mm and frequency of 23 kHz.
Mitutoyo Surftest SJ-301 was used for the measurement of the surface roughness of the workpiece (Fig. 1), which is a stylus form surface roughness measuring device that have the capability of measuring surface texture with a wide range of parameters according to several international standards. The measurement results are displayed digitally on the touch panel and graphically printed with a built-in printer. The stylus of the SJ-301 detector device records the minimal surface irregularities of the work piece .the surface roughness is concluded from the vertical stylus displacement generated in the course of the detector pass through over the irregularities of the surface.

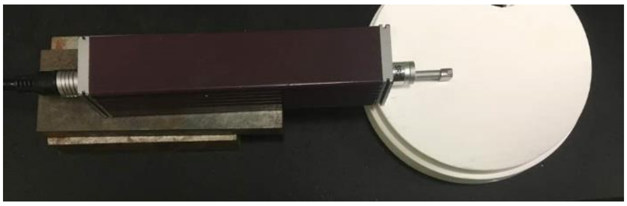

Fig. 1: tester of surface roughness

A comparison was made between RUM and traditional milling for the same cutting parameters to explore the impact of disparate cutting speeds on the surface roughness of dental zirconia.

3. Results and discussion

The influence of diverse cutting speeds on the surface roughness of dental zirconia during Rotary Ultrasonic machining and traditional milling is illustrated in Figure 2. The outcome of the evaluation revealed that surface roughness decreases as the spindle speed increased from 2000 to 6000 rpm for both RUM and traditional milling. Furthermore, higher tool rotation speeds gave rise to increased overall contact time of the cutting between the work piece and the cutting tool. Subsequently, increased overall contact time of the cutting led to the removal of more materials on the work piece surface.

The minimum value of surface roughness achieved during rotary ultrasonic machining was 0.18 µm of cutting parameters (that is, cutting speed of 6000 rpm, feed rate of 50mm/min, depth of cut at 0.025mm and frequency of 23 kHz) which is much less than the value of surface roughness achieved by Abdo et al. [1].

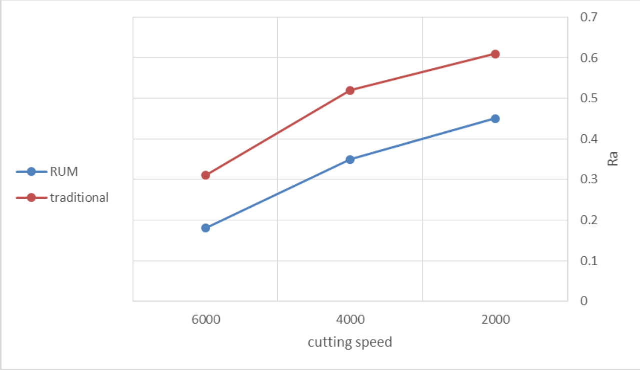

Fig. 2: Impact of diverse cutting speeds on the surface roughness between RUM and traditional milling

The use of rotary ultrasonic machining RUM can significantly cut down the resistance of friction, thereby allowing for the use of a higher milling speed. Nonetheless, the actions of micro-hammering emanating from the RUM operator's vertical oscillation force inadvertently has a negative effect on the surface finish of the work piece. As shown in Figure 3, the RUM produced a lower surface roughness from the traditional machining by 42% at cutting speed of 6000 rpm. While the difference was 26% at low cutting speed (2000 rpm).

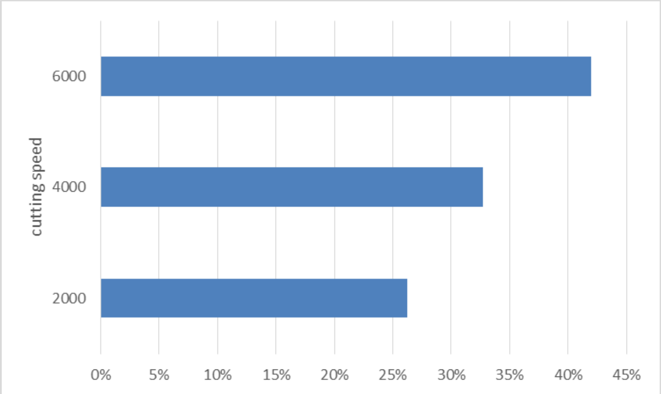

Fig. 1: percent of differences in Ra between RUM and traditional milling

4. Conclusion

1. The cutting speed has the most significant effect on the texture of the surface; surface roughness diminishes with a rise in the spindle speed.
2. The most ideal results were obtained using a combination of cutting parameters with a spindle speed of 6000 rpm, cutting depth of 0.025mm feed rate of 50mm/min and frequency of 23 kHz which produced the minimum value of Ra at 0.182 µm.
3. The maximum difference in the value of surface roughness between RUM and traditional milling was 42% at a cutting speed of 6000 rpm.

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