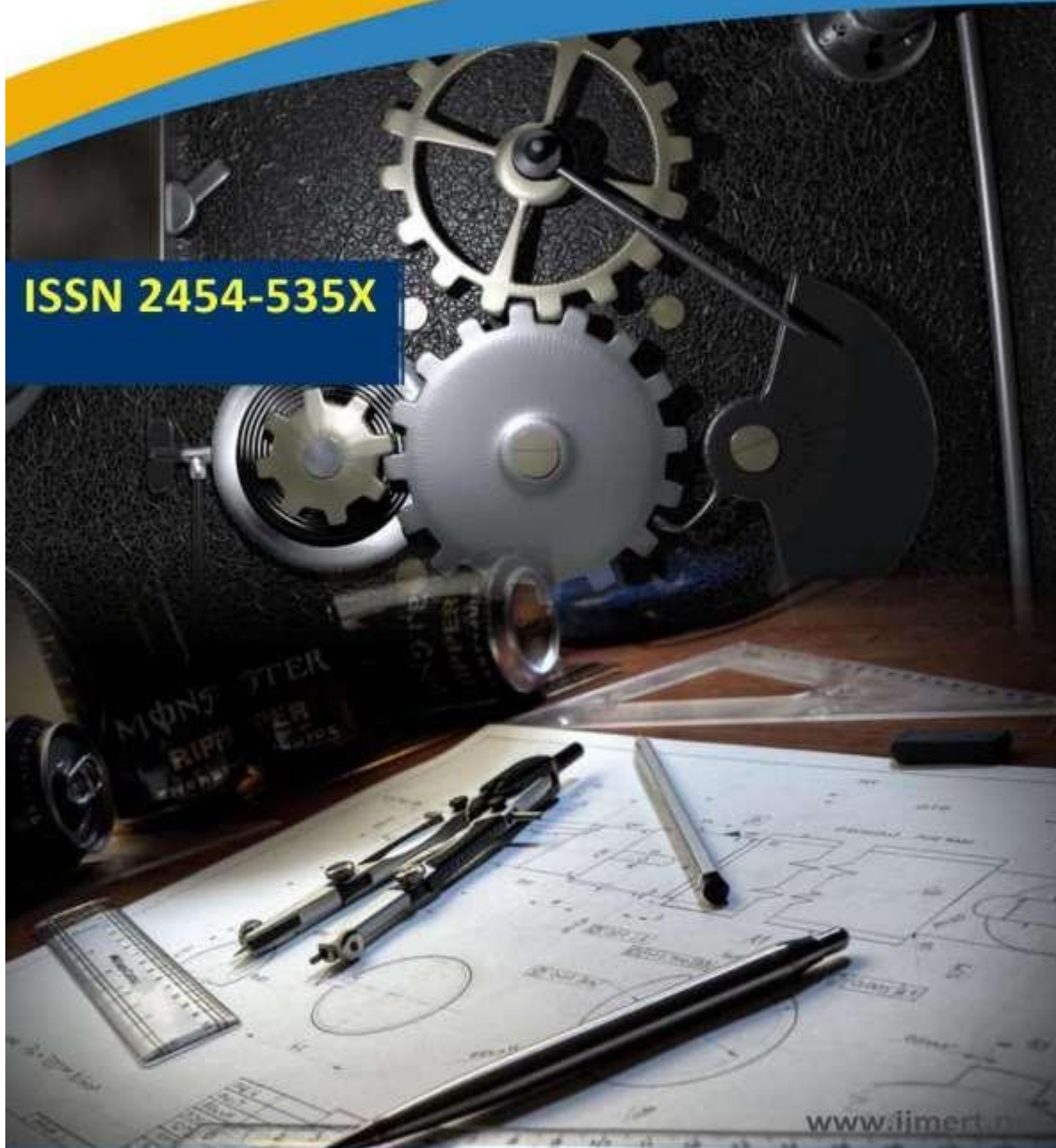




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Surface Roughness Prediction in Rotary Ultrasonic Machining of Zirconia Dental Ceramic Using RSM

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ABSTRACT: This research looks into the variables that affect dental zirconia ceramic's surface roughness after rotary ultrasonic machining. Response surface methodology (RSM) was used in the trials, and Box-Behnken design was used to assess how control factors affected the response. Cutting speed V_c (70, 135 and 200 m/min), feed rate F_z (25, 50 and 75 mm/min), and ultrasonic frequency U_s (20, 23.5 and 27 kHz) were the analyzed control variables. The findings show that the primary factor influencing surface roughness is the combination of the ultrasonic frequency and feed rate. The control variable responses were plotted on a three-dimensional surface graph. The interaction model between the two factors was created. a surface roughness minimum of 0.144

KEYWORDS: Zirconia ceramic; response surface method; rotary ultrasonic machining; surface roughness; optimization

INTRODUCTION

After many years of usage, dental implants are currently regarded as the best way to replace lost teeth and have a clear positive impact on patient care [1].

Zirconia is regarded as a chemically inert material with a low surface energy. Because of this, special surface treatments are needed for the restoration's medical application as a dental prosthesis in order to attach it to the tooth's structure [2]. One of dental

Zirconia's main drawbacks is that it is not easily processed to change the surface roughness. Preparing such Zirconia dental surfaces has two challenges: (i) limited success with abrasive techniques and (ii) potential for decreased toughened material strength [3].

However, the majority of dental ceramics have extremely low fracture toughness and tensile strength. These are

EXPERIMENTAL SET-UP

Computer control machines are used in this experiment. HAAS VOP-C with a maximum of 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 multilayer coating ball nose end mill insert with a 16 mm diameter, as recommended by [13]. The workpiece material was a block of zirconia ceramic with a dimension of 40 mm *20 mm *20 mm. 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 the Zirconia ceramic workpiece are depicted in Table 1.

Table 1. workpiece properties

Property	Value
Tensile strength (MPa)	448
Melting point (K)	2973
Thermal conductivity W/(m×K)	18-3.0

Density (Kg/m ³)	6000
Young's modulus (MPa)	205000
Vickers hardness (GPa)	12.5
Poisson's ratio	0.31

Tool wear was taken using an x- and y-axis microscope of a toolmaker with a resolution of 1 μm each.

The surface roughness measurement device is used to measure the surface roughness value. The Mitutoyo SJ 301 model. The ability of this device to measure the value of roughness in Ra, Rz and Rmak units. The data is recorded when the stylus moves on the surface of the specimen.

An experiment with the Box – Behnken approach was undertaken on the response surface methodology (RSM). A total of 17 tests have been conducted.

The machining parameters used for these experiments are shown in table 2. While, the depth of cut was constant at 0.025 mm.

Table 2. process parameters

Control parameters			
Level	-1	0	1
Cutting speed, VC	70 m/min	135 m/min	200 m/min
Ultrasonic frequency, Us	20 kHz	23.5 kHz	27 kHz
Feed, Fz	25 mm/min	50 mm/min	75 mm/min

RESULTS AND DISCUSSION

Measurement of Ra

The results of the experiment showed that a ball nose cutter finishing process can maintain low surface roughness. Ra measured value between 0.184 μm and 0.236 μm , which is less than manual polishing [14].

ANOVA of Ra model

According to ANOVA in Table 3, the two factors interaction model is significant with F-value 16.95 and lower than 0.05 of P-value. Such models influence the response in the design space greatly because of the factors with P values below 0.05. C, AC, and BC are significant terms of the model. Due to its relationship with other variables, Unable to use one individual factor in the evaluation. Insignificant terms like A, B, and AB didn't exclude from the model to prevent a major change in the results of the statistical model.

The interaction between feed rate and ultrasonic frequency with the F-value of (62.65) was the most dominant factor. The curvature form along the parameter shown in figure 1 confirmed this result [15-18].

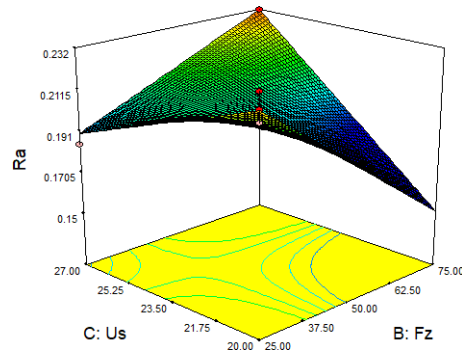


Figure 1. interaction effect of feed rate and ultrasonic frequency on the surface roughness

Table 3. ANOVA of Ra

Source	Sum of squares	Degree of freedom	Mean square	F-Value	p-value	
Model	0.003305	6	0.000551	16.95089	0.0004	significant
A	0.0000851	1	0.0000851	2.61753	0.1443	
B	0.000433	1	0.000433	13.31255	0.0065	
C	0.000513	1	0.000513	15.78478	0.0041	
AB	0.00000025	1	0.00000025	0.007693	0.9323	
AC	0.001066	1	0.001066	32.79679	0.0004	
BC	0.002036	1	0.002036	62.65789	< 0.0001	
Residual	0.00026	8	0.0000325			
Lack of Fit	0.000106	4	0.0000265	0.68808	0.637	not significant

The predicted R² (0.7269) is in a sensible correspondence with the adjusted R² (0.8724). A contrast of an average prediction error and the predicted values of design points demonstrate adequate precision. The desired signal-to-noise ratio of 12,825 is greater than 4. The model developed in the form of actual factors for surface roughness:

$$Ra = 0.24608 + 0.00213871 \times V_C - 0.00818731 \times F_Z$$

$$-0.000950549 \times U_S - 0.00000153846 \times V_C \times F_Z$$

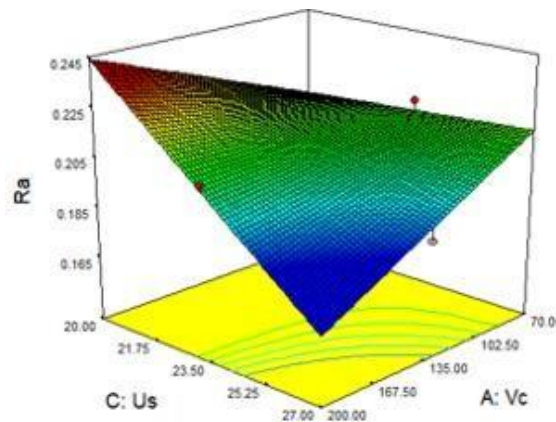
$$-0.0000931554 \times V_C \times U_S + 0.000334776 \times F_Z \times U_S$$

Process variables effect on Ra

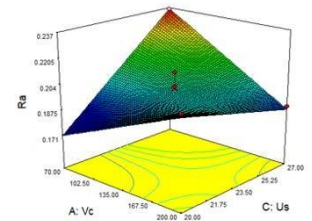
(1)

The interaction of feed rate and ultrasonic frequency is shown in figure 1. The cutting speed was set at 135 m/min. The plot shows that the highest Fz and the lowest Us could achieve the best surface roughness.

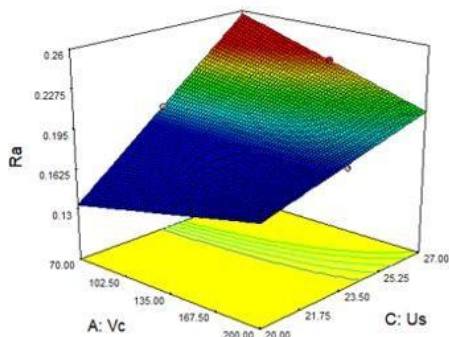
As shown in Figure 2, the interaction effect on surface roughness between the speed of cutting and ultrasonic frequency. Fig 2a shows that the minimum surface roughness could be obtained at the highest cutting speed and ultrasonic frequency when the feed rate at 25 mm/min. otherwise when the feed rate increased to 50 mm/min and 75 mm/min, the minimum roughness of the surface acquired at the minimum cutting speed and ultrasonic frequency, as shown in figure 2b and figure 2c.



(a)



(b)



(c)

Figure 2. the interaction effect on surface roughness between cutting speed and ultrasonic frequency when the feed rate is: a) 25 mm/min b) 50 mm/min c) 75 mm/min

Figure 3 shows the interaction between cutting speed and feed rate and their effect on surface roughness. It is obvious that the minimum value of surface roughness is achieved with the highest cutting speed and lowest feed rate.

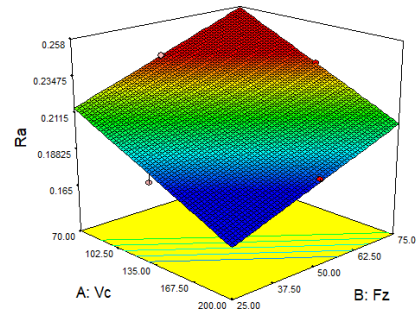


Figure 3. interaction effect of cutting speed and feed rate on the surface roughness

Figure 4a shows that the line is the best fit on the plots at an angle of 45°. It is clear from the plots that residuals are distributed around the most suitable line and affirm the normal distribution of errors. The authentication of the developed models was further checked by placed the graph in different combinations of input variables between the actual and predicted surface roughness values. The plot in figure 4b has interpreted the predicted and the actual values to be fine-tuned; therefore, the predictions of response models with a high level of reliability can be concluded.

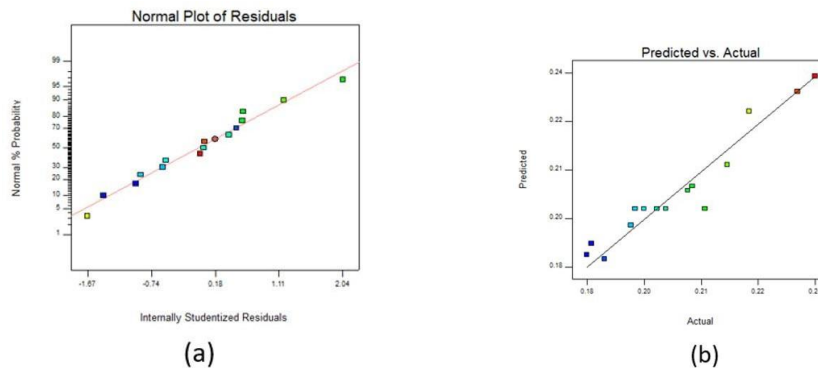


Figure 4. a) normal plot of residuals b) predicted vs. actual

Parameters Optimization

In order to obtain the superior surface finish within preset parameters, optimum conditions must be required for end milling of dental zirconia. The optimum values of the machining parameters are cutting speed 77.45 m/min, feed rate 73.14 mm/min, ultrasonic frequency 20.36 kHz. The surface roughness of 0.144 μm was achieved under such cutting conditions.

CONCLUSION

A number of RSM experiments have been carried out to study the influences of machining

variables on dental zirconia surface roughness during RUM machining. The cutting speed, feed rate, and ultrasonic frequency have been

investigated. It is possible to draw the following conclusions:

- This research has shown that the surface roughness meets the high finishing requirements adequately with Ra values between 0.184 μm and 0.236 μm .
- This study demonstrates that when the feed rate interacts with the ultrasonic

frequency is the main factor affecting surface roughness. This response was not affected by any main factor.

- The optimum cutting conditions were Vc 77.45 m/min, Fz 73.14 mm/min, and Us 20.36 kHz, the best surface finish was obtained.

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