

Optimization of Ultrasonic Assisted Drilling Parameter for Surface Roughness of Ti-6Al-4V using Box-Behnken Method

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ABSTRACT – In engineering practise, process optimization aims to reduce time, costs, and risks. In this study, Ti-6Al-4V material was machined using Ultrasonic Assisted Drilling, and the primary parameters used were cutting speed (Vc), feed rate (Fr), frequency (Fq), and amplitude (Amp) to get the smoothest surface roughness. The Response Surface Methodology (Box-Behnken) was employed as the analysis medium for optimization. The analysis determined that the optimum parameters were Vc 460 rpm, Fr 52 mm/min, Fq 20 kHz, and Amp 2 μm . From the analysis will produce the predicted surface roughness is 1.264 μm . The study also observed that feed rate and frequency are significant parameters in reducing surface roughness.

1. INTRODUCTION

Ultrasonic Assisted Drilling (UAD) is one of the most accurate and versatile drilling techniques because it can produce more precision in machining compared to conventional techniques [1]. However, based on the studies that have been conducted on drilling using Ultrasonic Assisted Drilling (UAD) for Ti-6Al-4V, it is found that most research related to ultrasonic machining is more focused on the manufacturing and rotation process. UAD drilling studies for TI-6Al-4V material are very lacking, mainly focusing on drilling results related to hole accuracy and surface roughness by taking into account the parameters of feed rate, cutting speed, vibration amplitude and frequency [2].

One of the main factors that has been tracked for measuring cutting quality in machining processes is surface roughness. In comparison to low cutting speed and high feed rate, surface roughness was significantly smoother at high cutting speed and low feed rate. At a low cutting speed, certain parallel grooves were created in the hole surface [3].

The drilled hole's surface quality has a direct effect on the final manufacturing performance [4]. While the drilling is carried out, chips will be formed and have the potential to stick to the workpiece and the drill bit. The surface of the drilled hole that has the effect of chip fragments will require a secondary cutting action where the effect will result in damage to the surface of the hole and the surface finish deteriorating [5].

This study used Ultrasonic Assisted Drilling (UAD) machining to optimize the surface roughness of Ti-6Al-4V material using several parameters with different values, including cutting speed, feed rate, frequency, and amplitude.

2. METHODOLOGY

In this experiment, a Ti-6Al-4V plate with dimensions of 8mmx8mmx6mm and a TiN Carbide type tool with 8mm diameter were employed. To make holes, a CNC Machine-HAAS (VF-1) 3-Axis vertical UAD with a BT40 ultrasonic holder is utilised. The MITUTOYO SURFTEST SJ-410 instrument is used to measure surface roughness. For the analysis used Response Surface Methodology (Box-Behnken).

Cutting speed (Vc) (rpm), feed rate (Fr) (mm/min), frequency (Fq) (kHz), and amplitude (Amp) (μm) are the factor parameters employed in this experiment. The surface roughness (Ra) of the hole was investigated. Table 1 shows machining parameters with three levels.

Table 1 Machining parameters

Machining Parameter	Level		
	1	2	3
Vc (rpm)	300	450	600
Fr (mm/min)	16	63	110
Fq (kHz)	20	23.5	27
Amp (μm)	1	2	3

3. RESULT AND DISCUSSION

The results for surface roughness of 29 runs based on Box-Behnken design are graphically presented in Figure 1. The findings showed that for UAD with various parameters, the measured surface roughness values ranged from 0.4581 μm (minimum) to 2.0667 μm (maximum).

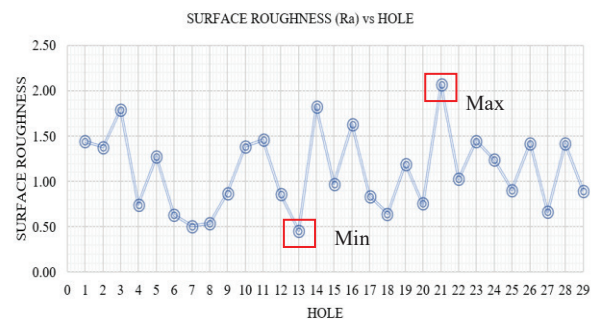


Figure 1 The result of an experiment.

Hole 13 has a minimum surface roughness of 0.4581 μm with the parameters Vc: 450 rpm, Fr: 16 mm/min, Fq: 27 kHz, and Amp: 2 μm . Figure 2 (a) shows that the surface finish of the Ti-6Al-4V material is exceptionally smooth with no damage. Meanwhile, Hole 21 produces the maximum value of surface

roughness of $2.0667\mu\text{m}$ by using the parameters Vc: 600 rpm, Fr: 16 mm/min, Fq: 23.5 kHz and Amp: $2\mu\text{m}$. From Figure 2 (b) shows that the surface finish is rough and uneven.

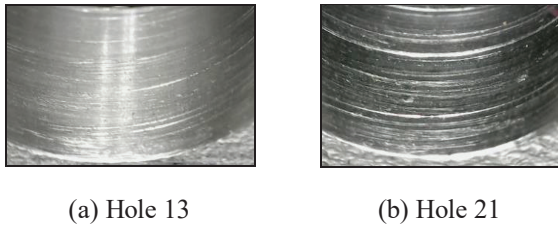


Figure 2 (a) and (b) show the surface finishing for Hole 13 and Hole 21

It can be observed that holes 13 and 21 have the same feed rate and amplitude but different cutting speed and frequency. Hole 13 has a smoother surface finish with low cutting speed and high frequency. This is due to high frequency with high vibration during drilling resulting in minimal contact between the tool point and the workpiece. The heat generated is also minimal compared to high cutting speed and low frequency.

Table 2 ANOVA for Reduced 2FI Model.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1.32	2	0.6623	4.43	0.0220	significant
B-Feed Rate	0.5590	1	0.5590	3.74	0.0640	
BC	0.7656	1	0.7656	5.13	0.0321	
Residual	3.88	26	0.1493			
Lack of Fit	3.32	22	0.1510	1.08	0.5349	not significant
Pure Error	0.5612	4	0.1403			
Cor Total	5.21	28				

Table 2 shows the 2FI model with an F-value 4.43, indicating that it is significant. The probability with this value of F that can occur due to noise is only 2.20%. The model is expressed as significant when the P-values are less than 0.0500. while a P-value above 0.1000 indicates the model is not significant. Therefore, the results of the Box-Behnken analysis for this study indicate BC is significant for this model.

The response surface method is capable to developing a mathematical model which illustrates the relationship of the parameter towards the response. The predicted surface roughness can be calculated by replacing the variable with feed rate (B) and frequency (C). the mathematical model for surface roughness as in Equation (1).

$$\text{Surface Roughness} = 1.11 - 0.2158B + 0.4375BC \quad (1)$$

Overall, the 3D Surface graph in Figure 3 shows the results of experiments conducted for surface roughness with various parameters and analyzed using the Response Surface Methodology (Box-Behnken). Figure 3 also shows the relationship between significant parameters of this study that is feed rate and frequency with surface roughness. A lower feed rate with a lower frequency can increase the value of surface roughness. While, a lower feed rate with higher frequency can decrease the value of surface roughness.

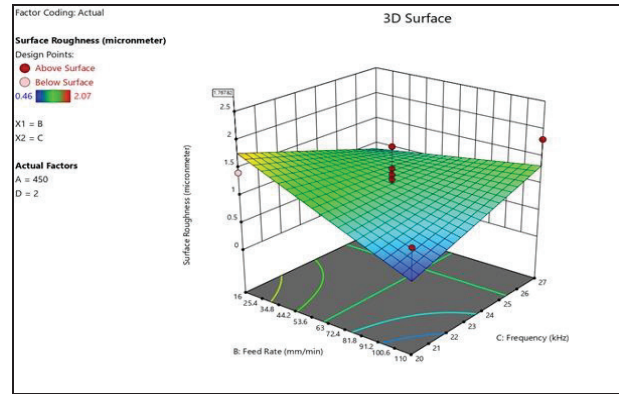


Figure 3 3D Surface for surface roughness.

Optimization parameters for producing a smooth surface finish is a cutting speed of 460 rpm, a feed rate of 52 mm/min, a frequency of 20 kHz, and an amplitude of $2\mu\text{m}$. From the Box- Behnken analysis will produce the predicted surface roughness is $1.264\mu\text{m}$. Validation needs to be carried out to verify the actual value of surface roughness. The low average relative errors of approximately 15% from the predicted value demonstrated conclusively that the model can be accepted.

4. CONCLUSIONS

According to the findings of this study, the best combination of parameters for producing a smooth surface finish is a cutting speed of 460 rpm, a feed rate of 52 mm/min, a frequency of 20 kHz, and an amplitude of $2\mu\text{m}$. The 2FI model from Box-Behnken analysis shows feed rate and frequency are factors that are significant in producing smoother surface roughness.

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