MACHINABILITY ULTRASONIC ASSISTED MILLING OF INCONEL 718 BY USING TAGUCHI METHOD

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ABSTRACT

Taguchi design was utilized to determine the significant impact of ultrasonic assisted milling cutting parameter performance on Inconel 718 material. An experiment using Taguchi orthogonal array, L9 with parameters namely ultrasonic frequency, feed rate cutting speed and at various cutting condition types was conducted. The cutting condition consist of a new approach of pulsating coolant to be compared with dry and normal flooded. An orthogonal array, Pareto analysis of variance (ANOVA) and signal-to-noise (S/N) ratio were evaluated to ascertain these machining parameters effects. The obtained results indicated that the most significant parameter on the surface roughness was the cooling strategies, followed by ultrasonic frequency, cutting speed and feed rate.

Keywords: ultrasonic assisted milling, taguchi method, surface roughness, pulsating coolant.

INTRODUCTION

Superalloy is commonly utilized in extreme applications because of its good mechanical properties. For example, aerospace industry utilizes 80% usage of Inconel 718 and Titanium. In addition, gas turbine engine utilizes about 45-50% nickel alloys [1, 2]. Inconel 718, a nickel based super-alloy, is commonly utilized in industry for it inherits required properties over a wide temperature range. Despite superalloy's good resistance of corrosion, strong resistance of creep and high strength of fatigue [3,4], it is compromised by strength of shear, strong hardening of work and strength of high temperature tensile which reduce tool life and cause severe damage on work-surface throughout the conventional machining [5].

LITERATURE REVIEW

Ultrasonic assisted milling development and application should highlight the advantages and reduce the possible weaknesses in the individual machining process. Ultrasonic machining is specialized ultrasonic machine tools which triggers a coarse tool oscillation. Figure-1 illustrates typical system with modes of vibration. Ultrasonic machining often operates at a longitudinal or a mode of bending vibration [6-10]. The ultrasonic generator utilizes a piezoelectric (PZT) or magnetostrictive actuator to form a responsive motion of harmony with high frequency and low amplitude. The ultrasonic motion is amplified by the acoustic waveguide booster and horn. The whole body ought to be scaffolded at the nodal points of its mode of longitudinal or bending vibration in obtaining a flexible range vibration. A cutting tool is fixed at horn end, and is aligned so that the cutting direction is parallel to the vibration motion.

Ultrasonic vibration assisted technique has been developed to improve Inconel 718 machinability [11-14]. Extant literature asserts that ultrasonic vibration significantly decreases cutting forces and enhances surface finish. Abootorabi *et al.* [15] studied the impact of UAM of AISI 1020 steel on rate of feed, depth of cut and speed of cutting. The surface roughness improved by up to 12.9 % through the UAM implementation. Throughout the UAM, the cutting tool cools faster due to the workpiece and cutting tool periodic separation. Lower cutting parameters are commended for UAM to improve surface roughness and acquire lower forces because the workpiece and tool are separated during vibration of ultrasonic [16].

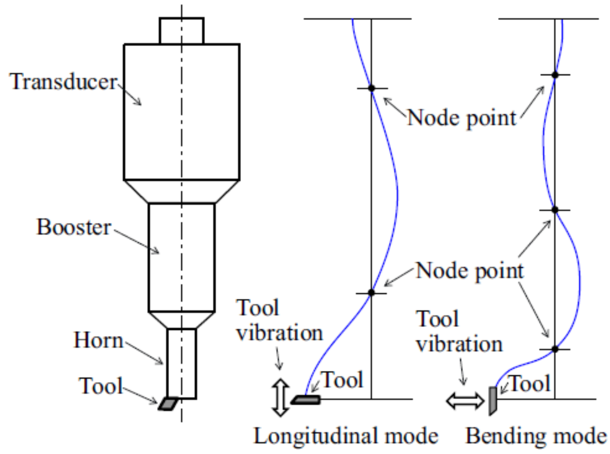

Figure-1. Schematic illustration of ultrasonic vibration system modes [6].

Lower Surface finish is difficult to gain in primary machining process without undergoing any secondary or finishing process. However, it is possible to eradicate the finishing process when the optimum machining technique is implemented in the near future. Lian *et al.* [17] ascertained surface finish results through testing ultrasonic vibration assisted micro-milling on Al6061 at different amplitudes. They verified that the UAM application improves Ra value compared with ordinary micro-milling process. This result was adhering to the findings of Abootorabi *et al.* [18]. As the feed escalates in UAM process, the chip curvature declines. These chips affect workpiece surface roughness and the result resonates Taghi and Bahman's[19] findings where

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the ultrasonic-assisted dry grinding (UADG) leads to significant enhancements on the parameters of Rz and Ra, assuming that the feed ultrasonic oscillation triggers the capability of grit in UADG to cut the surface peak and increase the grit and workpiece surface interaction possibility in each contact length.

Taguchi's parameter design, an essential tool for robust design, is successful in various manufacturing applications. Taguchi technique offers a systematic and simple approach to identify the main significant parameter of the machining performance. Few major tools utilized in robust design are [20-22]:

- Signal to noise ratio - measuring quality with variation emphasis
- Orthogonal arrays - accommodating various design parameters simultaneously

In machining hard to cut material, surface roughness is the most important element in obtaining high quality. Hence, this paper reports the effects of the ultrasonic assisted milling on the Inconel 718 surface roughness at three different conditions of cutting. The primary purpose of the paper was to identify the significant parameters that affect the machining performance in achieving low surface roughness. Figure-2 shows the schematic diagram for the overall set up of the machining process.

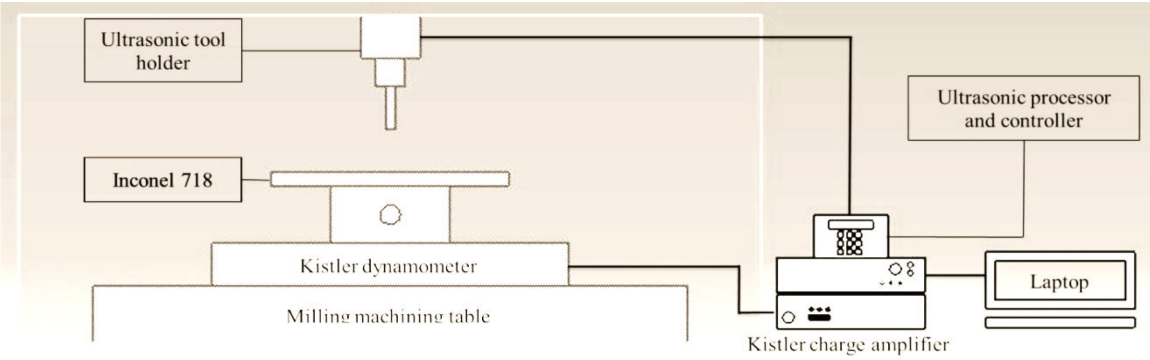

Figure-2. Schematic diagram of the overall experiment setup.

TAGUCHI METHOD, DESIGN OF EXPERIMENT AND EXPERIMENT DETAILS

Taguchi method

Taguchi method refers to a methodology to find the control factors optimum setting to generate product or process insensitivity to noise. Taguchi, in his empirical analysis, found that the two stage optimization procedure concerning S/N ratios definitely provides the combination of parameter levels where the mean on target is fixed while standard deviation is at minimum [22]. Hence, engineering systems act as such that the manipulated production factors are classified into the following:

- Control factors that influence variability of process as calculated by S/N ratio.
- Signal factors that do not affect S/N ratio or process mean.
- Factors that do not influence S/N ratio or process mean.

In general, the process development may witness the changes in target mean values. Two applications of S/N ratio concept are the quality improvement through reduction of variability and improvement of measurement. The S/N ratio traits are classified to three types when the characteristic is continuous:

Nominal the best:

$$S/_{N_T} = 10 \log \left(\frac{\bar{y}}{{S_y}^2}\right)$$

Larger is the better (Maximize):

$$S/_{N_L} = -10 \log \left(\frac{1}{n}\sum_{i=1}^{n} {y_i}^2\right)$$

Smaller is the better (Minimize):

$$S/_{N_S} = -10 \log \left(\frac{1}{n}\sum_{i=1}^{n} {y_i}^2\right)$$

Where $\bar{y}$ is the average of observed data, ${S_y}^2$the variance of y, n the number of observations, and y the observed data. Thus, the optimal cutting performance, lower-the-better quality characteristic for surface finish must be taken into consideration.

Experiment design

This paper utilized three factors at three levels each where a standard L_9 (3^4) orthogonal array was used as a fractional factorial design [20] for its ability to check factors interactions. Each matrix row signifies one trial. Nevertheless, the sequences of these trials are arranged at random. A '1' or a '2' or a '3' in the matrix represent the three levels of each factor. Table-1 shows the factors and

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levels which are assigned according to different types of cutting conditions for the Inconel 718 grade AMS 5663 when machining at high speed machining.

Table-1. Factors and level applied in the experiment (Axial depth of cut is kept constant at 1mm).

Factors	Level		
	1	2	3
A- Speed (m/min)	80	100	120
B- Feed (mm/tooth)	0.1	0.15	0.2
C- Vibration (kHz)	0	20	27
D- Cutting Condition	Dry	Flooded	PC

Experiment details

The experiments used a CNC Milling Machine HAAS CNC Milling 3 Axis machine in three different cutting conditions namely dry, flooded and the pulsating coolant (PC). The pulsating coolant was set with 1800 pulse/min with the pressure of 0.83 MPa. The coolant was jetted intermittently on cutting tool to create hydraulic shock. Figure 3 indicates the configuration of pulsating coolant. The insert used was round-shaped insert end mill TiCN/Al_2O_3 composition layer with 10 mm diameter recommended by the Sumitomo for the specific work material.

The Inconel 718 machining was assisted by the Nuth BT40 ultrasonic vibration tool holder. The result of surface roughness was measured by the Mitutoyo SJ-301 portable surface roughness adhering to ISO 3274: 1997 standards. In addition, the optical microscope was used to observe the machining surface texture. The chemical composition for the Inconel 718 is shown in Table-2.

EXPERIMENTAL RESULTS AND DATA ANALYSIS

Conceptual S/N ratio approach

The experiment objective was to investigate significant parameters that influence the ultrasonic assisted milling machining to achieve the lower surface roughness value. Table-3 illustrates the surface roughness and their S/N ratios computation. Table-4 shows the S/N ratio mean for surface roughness level. These data were plotted as shown in Figure-4. Taguchi is recommended to determine significant factors without utilizing ANOVA, thus, simplifying the mean and S/N ratio analysis concerning graphics [22]. Figure-4 shows the average S/N ratio for the smaller-the-better surface roughness and significant interaction.

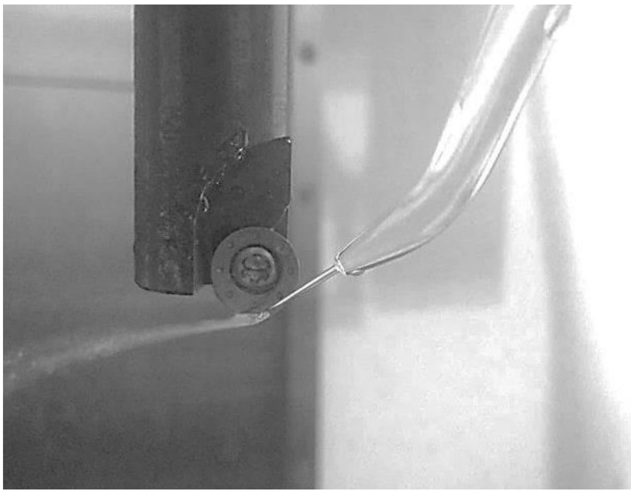

Figure-3. Pulsating coolant jetted on the rake face of the cutting tool.

Table-2. The chemical composition of the Inconel 718 in percentage by weight (Hynes, 2009).

Al	B	C	Nb.Ta	Co	Cr	Cu	Fe	Mn	Mo	Ni	P	S	Si	Ti
0.49	0.004	0.051	5.05	0.3	18.3	0.04	18.7	0.23	3.05	53	<0.005	<0.002	0.08	1.05

Table-3. Experimental results for surface roughness and their corresponding S/N ratio.

Experimental run	Factors				Designation	Measured parameter		Calculated S/N ratio
	A	B	C	D		Ra 1 (μm)	Ra 2 (μm)	
1	1	1	1	1	$A_1B_1C_1D_1$	0.55	0.66	4.315
2	1	2	2	2	$A_1B_2C_2D_2$	0.50	0.44	6.537
3	1	3	3	3	$A_1B_3C_3D_3$	0.78	0.67	2.784
4	2	1	2	3	$A_2B_1C_2D_3$	1.01	0.97	0.114
5	2	2	3	1	$A_2B_2C_3D_1$	0.59	0.58	4.688
6	2	3	1	2	$A_2B_3C_1D_2$	0.53	0.52	5.602
7	3	1	3	2	$A_3B_1C_3D_2$	0.39	0.37	8.377
8	3	2	1	3	$A_3B_2C_1D_3$	0.96	0.94	0.449
9	3	3	2	1	$A_3B_3C_2D_1$	0.55	0.66	4.315

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Table-4. Response table for average S/N ratio for surface roughness and significant interaction.

Symbol	Cutting parameter	Mean S/N ratio				Rank
		Level 1	Level 2	Level 3	Max-min	
A	Cutting speed	4.546	3.468	4.380	1.007	3
B	Feed rate	4.268	3.891	4.234	0.377	4
C	Frequency	3.455	3.655	5.283	1.115	2
D	Cutting condition	4.440	6.839	1.115	5.723	1

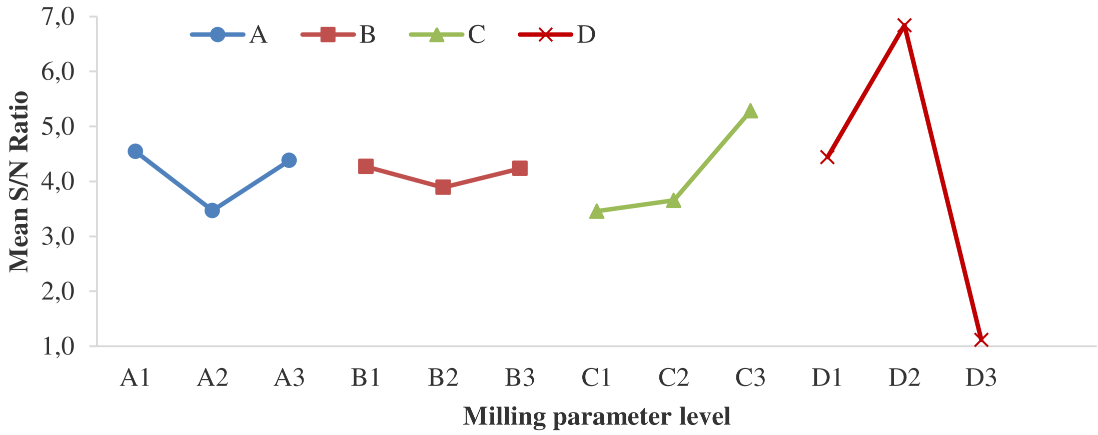

Figure-4. The smaller the better S/N graph for surface roughness.

S/N response graph on Figure-4 shows the effect of the machining factors on the roughness of milled surface. A steep slope for the cutting conditions (factor D) indicates this parameter is the most significant factors followed by the frequency (factor C). However, the factors of the cutting speed (factor A) and feed rate (factor B) found to be insignificant. It was supported by the Max-min table on Table-4 to rank each input parameter. By comparing these cutting conditions, D2 parameter is found the highest of S/N ratio showing the cutting with flooded coolant results better surface finish compare to dry and pulsating coolant condition. Secondary most significant factor of ultrasonic setting indicating that the frequency of 27 kHz (C3) assists in low surface roughness. In conclusion, the surface roughness can be improved by implementing flooded with high frequency vibration during the cutting process.

Pareto analysis of variance (ANOVA)

The primary aim of ANOVA is to analyze the design parameters and to specify which parameters are significantly influencing the output parameters [23]. Table-3 illustrates the calculated S/N ratio for Ra. Table-4 shows the S/N ratio analysis of rank of various parameters whilst Figure-5 demonstrates the analysis of variance of singular factor for S/N ratios for surface roughness which indicates the contribution for each parameter. As the results shown, the most contributed on Inconel 718 Ra is the cutting condition (factor D) followed by vibration of the tool holder (factor C), speed which preferred to the machine cutting speed (factor A) and feed rate (factor B).

DISCUSSIONS

In this study, machining under flooded have proved in improving surface topography, hence it was broadly applied in the industry. During the machining of the Inconel 718, the utilization of conventional cutting fluids is considered effective for controlling the cutting temperature while enhancing the machinability of certain materials. This is due to the ability of the fluid to dissipate heat generated during the interrupted cutting process. Coolant helps to artificially lower the shear stress. Besides, it lowers the friction and temperature and reduces the extent of temperature-induced wear types [24].

The ultrasonic application is employed on the milling process. The S/N ratio indicates that frequency also slightly contributes on the machining performance. The explanation for the influence of frequency on surface roughness is due to the phenomenon of the engagement between the cutting tool and workpiece against the continuous cutting. Mechanically, the added motion on longitudinal mode of the cutting tool at small amplitude and high frequency [6, 25], thus reducing the contact force [26].

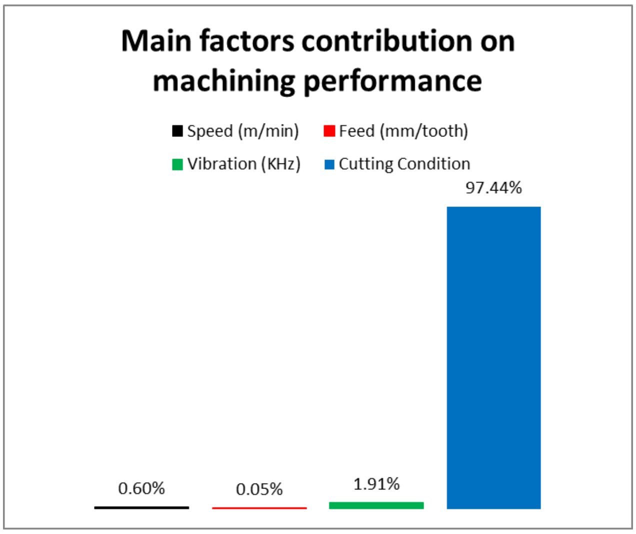

Figure-5. Main factor contribution percentage.

CONCLUSIONS

In conclusion, Taguchi Design of Experiments is applied for the milling parameters to attain the optimal surface roughness. L_9 orthogonal array is utilized in experiments where surface roughness is measured recorded and analyzed using Taguchi S/N ratios. These ratios are measured with performance characteristic consideration: Lower-the-Better, as surface roughness is requested to be low. The results show mill under flooded coolant over performed dry and pulsating coolant condition. The S/N ratios also indicate that ultrasonic with 27 kHz has slightly influence on the machined surface roughness; the more increase of frequency, the better the surface roughness, whilst for the optimum surface roughness for the machining the Inconel 718, the combination of the parameter is suggested as A1B1C3D2.

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