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Prediction the Effect of Cutting Parameters on Surface Roughness Using Taguchi Method

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ABSTRACT

In this study, the prediction of surface roughness of milled surfaces was carried out using Taguchi Method with four inputs, namely, cutting direction, stepover, feed per tooth and workpiece surface geometry. A systematic approach to obtain an optimal surface roughness was employed to consider the effects of Taguchi method for this application using CNC milling machine with ball mill cutter. The results show that the Taguchi method is an effective tool in predicting the optimum factors to obtain minimum surface roughness, which are stepover, surface type, feed per tooth and cutting direction respectively.

Keywords: Cutting parameters, Surface roughness, Taguchi method

التنبؤ بتأثير معاملات القطع على الخشونة السطحية باستخدام طريقة Taguchi

الخلاصة

في هذه الدراسة ، تم العمل على التنبؤ بالخشونة السطحية لسطوح مشغلة بالتفريز باستخدام طريقة Taguchi بالأعتماد على اربعة مدخلات اساسية هي اتجاه القطع، مقدار الخطوة، التغذية / سن وهندسية السطح. تم وضع طريقة منهجية للحصول على أمثل قيمة للخشونة السطحية من خلال اعتبار مؤثرات طريقة Taguchi لهذا التطبيق باستخدام ماكنة التفريز المبرمجة واداة قطع كروية.اظهرت النتائج ان طريقة Taguchi هي اداة فعالة للتنبؤ بامثل العوامل المؤثرة للحصول على اقل خشونة سطحية وهي كل من مقدار الخطوة ، هندسية السطح ، التغذية / سن واتجاه القطع على الترتيب.

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INTRODUCTION

The manufacture of dimensionally accurate, closely fitting parts is essential in interchangeable manufacturing. The accuracy and wearability of mating surfaces is directly proportional to the surface finish produced on the part. Good surface finish also contributes to the aesthetic appeal of the product. Though many new cutting tools and methods have evolved, much work remains to be done before all the factors contributing to the surface finish and tool life can be controlled.

Surface finish is an important attribute of quality in any machining operation. Researchers have studied the influence of various factors that can improve the surface finish of a workpiece, but results are not very satisfactory, especially in terms of the complex interactions of the various factors [1].

The theoretical arithmetic average surface roughness (mm), *Ra*, is given by [2,3,4].

$$R_a = \frac{f_t^{\,2}}{32 \quad [R_c \pm f_t \quad (n_t / \pi)]} \qquad \ldots(1)$$

Where (f_t) is the feed per tooth, +ve sign refers to up-milling and the –ve sign to down-milling, and (n_t) is the number of edge or tooth on the cutter, and (R_c) is the effective cutter radius.

This means that surface roughness increases with increasing feed rate, and a large tool nose radius reduces surface roughness of the workpiece. However, a significant trend in the surface roughness with increasing depth of cut could not be found, which differs from the traditional expectation that a greater depth of cut results in greater roughness. One reason for this might be the presence of voids, impurities, swelling and recovery of the workpiece materials that might affect the trend from occurring. However, the trend that surface roughness decreased with increasing spindle rate was observed [5]. Many theoretical models have concluded that the effect of cutting speed on surface finish is insignificant. In practice, however, cutting speed has been found to be a significant factor. The speed also has mixed effects on the surface finish of workpieces. An intermediate region of deterioration on surface finish due to the formation of built-up edge was discovered, but this trend was not observed with ceramic tools [6].

In recent years, many optical measuring methods have been applied to overcome the limitations of stylus method in measuring the surface roughness of work parts. Galante[7]applied an image processing technique for the on-line control of the surface roughness in the finishing turning operation by means of tool image detection and processing. The authors also built a model to estimate the value of the effective roughness of the work pieces from one related to the deal profile. Yet, tests varying the cutting speed were not carried out in their study. Choudhury, I.A.[8] used a model for surface roughness prediction using the response surface method by combining its methodology with factorial design of experiments developed. Dimla, E. [9] adopted the application of perception-type neural networks for tool-state classification during metal-turning operation that has been studied. They investigated both single layer networks and multi-layer networks and found that the multi-layer networks had better performance than the single-layer tool-state classification. Al-Kindi [10] assessed a system in the automation inspection of engineering surface. The parameters they got were based on spacing peaks and the number of peaks per unit length of a scanned line in the gray-level image. This one-dimensional (1D) image is sensitive to lighting and noise.

In order to predict surface roughness in real time, a Taguchi method is used to construct the relationships between the input factors machining parameters (cutting direction, feed per tooth, stepover and workpiece surface geometry).

PLAN OF EXPERIMENTS

Multi-axis CNC machine have been utilized to implement the experimental work in the present work using Ball End Milling cutter (R=3mm), in CAD/CAM laboratory / mechanical department in Nanjing University for Aeronautics and Astronautics in China. And Figures(1) and(2 a, b and c) show the CNC machine and the specimens (made of Aluminum alloy) that implemented in the experimental work respectively.

The experimental layout was developed based on Taguchi's orthogonal array experimentation technique. An L_9 orthogonal array experimental layout was selected to satisfy the minimum number of experiments conditions for the factors and levels. This array has four control parameters and three levels, as shown in Table (1).

A series of machining tests are conducted to assess the effect of machining parameters on the surface roughness. Experimental results are shown in Table(2).

TAGUCHI METHOD

In this work, analysis based on the Taguchi method is performed by utilizing the Minitab software to estimate the significant factors of the CNC milling process parameters on surface roughness for taken surface geometries and graphical analysis of the obtained data.

Taguchi's orthogonal array is highly functional design, used to estimate main effects using few experimental tests only [11, 12].

These designs can investigate main effects when factors have more than two levels. In Taguchi method, the analysis of variation is performed using Signal – to – Noise ratio (S/N). There are three S/N ratio approaches of common interest for optimization [13]:

1. Smaller – the better (for making the system response as small as possible).
2. Larger – the better (for making the system response as large as possible).
3. Nominal – the best (for reducing variability around the target).

In this work, the objective is to minimize the surface roughness parameter. Therefore, the S/N ratio for each experiment of L_9 calculated using smaller the better approach. The objective of using S/N ratio as a performance measurement is to develop a product and process insensitive to noise factor. In Taguchi method, the term "signal" represents the desirable value (mean) for the output characteristic, and the term "noise" represents the undesirable value (square deviation) for the output characteristic [14]. Therefore, the S/N ratio is the ratio of the mean to square deviation. S/N ratio of the overcut is calculated by [14, 15, and 16]:

$$\frac{S}{N} = -10\log\left(\frac{(\sum Y_i)^2}{n}\right)1 \qquad \dots (2)$$

Where: Y_i: is the i^{th} observed value of the response.

(n: number of observations).

S/N ratio is used to measure the quality characteristic deviating from the desired value. Steps applied in Taguchi method are summarized in Figure (3).

Figure (4), shows the main effects of surface roughness of each factor for various level conditions. According to this figure, the surface roughness decreases with low level of stepover.

The analysis of S/N ratio of surface roughness parameter with small – the better approach shown in Figure (5), revealed that the smallest value of surface roughness is achieved at stepover of (5), feed/tooth of (0.10), and cutting direction of (30 degree).

MEASURING SURFACE ROUGHNESS DEPENDING ON SCALLOP HEIGHT VALUE

In the present work the electronic microscope connecting with computer by a cable and LAN card had been used so as to measure the experimental value of scallop height, since the picture of the scallop height is apper in each plane clearly and it can gauge the scallop height by utilize a spcifice program which is the frontage of the electronic microscope on computer. see Figure (6).

RESULTS

Surface roughness parameter is one of the main parameters in milling processes. It plays the major role to optimize the process of producing smooth machined surface using CNC milling machine. Where, parallel tool path have been selected to generate a clear and measurable surface profile which is suitable to get an accurate measurement for the values of scallop height and step over by using the electronic microscope. Also, The simple trimmed surfaces have been used in present work to facilitate the process of measuring step over and make the comparison between experimental results with the theoretical results.

According to the ranks of the slop of S/N ratios plot, shown in Table. 3, that affect of various input factors on surface roughness in sequence of its effect are: stepover of (5), feed/tooth of (0.10), and cutting direction of (30 degree).

CONCLUSIONS

This paper has discussed the process of machining Aluminum alloys by CNC milling machine for three types of surface geometries. Taguchi method has been used to determine the main effects, significant and optimum machining parameters. Based on the results, it can conclude that, the stepover mainly affects the surface roughness, then surface type and feed/tooth and then cutting direction. Taguchi method gives systematic simple approach and efficient method for the optimum operating conditions.

The Taguchi method can optimize performance characteristics through the settings of cutting parameters and reduce the sensitivity of the system performance to sources of variation. As a result, the Taguchi method has become a powerful tool in the design of experiment methods. However, most published Taguchi applications to date have been concerned with the optimization of a single performance characteristic. Handling the more demanding multiple performance characteristics are still an interesting research problem.

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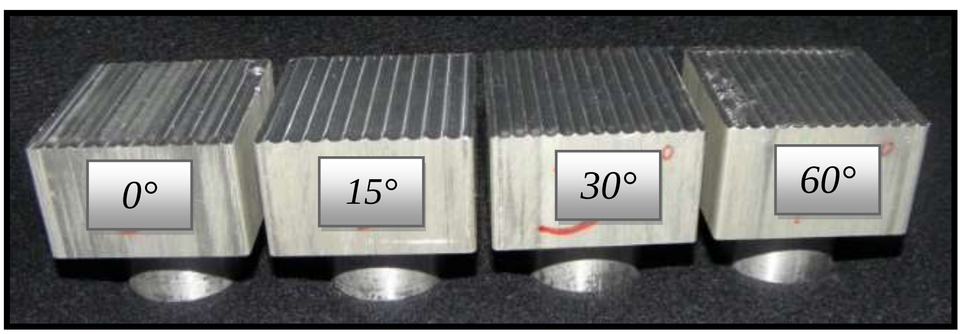
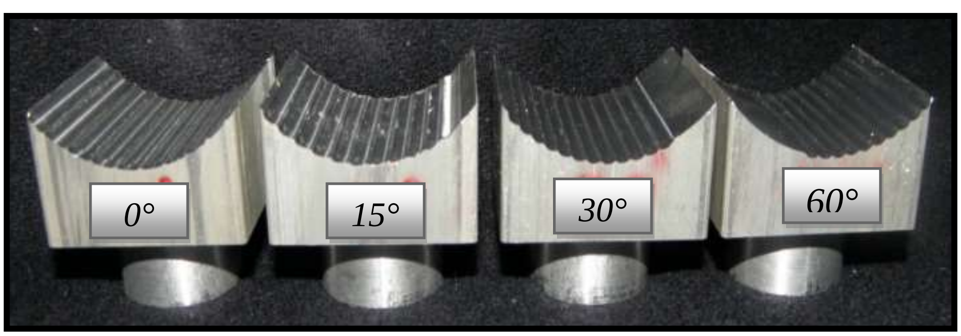
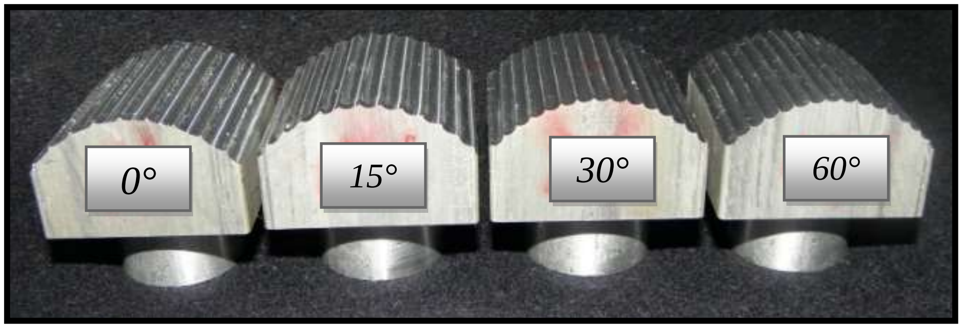
Figure (1) CNC milling machine in Nanjing University.



(a) Flat surface.



(b) Concave surface.



(c) Convex surface.

Figure (2 a, b and c): Explain the specimens that have been implemented in the work for twelve specimens and the test was divided into three division related to the shape of the specimen profile, as follow:

- **Shape of the specimens profile =3 (flat, concave, convex)**
- **Lead angle =** 0° **for three type of specimens.**
- **Lead angle =**15° **for three type of specimens.**
- **Lead angle =** 30° **for three type of specimens.**
- **Lead angle =** 45° **for three type of specimens.**

Table (1) Design of Experiment (Factors and Levels).

Factors	**levels**		
	1	**2**	**3**
Cutting Direction (degree)	0	30	60
Step over (mm)	1	3	5
Feed per tooth (mm)	0.04	0.1	0.16
Surface type	horizontal	concave	convex

Table (2) Experimental results.

Exp. No.	**Surface type**		**Feed per tooth (mm)**		**Step over (mm)**		**Cutting Direction (degree)**		**Surface Roughness *Ra***
1	1	Horizontal	1	0.04	1	1	1	0	0.0314
2	1	Horizontal	2	0.1	2	3	2	30	0.2919
3	1	Horizontal	3	0.16	3	5	3	60	0.3102
4	2	Concave	1	0.04	2	3	3	60	0.2936
5	2	Concave	2	0.1	3	5	1	0	0.9777
6	2	Concave	3	0.16	1	1	2	30	0.2923
7	3	Convex	1	0.04	3	5	2	30	0.7410

8	3	Convex	2	0.1	1	1	3	60	0.3656
9	3	Convex	3	0.16	2	3	1	0	0.2919

Table (3) Response Table for Signal to Noise Ratios.

Level	Surface type	Feed per tooth	Step over (mm)	Cutting direction (degree)
1	16.975	14.437	16.495	13.651
2	7.175	6.544	10.679	7.994
3	7.346	10.515	4.322	9.851
Delta	9.800	7.893	12.173	5.657
Rank	2	3	1	4

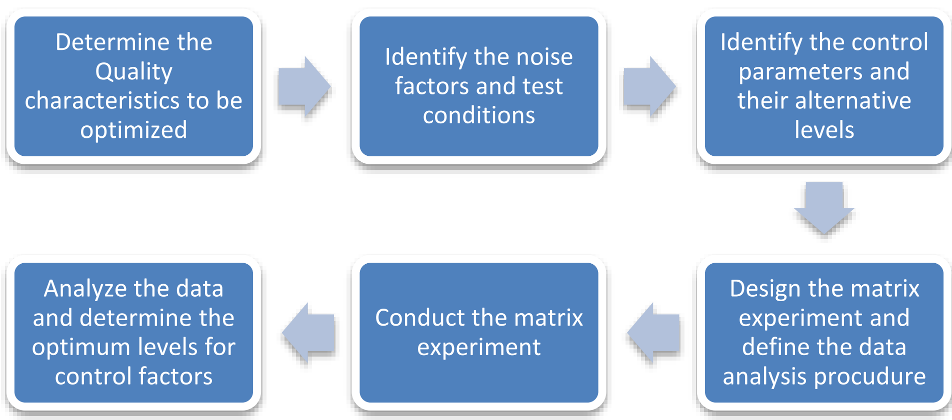


Figure (3) Flow chart of Taguchi analysis steps.

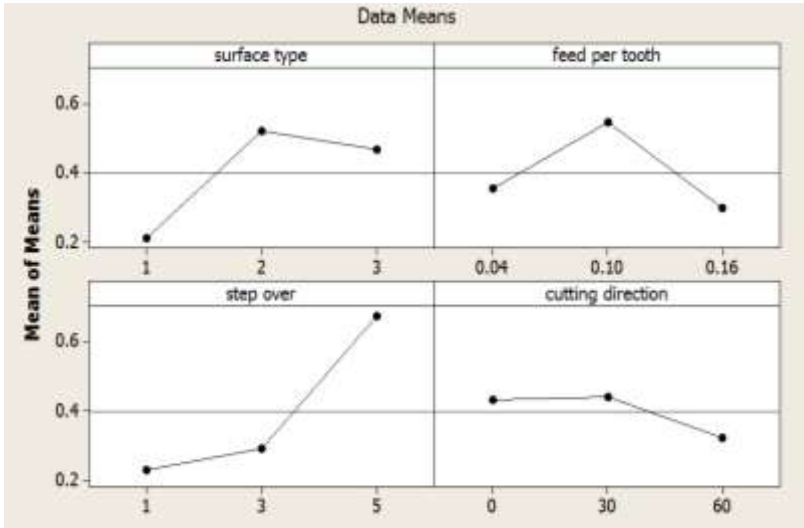


Figure (4) Main effects plot for means.

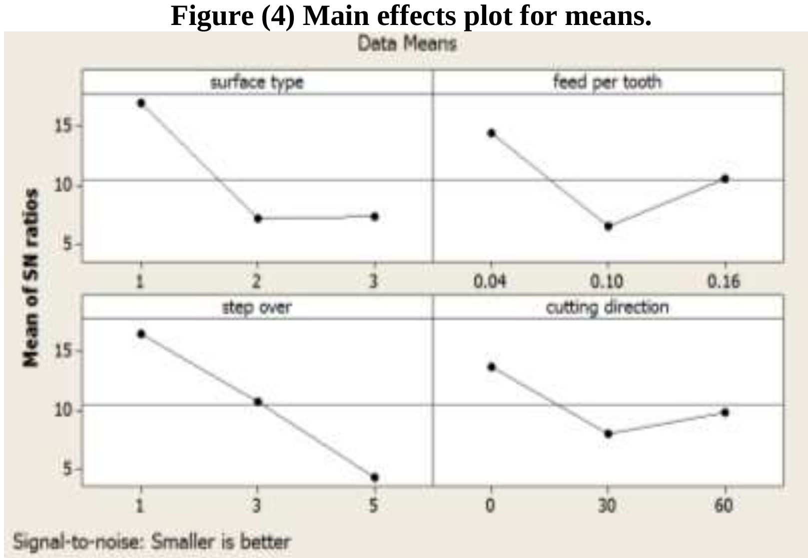


Figure (5) Main effects plot for S/N ratios for surface roughness.

USB Cable connect between electronic microscope and the computer.

LAN card to define electronic microscope to the hardware of the computer.

Figure (6) Show electronic microscope with a USB cable and LAN card.