EXPERIMENTAL STUDY ON END-MILLING OF STEEL AISI 1060 FOR OPTIMUM SURFACE ROUGHNESS

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الملخص

تم تطبيق منهجية تاقوشي التفاضلية للحصول على العوامل المثلى للقطع في عمليات التفريز الطرفي. وقد استخدم في هذه الدارسة الصلب الكربوني (AISI 1060) مع استخدام أداة قطع من صلب السرعات العالية تحت ظروف الإنهاء مع التبريد. أجريت التجارب المعملية باستخدام آلة مبرمجة بالحاسوب (CNC) وذلك باستخدام الصفوف المتعامدة كما أوصت به منهجية تاقوشي. حيث تشمل عوامل التفريز سرعة القطع ومعدل التغذية وعمق القطع وأداة القطع مع استخدام عدد من الأخاديد كعوامل إضافية لظروف القطع. أستخدم لتحليل تأثير عوامل التفريز علي نعومة السطح الصفوف المتعامدة ومعدل نسبة الإشارة إلي الضوضاء (S/N) ومن خلال النتائج التي تم الحصول عليها تبين أن العوامل المثلى للتشغيل كانت عند عمق قطع 0.3 mm وسرعة قطع 1000 rpm ومعدل تغذية 50mm/min وعدد الأخاديد أربعة. ومن خلال تأكيد الاختبارات مع المستويات المثلي لعوامل القطع تبين مدي تأثير طريقة تاقوشي المثلي كإدارة فعًالة للحصول علي خشونة سطح مثلي أو بمعني أخر أقل خشونة سطح ممكنة.

ABSTRACT

Taguchi optimization methodology was applied to optimize cutting parameters in end milling operation. Machining carbon steel AISI 1060 with high speed steel tool under finishing conditions with coolant is used in this study. The experimental work has been conducted on CNC milling machine tool, and the experiments carried out by using orthogonal array as suggested by Taguchi. The milling parameters are; cutting speed, feed rate, depth of cut and cutting tools with different number of flutes were used as additional factor in cutting conditions. An orthogonal array signal-to-noise (S/N) ratio is employed to analyze the effect of these milling parameters on surface roughness. The results show that the optimum parameters of machining is obtained at a depth of cut of 0.3 mm, cutting speed 1000 rpm, feed rate 50 mm/min. and number of flutes of four. Confirmation tests with the optimal levels of cutting parameters are carried out in order to illustrate the effectiveness of Taguchi optimization method. Taguchi method has been found very efficient tool to obtain an optimum surface roughness namely a smaller surface roughness.

Keywords: Taguchi Optimization Methodology; CNC Milling Machine; Surface roughness; Cutting speed; Feed rate; Depth of cut.

INTRODUCTION

Computer numerical controlled milling (CNC) has become one of the most competent, productive and flexible manufacturing methods, for complicated surfaces. The milling process is one of the most widely used material removal processes in industry. It is widely used in a variety of manufacturing industries including the aerospace and automotive sectors [1-4]. The cutting operations by end mills can be as simple as the face milling of the top of a flat surface with rigid cutter or the milling of very complex parts, where quality is an important factor in the production of faces, slots, pockets, precision molds and dies. The quality of the surface plays a very important role in the micro crack elimination. So a good quality milled surface significantly improves fatigue strength, or creep life. Surface roughness also affects several functional attributes of parts, such as contact causing surface friction wearing. Therefore, the desired finish surface is usually specified and the appropriate processes are selected to reach the required quality [3, 4].

Surface roughness is a measure of finer surface irregularities in the surface texture. These are the results of the manufacturing process employed to create the surface. Surface roughness Ra is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micro inches or micrometers. ISO standards use the term CLA (centerline average). The ability of manufacturing operation to produce a specific surface roughness depends on many factors. For example, in end mill cutting, the final surface depends on the rotational speed of the end mill cutter, the rate of feed, the depth of cut, lubricant and mechanical properties of the piece being machined [1, 5-8]. A small change in any of the above factors can have a significant effect on the surface produced. The quality of a machined surface is becoming more and more important to satisfy the increasing demand of sophisticated component performance, longevity, and reliability. Engineering continue to desire material that are capable of longer service lives, and processes for shaping those materials into finishing products that are capable of machining tighter geometric tolerances and improved surface finish. Hardened steel is one such material that has been used extensively in the tool manufacturing such as dies and molds. Traditionally, finished surfaces have been ground from near net shape hardened steel parts. However, the grinding process it self may require several machine tools and several setups to finish all component surfaces. As grinding can be a slow process with low material removal rates, replacement processes are desired. Many factors effects the surface roughness produced by a machining operation, the most common being feed rate, the nose radius of the tool, the cutting speed, the rigidity of the machining operation, and the temperature generated during the machining process. The increasing requirement on precision machining and work piece quality has brought a long research on cutting behaviors and improve surface roughness since the beginning of the 20th century. An investigation in the machining process as well as effect of machining parameters on surface characteristics was carried out as well as result drive was exhibited, and some improvements were achieved as, good correlation between the experimental and theoretical, cutting speed that gives the best values of surface roughness, the best results of surface finish can be achieved at medium cutting speed, the best values of surface finish were obtained at the lowest depth of cut used in this work compared to other works [17].

BACKGROUND OF TAGUCHI DESIGN

The design of experiments (DOE), described by the Taguchi principle, is one of the most important statistical technique of total quality management (TQM) for designing high quality systems at reduced cost. Taguchi methods provide an efficient and systematic way to optimize designs for performance, quality, and cost [9-10]. Fundamentally, traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of the process parameters increases. To solve this problem, the Taguchi method has used a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [11-14]. Taguchi methods has been widely utilized in engineering analysis and consists of a plan of experiments with the objective of acquiring data in a controlled way and in order to obtain information about the behavior of a given process. The greatest advantage of this method is to save the effort in conducting experiments. Therefore, it reduces the experimental time as well as the cost [7-11].

STEPS OF TAGUCHI PARAMETER DESIGN

Selection of Quality Characteristic

There are three types of quality characteristics in the Taguchi methodology, such as smaller-the-better, larger-the-better, and nominal-the-best. The goal of this research was to produce minimum surface roughness (Ra) in an end-milling operation. Smaller Ra values represent better or improved surface roughness. Therefore, a smaller-the-better quality characteristic was implemented and introduced in this study.

Selection of Control Factors

The previous studies [12-13], indicated that depth of cut, cutting speed, and feed rate had significant effects on surface roughness in the end milling operations. In this study, the controllable factors are depth of cut (A), cutting speed (B), feed rate (C),and number of flutes (D), which were selected because they can potentially affect surface roughness performance in end-milling operations. Since these factors are controllable in the machining process, they are considered as controllable factors in the study. Table (1) listed all the Taguchi design parameters and levels.

Table 1: Variable Factor Levels.

Factor	Level 1	Level 2	Level 3
A: Depth of cut	0.3 mm	0.5 mm	0.7 mm
B: Cutting speed	500 (rpm)	750(rpm)	1000(rpm)
C: Feed rate	50 mm/min	150 mm/min	250 mm/min
D: Number of flutes	2	3	4

Selection of Orthogonal Array

One of the steps included in the Taguchi parameter design is selecting the proper orthogonal array (OA) according to the number of controllable factors (parameters) [7-8]. Since four factors were studied in this research, three levels of each factor were considered. The orthogonal array selected was the L27, which has 27 rows corresponding to the number of tests with four columns at three levels and each experimental run will have three data collected as shown in an appendix A-Table (2). Therefore a total of (27*3) = 81 data values were collected, which were conducted for analysis in this study.

Conducting the Experiments

Figure (1) illustrates the experimental settings in this study for work piece and end-milling operations. The tool used in this experiment was tow three and four tooth, high-speed steel end mill. The material used for the experiment were a High-Carbon Steel (DINI 1.060- AISI 1060). The 27 experiments, shown in an appendix A-Table (3), were randomly run by the CNC Bridgeport VMC 500 vertical milling machine.

Figure 1: Tool-Work piece-Nozzles Setup

Also, three measured surface roughness data values were collected using the manual stylus type instrument to measure the finished work pieces after end milling was completed. After the data were collected and recorded signal-to-noise ratios of each experimental run were calculated based on the following equation,

$$S/N = -10 \log \left| \frac{y_1^2 + \dots + y_n^2}{n} \right| \quad (1)$$

Where n = number of measurements in a trial/row, in this case, n=3 and yi is the i^{th} measured value in a run/row. The average response values were also calculated and recorded.

RESULTS AND DISCUSSION

In this study, it is the smaller the better case, which means the smallest surface roughness, would be the ideal situation. This is criteria employed in this study to determine the optimal cutting condition. By following the criteria of smaller surface roughness and larger S/N ratio, the graphs in Figures (2-5) were used to determine the optimal set of parameters from the experimental design.

Figure (2) shows the control factor of depth of cut (A) at level one (0.3mm) provided the best result. Because it has the highest S/N ratio value, which indicated that the machining performance at such level produced minimum variation of the surface roughness. In addition, the lower surface roughness value had a better machining performance.

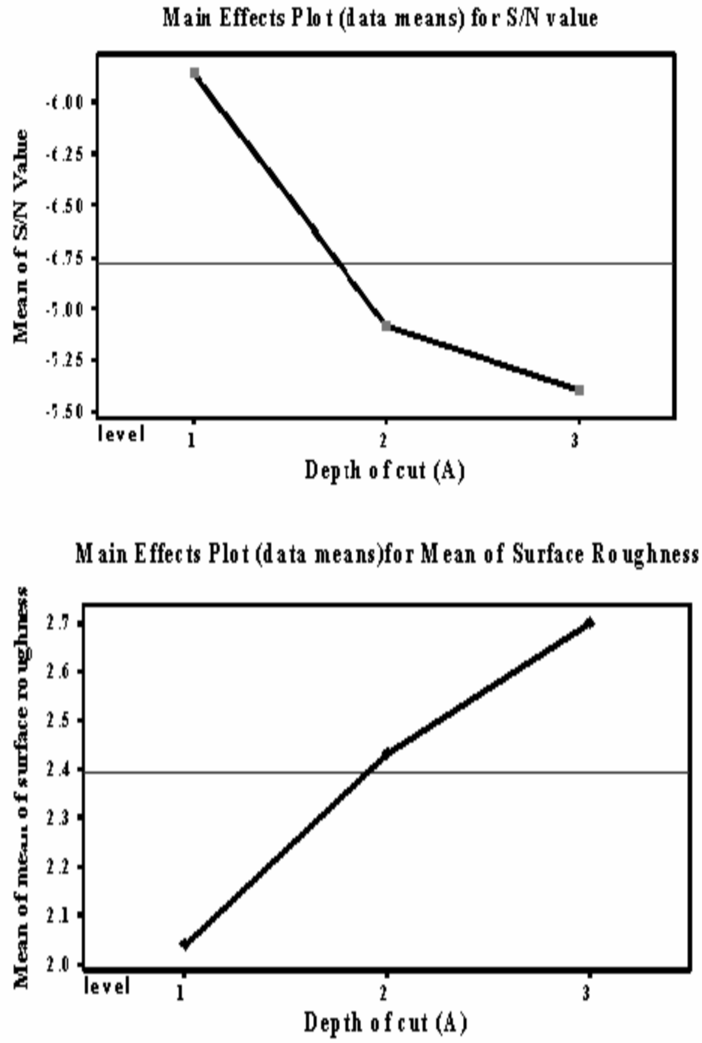

Figure 2: Effect of depth of cut on Ra and S/N ratio.

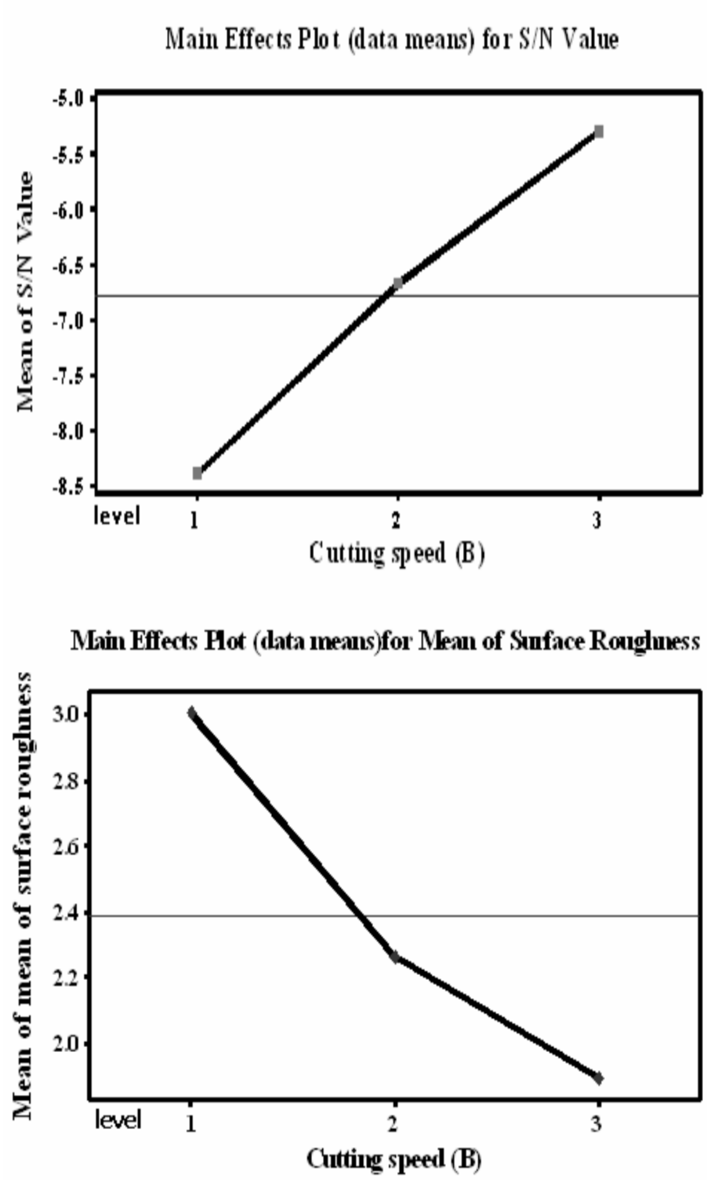

Figure 3: Effects of cutting speed on Ra and S/N ratio

Similarly, Figures (3-5) shows the control factors of cutting speed (B) at level three (1000 rpm), and feed rate (C) at level one (50 mm/min), also the control factor of number of flutes (D) at level three (4 flutes) provided the best results. Therefore, the optimum cutting condition will be (depth of cut = 0.3 mm (A1), cutting speed =1000 rpm (B3), and feed rate =50 mm/min (C1), and number of flutes = 4 flutes (D3).

The comparison of the optimal set of parameters by graph with the data in appendix A-Table (3) which represents the experimental design, new parameters arises and obtained and these parameters are not exist in this table. To predict the mean for the treatment condition average of the result for the trail is set at this particular level is calculated by the following equation [12]:

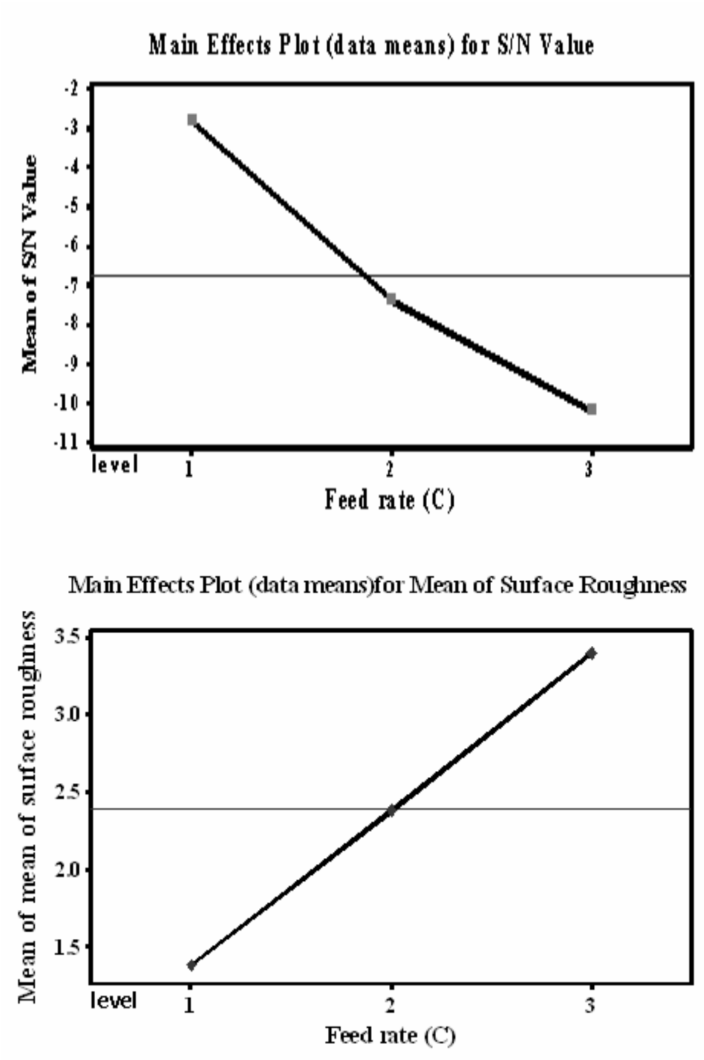

Figure 4: Effects of feed rate on Ra and S/N ratio

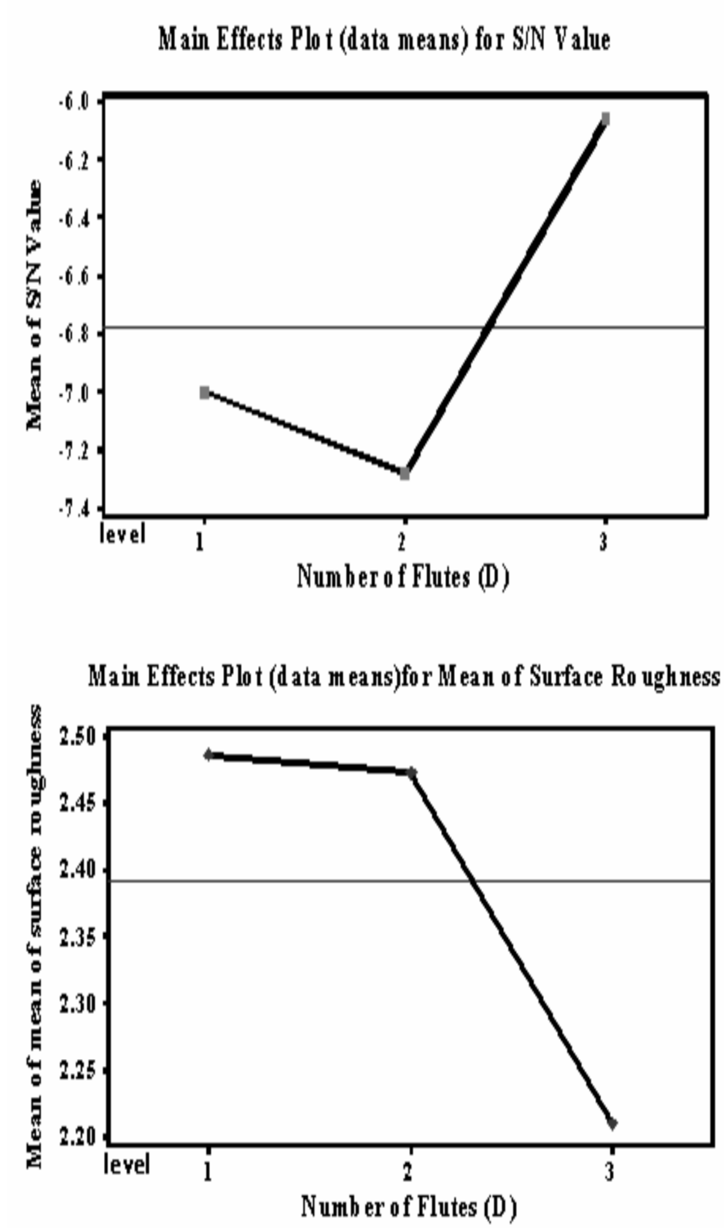

Figure 5: Effect of number of flutes on Ra and S/N ratio

$$\eta_{calc}=\overline{\eta}_{avg}+(\overline{A}_i-\overline{\eta}_{avg})+(\overline{B}_i+\overline{\eta}_{avg})+(\overline{C}_i+\overline{\eta}_{avg})+(\overline{D}_i+\overline{\eta}_{avg}) \quad (2)$$

Where:

η_{calc} is the calculated S/N ratio at optimal machining conditions. $\overline{\eta}_{avg}$ is the average S/N ratio of all control factors. $\overline{A}_i$ is the average S/N ratio when the factor A (depth of cut) is at level i. $\overline{B}_i$ is The average S/N ratio when the factor B (cutting speed) is at level i. $\overline{C}_i$ is The average S/N ratio when the factor C (feed rate) is at level i. $\overline{D}_i$ is The average S/N ratio when the factor D (number of flutes) is at level i.

The expression for surface roughness value is:

$$Ra_{calc} = 10^{-\eta_{calc}/20} \quad (3)$$

The average S/N ratios of for all control factors $\overline{\eta}_{avg}$ and the average S/N ratio for each control factor $\overline{A}_1$, $\overline{B}_3$, $\overline{C}_1$ and $\overline{D}_3$ can be obtainable from the Figures (2) through (5).

Then the values of S/N ratios is substituted in Equation (1) and we obtain

$$\eta_{calc} = -6.77847 + (-5.85669 - (-6.77847)) + (-5.28515 - (-6.77847))$$
$$+ (-2.77711 - (-6.77847)) + (-6.05947 - (-6.77847))$$

$$\eta_{calc} = 0.35699 \text{ dB}$$

Substituting this value in Equation (3) we obtain the surface roughness value as:

$$Ra_{calc} = 0.95973\ \mu\text{m}$$

Confirmation Experimental

The confirmation experiment is very important in parameter design to compare with the minimum surface roughness resulting from the optimization process [14-16]. Two trails for each of cutting at the optimal control factor settings were conducted in confirmation experiments. The tests were carried out with new cutter to prevent undesirable effects caused by worn tools. Two samples of confirmation experimental were carried out and three point of measuring of Ra were taken. The average of Ra for each sample Ra =0.96µm and Ra=1.01µm were obtained. The average of the surface roughness of the two samples are Ra (985 µm) which is little pit larger than the calculated one Ra (95973 µm).

CONCLUSIONS

This paper presented the possibility of utilization the Taguchi method in optimizing experimental tests done in milling operations. The parameter under investigation is the surface roughness. This factor is studied using the method under the effect of four factors; cutting speed, feed rate, depth of cut and number of flutes of the milling cutter. The work-piece material was high carbon steel and the tool is made of high speed steel. Using Taguchi method, the optimum parameters for better surface roughness are obtained at a depth of cut 0.3 mm, cutting speed 1000 rpm, feed rate 50 mm/min and number of flutes 4, (ie, A1B3C1D3). Confirmation experiments at optimal conditions were carried out. The outcomes of experimental results are fairly close to the predicted values. The minimum surface roughness is calculated as 0.959 µm, which is smaller than the value of 0.985 µm obtained in confirmation experiments.

It can be concluded that better optimization of cutting parameters are necessary in order to obtain a good finish. The cutting parameters settings for best surface roughness by using Taguchi parameter design were able to produce that. Taguchi parameter design is an efficient and effective method for optimizing surface roughness in milling operations and can be obtained a remarkable savings in time and cost.

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APPENDIX (A)

Table 2: AN L27 (3^4) Taguchi Orthogonal Array

Exper. No.	(1)	(2)	(3)	($)	**Depth of cut A (mm)**	**Feed rate C (mm/min)**	**Cutting speed B (rpm)**	**Flutes D(fluttes)**
1	1	1	1	1	0.3	500	50	2
2	1	1	1	2	0.3	500	50	3
3	1	1	1	3	0.3	500	50	4
4	1	2	2	1	0.3	750	150	2
5	1	2	2	2	0.3	750	150	3
6	1	2	2	3	0.3	750	150	4
7	1	3	3	1	0.3	1000	250	2
8	1	3	3	2	0.3	1000	250	3
9	1	3	3	3	0.3	1000	250	4
10	2	1	2	1	0.5	500	150	2
11	2	1	2	2	0.5	500	150	3
12	2	1	2	3	0.5	500	150	4
13	2	2	3	1	0.5	750	250	2
14	2	2	3	2	0.5	750	250	3
15	2	2	3	3	0.5	750	250	4
16	2	3	1	1	0.5	1000	50	2
17	2	3	1	2	0.5	1000	50	3
18	2	3	1	3	0.5	1000	50	4
19	3	1	3	1	0.7	500	250	2
20	3	1	3	2	0.7	500	250	3
21	3	1	3	3	0.7	500	250	4
22	3	2	1	1	0.7	750	50	2
23	3	2	1	2	0.7	750	50	3
24	3	2	1	3	0.7	750	50	4
25	3	3	2	1	0.7	1000	150	2
26	3	3	2	2	0.7	1000	150	3
27	3	3	2	3	0.7	1000	150	4

Table 3: The experimental Results for surface roughness and S/N ratio.

Experiment No.	Response value			Average response value	S/N value
	Ra1	Ra2	Ra3		
1	1.52	1.64	1.76	1.64	-4.31235
2	1.48	1.44	1.54	1.486667	-3.44759
3	0.98	1.1	1.04	1.04	-0.35029
4	1.94	2.14	1.9	1.993333	-6.00363
5	2.2	2.48	2.32	2.333333	-7.37002
6	2.06	2.66	2.92	2.546667	-8.20543
7	2.46	2.78	2.64	2.626667	-8.39888
8	2.74	2.64	2.7	2.693333	-8.60681
9	1.98	2.18	1.82	1.993333	-6.01524
10	2.34	2.44	2.54	2.44	-7.75266
11	3.62	3.9	3.32	3.613333	-11.1768
12	2.64	2.82	2.62	2.693333	-8.61064
13	2.68	2.8	2.78	2.753333	-8.79875
14	3.68	3.72	3.6	3.666667	-11.2862
15	2.66	2.88	2.72	2.753333	-8.80211
16	1.52	1.38	1.3	1.4	-2.94084
17	1.4	1.1	1.28	1.26	-2.04879
18	1.24	1.36	1.32	1.306667	-2.32962
19	6.22	6.02	6.12	6.12	-15.7358
20	3.32	3.36	3.8	3.493333	-10.8816
21	3.72	5.18	4.62	4.506667	-13.1538
22	1.36	1.48	1.42	1.42	-3.05093
23	1.6	1.8	1.66	1.686667	-4.55129
24	1.28	1.24	1.24	1.253333	-1.96231
25	2.14	1.98	1.84	1.986667	-5.979
26	1.94	2.12	2.02	2.026667	-6.14138
27	1.8	1.78	1.82	1.8	-5.10581