DETERMINATION THE OPTIMAL CUTTING CONDITIONS AFFECTING THE SURFACE ROUGHNESS USING TAGUCHI METHOD IN TURNING (AL-12%SI) BY CARBIDE TOOL

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ABSTRACT

Surface Roughness (SR) is considered one of the most important indications to specify the quality of machined parts. There are many machining parameters having a large effect on it. The objective of the present study is to find the optimum conditions in turning of Al-12%Si alloy to get lowest surface roughness by applying the Taguchi method. The basic parameters which were taken into consideration in this work are: cutting speed, feed rate, and depth of cut in order. Experiments have been conducted by using L_9 orthogonal array with three levels for each parameter. The nine test specimens were machined in terms of their levels, and average of SR (R_a) values were measured by means of surface roughness tester SRT 6210 device. The optimum combination of process parameters has been found through analysis of main effects for R_a and Signal-to-Noise S/N ratio, and the significant parameter was identified depending on ANOVA analyses. In the present work, the results show that the significant factor is depth of cut followed by feed rate and cutting speed, and the obtained results from the experiments are acceptable for the ranges of cutting conditions that have been selected in this case study. The predicted values and measured values are fairly close, which indicates that the Taguchi method can be effectively used to predict the surface roughness.

ايجاد متغيرات القطع المثلى المؤثرة على خشونة السطح باستخدام طريقة تاكوجي عند اجراء عملية الخراطة لسبيكة (AL-12%SI) بعدة كاربيدية

الخلاصة:

تعتبر الخشونة السطحية من اهم المؤشرات ل تحديد جودة الاجزاء المشغلة. وهنالك العديد من ظروف التشغيل التي تؤثر عليها بشكل كبير. الهدف من البحث الحالي هو ايجاد الظروف المثلى التي تحقق اقل مايمكن من الخشونة عند اجراء عملية الخرطة لاجزاء مصنعة من سبيكة الالمنيوم – سيلكون بتطبيق طريقة تاكوجي. ظروف العملية التي اخذت بعين الاعتبار هي بللترتيب التالي: سرعة القطع ومعدل التغذية وعمق القطع. اجريت التجارب باستخدام المصفوفة القياسية L_9 بواقع ثلاث مستويات من القيم لكل متغير. شغلت نماذج الاختبار التسعة

بحسب مستوياتها ضمن المصفوفة وقيست قيم الخشونة باستخدام جهاز SRT 6210. اوجدت من هذه الدراسة التركيبية المثالية لمتغيرات العملية من خلال تحليلات معدلات قيم R_a و نسبة S/N. كذلك وباعتماد تحليل ANOVA وجد بان عمق القطع هو المتغير الاكثر تاثيرا في العملية يليه معدل التغذية وسرعة القطع وان النتائج المستحصلة من اجراء التجارب مقبولة لمديات ظروف القطع التي تم اختيارها في الدراسة الحالية . ان تقارب القيم المتوقعة مع القيم المقاسة في هذا العمل يشير الى فاعلية استخدام طريقة تاكوجي.

Keywords: Taguchi Method, Surface Roughness, Turning Cutting Conditions, Optimization, and Analysis of Variance (ANOVA).

1. INTRODUCTION

In machining operation, the quality of surface finish is an important requirement for many turned workpieces. Thus, the choice of optimized cutting parameters is very important for controlling the required surface quality (Adeel H. Suhail, 2010). The challenge of modern machining industries is mainly focused on the achievement of high quality, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact (S. Thamizhmanii, 2007). The increase of need for quality metal cutting (better product surface roughness) has driven the metal cutting industries to continuously improve quality control of metal cutting processes. For decreasing the surface roughness that is known to be significantly affected by different cutting parameters like the depth of cut, cutting speed and feed rate, the control of cutting parameters is very important as well as the selection of optimum conditions of these parameters plays an important role before the process takes place. Therefore, the surface roughness will be optimized if the appropriate cutting conditions are selected (Kandananond, 2009).

Recently, a Design Of Experiment (DOE) has been implemented to select manufacturing process parameters that could result in a better quality product. The DOE is an effective approach of optimization in various manufacturing-related processes (Chen, 2001 and Lee, 2007). By application of the method many successful results can be obtained such as elimination of various quality nonconformities, reduction in failure, time and cost by half, improvement in machining accuracy and production efficiency (Ryoichi, 2003). In the present study, many experiments were conducted using turning operation, which is considered the primary operation in most of the production processes in the industry. In turning operation a single point cutting tool removes unwanted material from the surface of a rotating cylindrical workpiece, and by which, a lot of parts can be machined with high surface finish to use in several applications include: bearing surfaces on axles, bearings, ultra-clean surfaces in contaminant-sensitive components, and pistons (E. Daniel Kirby, 2006 and Xue, 2001) .

There are more than one factor (parameter) affects any manufacturing process in general. In turning operation, there are many factors taken into consideration during the experimental test. In addition to this, if each factor has more than one level, the result will be a plenty of experiments. For example, if there are three levels for a certain operation and four factors, as a result, 81 experiments (3^4) must be carried out. In case of increasing of the levels or the factors, the number of experiments will certainly increase too. Therefore, the need to reduce these experiments is so necessary. A statistical experimental design method named “Taguchi method” is the method that is presented for this purpose, and it is an effective approach for improving quality and productivity at low cost. Taguchi method has been used in current study to optimize the setting of the machining parameters that usually affect surface roughness in turning operation sharing with analysis of variance (ANOVA) and confirmation experiment to verify the objective.

2. CONCLUSIONS

In this study the optimal cutting conditions for turning operation of Al-12%Si alloy have been specified through Taguchi method, and the obtained results are acceptable for the ranges of cutting conditions that have been selected in the present research. According to the results, the following conclusions can be drawn:

- The combination of conditions and their levels $A_2B_2C_1$(cutting speed 47 m/min, feed rate 0.12 mm/rev, and depth of cut 1.0 mm) are recommended to order to obtain a good surface finish for turning that alloy through using carbide insert tool which has (1.2 mm) as a nose radius and (15^{o}) as a rake angle.
- The percent contribution of the significant factor produced from analysis of variance ANOVA is 53.14 %. This is, for this case study, the depth of cut has the highest contribution; therefore, the depth of cut is an important factor to be taken into consideration during machining Al-12%Si alloy followed by feed rate, and cutting speed respectively. In comparison with the two other conditions in the present work, cutting speed has minimal effect on surface roughness.

3. SURFACE ROUGHNESS

Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of machining accuracy (S. Thamizhmanii, 2007). The surface roughness is mainly a result of various controllable or uncontrollable process parameters. Generally, there are great numbers of factors influencing the surface roughness. **Fig.** 1 shows all influential factors on machined surface roughness (D. BAJI, 2008 and KUMAR H. S., 2006). There are various simple surface roughness amplitude parameters used in industry, such as roughness average (R_a), root-mean-square (rms) roughness (Rq), and maximum peak-to-valley roughness (Ry or Rmax) (Chen, 2001). In the present study, the surface parameter used for evaluating surface roughness is the roughness average (R_a). The average roughness (R_a) is the area between the roughness profile and its central line, or the integral of the absolute value of the roughness profile height over the evaluation length (Chen, 2001 and D. BAJI, 2008) as shown in **Fig.** 1, therefore, the R_a is specified by using eq. (1) (Chen, 2001):

$$R_a = \frac{1}{L}\int_0^L |\, y(x) \,|\, dx \tag{1}$$

Where: R_a = the arithmetic average deviation from the mean line; L = the sampling length; y = the coordinate of the profile curve.

In turning operation many parameters such as cutting speed, feed rate, and depth of cut, have a large impact on surface quality. Several researchers studied the effect of machining parameters on the surface roughness. The researchers (Julie Z. Zhang, 2007, C.Y. CHOU, 2005, V.S. Sharma, 2008, and S.S.Mahapatra, 2006) had studied the impact of different cutting parameters on surface roughness through optimization those parameters by using Taguchi approach. The present research is considered as an extension for this field, where Taguchi technique was applied to obtain the optimum setting of cutting conditions that leads to better surface roughness as well as to determine the significant factor.

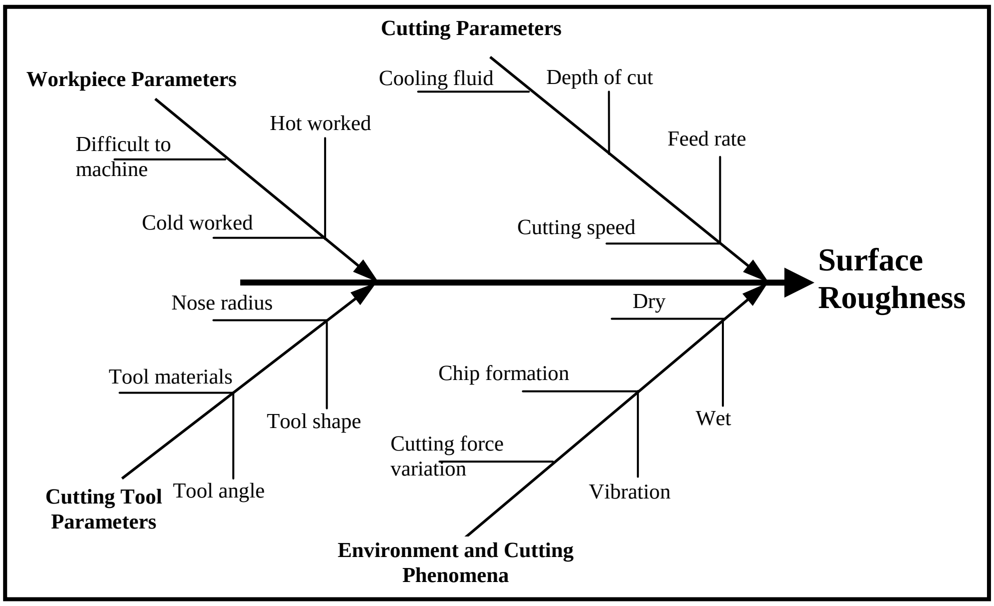

Fig. 1 Fishbone diagram with factors that influence on surface roughness (D. BAJI, 2008).

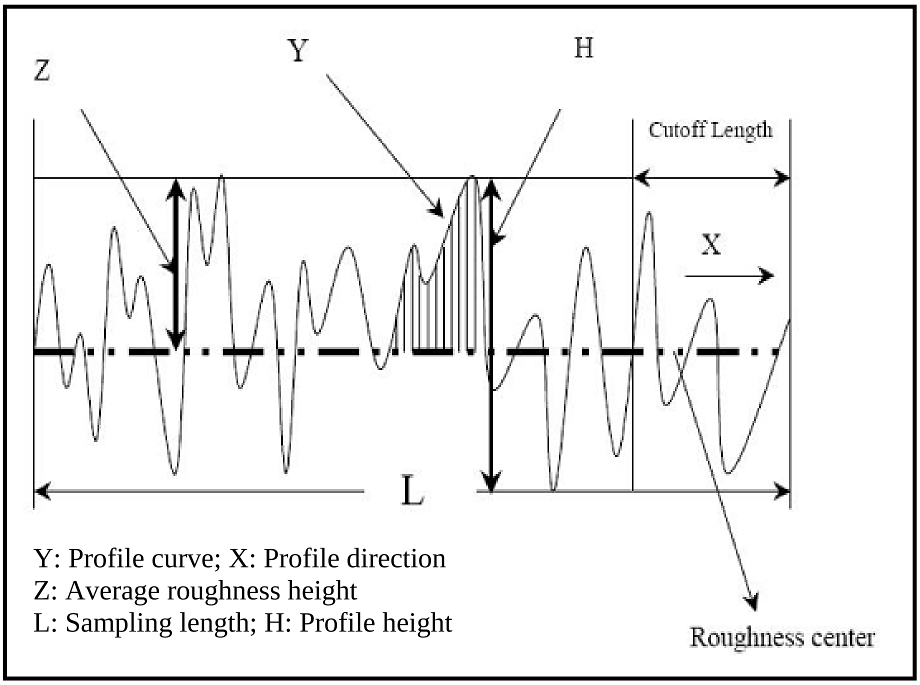

Fig. 2 Surface roughness profile (S. Thamizhmanii, 2007).

4. TAGUCHI METHOD

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost (S. Thamizhmanii, 2007).The main trust of the Taguchi techniques is the use of parameter design, which is an engineering method for product or process design that focuses on determining the parameter (factor) settings producing the best levels of a quality characteristic (performance measure) with minimum variation. Taguchi's approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics; hence it has gained a wide popularity in the engineering and scientific community (Raviraj Shetty, 2008). A large numbers 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 with only a small numbers of experiments. 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 by finding out significant factors fast (KUMAR D. M., 2008). Taguchi method is especially suitable for industrial use, but can also be used for scientific research (S. Thamizhmanii, 2007). Taguchi has used signal-noise [S/N] ratio as the quality characteristic of choice. There are several (S/N) ratios available depending on objective of optimization of the response. The characteristic with higher value represents better performance (e.g. tensile strength) is called “larger is better”. Inversely, the characteristic that has lower value represents better performance (e.g product shrinkage, surface roughness) is called “smaller is better” (Bučinskas, 2006 and S.S. Mahapatra, 2006). Therefore, for the present study, “smaller is better” has been depended to find the optimum machining (optimum cutting parameters) which result in a best surface roughness. The signal-noise [S/N] ratio is calculated from applying eq. (2) and eq. (3) (Raviraj Shetty, 2008):

i) For the “smaller is better” quality characteristic, the equation is:

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

ii) For the “larger is better” quality characteristic, the equation is:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \tag{3}$$

Where: S/N is the signal-noise ratio; n the number of observations; and y_i the observed data. To achieve the goal of this research “minimum surface roughness (R_a)”, the smaller (R_a) value, results in better surface roughness or enhancement the finishing of machined parts. The eq. (2) will therefore be used for that, and y_i will represent the surface roughness measurements that will be repeated three times for each experiment. The major steps of implementing the Taguchi method are demonstrated in the flow chart shown in **Fig. 3**.

5. EXPERIMENTAL DETAILS, RESULTS, ANALYSIS, AND DISCUSSION

The type of a machine used for carrying out the experiments in this study was traditional turning machine (Type SN 50 B Czechoslovakia), and the surface roughness values (R_a) of machined parts were measured by SRT 6210 shown in **Fig. 4**. The workpiece material that was used for performing experimental tests is from Al-12%Si alloy with dimensions (Ø15×50) mm. It is widely used in manufacturing some of the vehicles engines parts, and the carbide insert (SANDVIK DNMG 443 - diamond 55^{o}) has been used as a cutting tool.

After machining each specimen, three measurements were taken at different points (angles) along the turned part around the specimen. As mentioned previously, the high surface finish for machined parts demands reaching to minimum surface roughness average (R_a), therefore “smaller is better” was depended as a quality characteristic in this research. The experimental details, results, and analysis are described as follows:

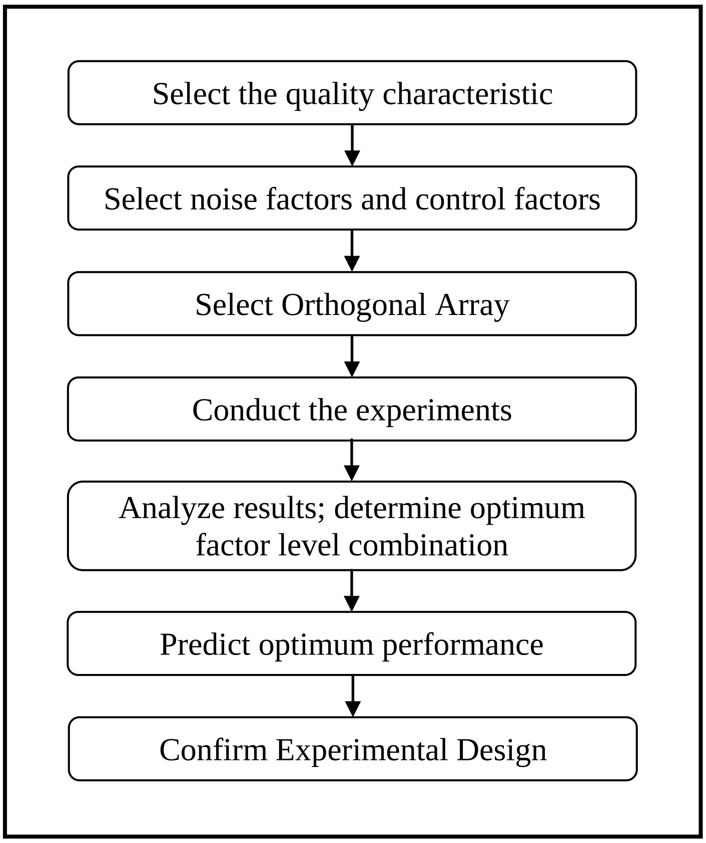

Fig. 3 Steps of Taguchi method achievement (H. Chen, 1996).

Fig. 4 Surface roughness tester.

4.1 Specification of Cutting Parameters (Factors) and Their Levels

The most important machining process variables that have a large impact on surface roughness are cutting parameters. According to literatures, the researchers frequently had studied the major parameters for machining: cutting speed, feed rate, and depth of cut, which have strong effect on the quality of machined surface. Some of them had studied other parameters besides the major parameters such as cooling fluid, nose radius, etc. Al-12%Si alloy was used as a workpiece material for the present work. The alloy has the chemical composition shown in **Table 1**, as well as, three controllable factors: Cutting Speed, Feed Rate, and Depth of Cut were depended (A, B, and C). The factors and levels are listed in **Table 2**.

Table 1 Chemical composition of Al-12%Si alloy

Si	Cu	Fe	Zn	Mg	Mn	Ti	Al
12.1	0.83	0.65	0.45	0.27	0.2	0.02	Rem.

Table 2 Cutting conditions and their levels

Symbol	Cutting Conditions	Unit	Level1	Level2	Level3
A	Cutting Speed	m/min	33.5	47	66
B	Feed Rate	mm/rev	0.08	0.12	0.20
C	Depth of Cut	mm	1.0	1.5	2.0

4.2 Selection of Orthogonal Array (OA)

The selection of an appropriate orthogonal array (OA) depends on the total degrees of freedom of process parameters. Degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is (S. Kamaruddin, 2004). Each factor of the three cutting parameters used in this study has three levels; a plenty of experiments will be needed. To achieve all these experiments, this demands much cost and time, so using the orthogonal array (OA) with many rows and columns leads to reduce cost and time of implementing tests by decreasing the number of experiments according to the orthogonal array. The L_9 orthogonal array with three columns and nine rows was appropriate selection in this study. The factors and levels for surface roughness are arranged as shown in **Table 3** such that each row of this table represents an experiment with different combination of factors and their levels. According to L_9 array, nine specimens were prepared to be machined and measured.

Table 3 The Taguchi L_9 orthogonal array

Experiment number	Cutting parameters level		
	A	B	C
	Cutting Speed m/min	Feed Rate mm/rev	Depth of Cut mm
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4.3 Results, Analysis, and Discussion

The conditions combination for the three cutting parameters: cutting speed, feed rate, and depth of cut have placed as shown in **Table 4** according to their places in the orthogonal array L_9 shown in **Table 3**. These conditions are considered as input (inner array). The surface roughness (R_a) was calculated as average for three different measurements for each experiment (noise factors in columns: n1, n2, and n3). Because the Signal-to-Noise ratio (S/N) should be as smaller as possible, the quality characteristic "smaller is better" was used. S/N values were calculated from eq. (2), and the results have been arranged in the last column of array. S.R and S/N ratio represent the output (outer array) in that array. Depending on n factor, the total number of values obtained is (n * experiment no. = 3 * 9 = 27 values). The results were analyzed by using main effects for both (R_a) values and Signal-to-Noise ratio (S/N), and ANOVA analyses. Then, a confirmation test was carried out to compare the experimental results with the estimated results.

4.3.1 Main Effects:

In terms of the average effects, the average value of surface roughness (R_a) and (S/N) ratio for each parameter (A, B, an C) at each level (level 1, level 2, and level 3) were obtained and the results are summarized in **Table 5** and **Table 6** respectively. For example, level 1 in **Table 5** is the average of S.R for the first three experiments 1, 2, and 3 labeled in Table **4**, therefore, level 1 for cutting speed condition A = (3.708 + 4.387 + 6.279) / 3 = 4.791. For B condition, level 1 is equal to (S.R at experiment no.1 + S.R at experiment no.4 + S.R at experiment no.7) / 3, this is according to the distribution of experiments in **Table 3**, therefore, level 1 for condition B = (3.708 + 2.494 + 7.272) / 3 = 4.491, and for the depth of cut, level 1 for C = (3.708 + 4.658 + 1.962) / 3 = 3.442, and so on for other levels.

The graph that shows the main effects for both R_a and S/N ratio can be represented as shown in **Fig. 5** depending on data in **Table 5** and **Table 6**. Because of using "smaller is better" quality characteristic in this study, the smaller average of (R_a) that appears in **Fig. 5** represents the higher quality of the surface, so the combination of parameters and their levels $A_2B_2C_1$(Cutting Speed 47m/min, Feed Rate 0.12 mm/rev, and Depth of Cut 1.0 mm) represents the optimum condition. The difference (max-min) of three levels for each parameter indicates that the depth of cut has the highest effect on the surface roughness followed by feed rate and cutting speed.

Table 4 Cutting conditions of experiments, S.R*, and S/N results

No. of runs	Experimental conditions			Individual S.R measurements for each experiment			S.R average (R_a) µm	S/N (dB)
	A	B	C					
	Cutting Speed m/min	Feed Rate mm/rev	Depth of Cut mm	n1 µm	n2 µm	n3 µm		
1	33.5	0.08	1.0	4.091	3.320	3.715	3.708	-11.415
2	33.5	0.12	1.5	4.461	4.904	3.798	4.387	-12.890
3	33.5	0.20	2.0	6.505	6.441	5.891	6.279	-15.966
4	47	0.08	1.5	2.988	2.454	2.042	2.494	-8.043
5	47	0.12	2.0	6.103	7.811	7.202	7.038	-16.993
6	47	0.20	1.0	4.449	4.155	5.371	4.658	-13.418
7	66	0.08	2.0	6.703	7.881	7.232	7.272	-17.252
8	66	0.12	1.0	1.837	2.138	1.911	1.962	-5.872
9	66	0.20	1.5	5.534	6.093	5.974	5.867	-15.375

*** Surface Roughness**

Table 5 Main effect table for R_a

Symbol	Cutting Conditions	Average of S.R (R_a) µm			Delta (max-min) µm	Rank
		Level1	Level2	Level3		
A	Cutting Speed m/min	4.791	4.730*	5.033	0.303	3
B	Feed Rate mm/rev	4.491	4.462*	5.601	1.139	2
C	Depth of Cut mm	3.442*	4.249	6.863	3.421	1

***Optimum Level**

Table 6 Main effect table for S/N ratio

Symbol	Cutting Parameters	Average of S/N dB			Delta	Rank
		Level1	Level2	Level3		
A	Cutting Speed m/min	-13.423	-12.818*	-12.833	0.605	3
B	Feed Rate mm/rev	-12.236	-11.918*	-14.616	2.698	2
C	Depth of Cut mm	-10.235*	-11.799	-16.737	6.502	1

***Optimum Level**

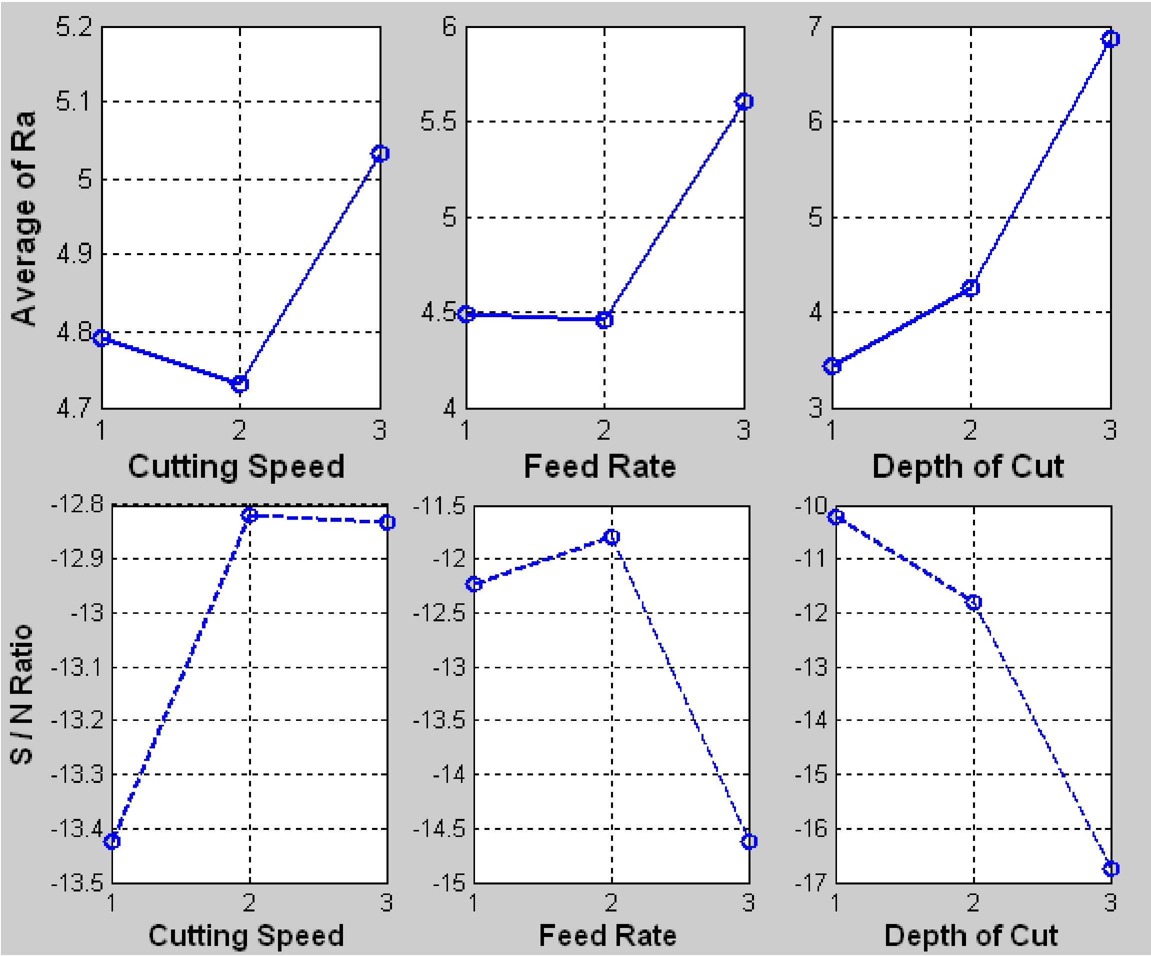

Fig.5 Main effects graph for Ra and S/N.

4.3.2 Analysis of Variance (ANOVA):

The analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant. It is widely used in the design of experiment, and it searches for the source of most influence. Therefore the purpose of the analysis of variance is to investigate which factors significantly affect quality characteristics (Sang-Heon Lim, 2006). The percent contribution of each parameter is evaluated to make a decision on how significant the effect of each parameter (Dasharath Ram, 2004). ANOVA table for the roughness test is organized as shown in **Table 7**.

Table 7 ANOVA table for the surface roughness

Symbol	Sum of Squares	Degrees of Freedom	Mean Squares	F value	Contribution (%)
A	0.716		0.358	0.02	0.5658
B	16.308	2	8.1539	0.39	12.888
C	67.241	2	33.6206	1.59	53.14
E	42.27	2	21.135		33.4
Total	126.535	8			100

4.3.3 Confirmation Test:

The final step of the Taguchi method is confirmation the results to verify the matching between the predicted result matches the experimental value, and this step is carried out after the optimal conditions of machining parameters are identified. The combination of the optimal levels of all the parameters should produce the optimal magnitude of surface roughness. The confirmation test is a repetition of the experiment at selected optimal levels of parameters to obtain the predicted value of the quality characteristic. As a result, eight samples were machined under the optimal parameter setting in this research for the purpose of confirmation test. The optimal levels for the controllable factors were cutting speed 47 m/min, feed rate 0.12 mm/rev, and depth of cut 1.0 mm. The results of confirmation test are shown in **Table 8**. It can be seen from this table that the difference between experimental result and the estimated result is very close such that the mean value (1.782 µm) is clearly close to the smallest value (1.837 µm) of surface roughness in **Table 4**. Therefore, the confirmation test indicates that the optimal levels, which have obtained above, produce the best surface roughness.

Table 8 the results of confirmation test

Specimen no.	1	2	3	4	5	6	7	8	M
R_a (µm)	1.907	2.929	2.496	1.478	1.826	1.109	0.998	1.517	1.782

M: Mean

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