Turning Parameters Optimization for Surface Roughness of Aluminum 7075via Taguchi Method

*Msc.Eisay F. Almshraqi, **Msc.Abubakr A. Karoud ***Msc.Sami A. Mashat

ABSTRACT

This paper deals with the optimization of turning process parameters of Aluminium alloy 7075 using Taguchi methodology. The cutting parameters considered for the study are feed rate, cutting speed, and depth of cut, with two different tool noses to get minimum surface roughness. The type of insert used was a tungsten carbide, while the coolant was soluble oilperformed at 150mL/hr. Taguchi orthogonal array (L9) using nine experimental runs are designed for machining. The results show that the optimum parameters of machining are obtained at a feed rate of 0.3mm/rev, cutting speed 900rpm, depth of cut 1.0mm in the case of nose radius (0.8mm), and a feed rate of 0.5mm/rev, cutting speed 900rpm, depth of cut 0.5mm in the case of nose radius (1.2mm). Confirmation tests with the optimal levels of cutting parameters were done to illustrate the effectiveness of the Taguchi optimization method. Taguchi method is found to be a very efficient tool to obtain an optimum surface roughness. The results show that the optimum parameters of machining are obtained at a feed rate of 0.3mm/rev, cutting speed 900rpm, depth of cut 1.0mm in the case of nose radius (0.8mm), and a feed rate of 0.5mm/rev, cutting speed 900rpm, depth of cut 0.5mm in the case of nose radius (1.2mm). Confirmation tests with the optimal levels of cutting parameters were done to illustrate the effectiveness of the Taguchi optimization method. Taguchi method is found to be a very efficient tool to obtain an optimum surface roughness.

*Staff member at Higher Institute of Technical Water Affairs, Ajelat, Libya, mshrgi08@yahoo.com

**Staff member at College of Engineering Technology-Janzour, Tripoli, Libya, a.karoud@cetj.edu.ly

*** Staff member at Collegeof Engineering Technology-Janzour, Tripoli, Libya, Sami9mash73@yahoo.com

I. INTRODUCTION

Computer numerical control (CNC) Lathes has become one of the most competent productive and flexible manufacturing machines, where specially designed for turning operations to produce complicated surfaces (A.M. Khan, et al 2020). The turning process is one of the most widely used material removal processes in the industry. It has the advantage of reduced lead time with smooth finishing (A.M. Khan, N. He, L. Li, W. Zhao, M. Jamil2020, pp. 111-118). It is widely used in a variety of manufacturing industries including the aerospace and automotive sectors (Krar, Stephen F, 2005 &Krar, Stephen F. J.W. Oswald, 1983). Lathe is used primarily to produce conical or cylindrical parts, flat faces, and curved surfaces. It is one of the most versatile machines in industry. Lathes come in all sizes from very small jewellers lathes used to produce watch parts to lathes that produce huge drive shafts for oil tankers. The principles on which they operate are all the same. A piece of stock is held in a chuk or collet and rotated against a cutting tool(LAWRENCE E. 1985, P508-510). As the competition grows, customers now have increasingly high demands on quality, making surface roughness one of the most competitive parameters in today's manufacturing industry (A Jayant, V Kumar, 2008).Surface roughness(Ra) is a measure of finer surface irregularities in the surface texture. It is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micrometres(N.MANOJ et al, 2017). The ability of a manufacturing operation to produce a specific surface roughness depends on many factors. For example, in turning process, the final surface depends on the cutting speed, the rate of feed, the depth of cut, nose radius of tool and mechanical properties of the piece being machined (Kishawy H.A. &Elbestawi M.A. 1999, PP 1017-1030,Thamizhmanii et al.

2007, Lin 2008,Gusri, A.I et al, 2008). A small change in any of the above factors can have a significant effect on the surface produced.

Design of experiments (DOE), described by the Taguchi principle, is one of the most important statistical techniques of total quality management (TQM). Taguchi methods provide an efficient and systematic way to optimize designs for performance, quality, and cost (Resit Unal and Edwin B. Dean, 1991). Fundamentally, traditional experimental design procedures are too complicated and not easy to use.

A large number of experimental works have to be carried out as the number of 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] (Bryne M.D. (1994) pp 39-47). It has been widely utilized in engineering analysis and consists of a plan of experiments to acquire data in a controlled way and to obtain information about the behaviour 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(E. Daniel Kirby, (2010 pp. 14-17). Engineering continue to desire materials 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. Aluminium is the world's most abundant metal and it is the third most common element comprising 8% of the earth's crust (Haynes, 2016–2017 p p. 14-17).

The versatility of aluminium makes it the most widely used metal after steel. Aluminium alloys are alloys in which aluminium is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. This paper aims to study the effect of turning parameters, resulting in an optimum value of surface roughness. The effects of the process machining parameters are very essential. The present method of selection of parameters on desired surface roughness has been accomplished using Taguchi's parameter design approach. In this paper the objective is to minimize surface roughness, so a smaller-the better criterion for each response has been implemented.

II. TAGUCHI PARAMETER DESIGN

The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. The general steps involved in the Taguchi Method are as follows:

A. 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 turning operation. Smaller Ra values represent better or improved surface roughness. Therefore, a smaller-the better quality characteristic was implemented and introduced in this study.

B. Selection of Control Factors

Previous studies indicated that depth of cut, cutting speed, and feed rate had significant effects on surface roughness in the machining operations. In this study, the controllable factors are feed rate (A), cutting speed (B), depth of cut (C),with two different nose radii of the tool, which were selected because they can potentially affect surface roughness performance in turning operation. 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
Feed rate (mm/rev)	0.3	0.5	0.7
Cutting speed (rpm)	500	700	900
Depth of cut (mm)	0.5	1	1.5

C. 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). Since three factors were studied in this research, three levels of each factor were considered. The orthogonal array selected as the L9, which has 9 rows corresponding to the number of tests with three columns at three levels,and each experimental run will have three data as shown in table (2). Therefore a total of (9×3) = 27 data values were collected for each nose radius.

Table (2) L9 Taguchi orthogonal array

Experiment number	Feed rate A	Cutting speed B	Depth of cut C
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

D. Conducting the Experiments

The workpiece used for the testes was in the form of round rod with diameter of 20mm and length of 130mm.Two inserts were used with two different nose radii; commercially available tungsten–based coated inserts flat faced cemented carbide (grade sandvik). These inserts have geometries identical to those designated by ISO (rhombus shape inserts 55°, with nose radius 0.8, 1.2 mm). The experiments, sorted in tables (3,4), were randomly run by the CNC machine. Three measured surface roughness data values were collected, S/N signal–to–noise ratio of each experimental run were calculated. Each experimental run were calculated based on the following equation:

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

Where n = number of measurements in a trial/row, in this case, n=3 and y_i is the ith measured value in a run/row. The average response values were also calculated and recorded.

Table (3): Experiment design (Nose radius 0.8 mm)

Experiment number	Feed rate A (mm/rev)	Cutting speed B (rpm)	Depth of cut C (mm)	Response value Ra1	Ra2	Ra3	Average response value	Sum of squares	MSD	S/N value
1	0.3	500	0.5	1.6	1.54	1.56	1.566667	7.3652	2.4551	-3.90063
2	0.3	700	1	1.58	1.6	1.56	1.58	7.49	2.4967	-3.97361
3	0.3	900	1.5	1.66	1.56	1.54	1.586667	7.5608	2.5203	-4.01446
4	0.5	500	1	2.4	2.58	2.54	2.506667	18.868	6.2893	-7.98605
5	0.5	700	1.5	4.68	4.24	3.68	4.2	53.4224	17.807	-12.506
6	0.5	900	0.5	2.76	2.68	2.8	2.746667	22.64	7.5467	-8.77755
7	0.7	500	1.5	6.12	5.34	4.96	5.473333	90.5716	30.191	-14.7987
8	0.7	700	0.5	4.36	5.88	6.34	5.526667	93.7796	31.26	-14.9499
9	0.7	900	1	5.1	4	3.98	4.36	57.8504	19.283	-12.8519

Table (4): Experiment design (Nose radius 1.2 mm)

Experiment number	Feed rate A (mm/rev)	Cutting speed B (rpm)	Depth of cut C (mm)	Response value Ra1	Ra2	Ra3	Average response value	Sum of squares	MSD	S/N value
1	0.3	500	0.5	0.58	0.54	0.54	0.553333	0.9196	0.3065	5.135223
2	0.3	700	1	0.76	0.8	0.78	0.78	1.826	0.6087	2.156205
3	0.3	900	1.5	0.8	0.74	0.74	0.76	1.7352	0.5784	2.377717
4	0.5	500	1	0.66	0.58	0.62	0.62	1.1564	0.3855	4.140132
5	0.5	700	1.5	0.88	0.94	0.82	0.88	2.3304	0.7768	1.096908
6	0.5	900	0.5	0.32	0.36	0.34	0.34	0.3476	0.1159	9.360415
7	0.7	500	1.5	0.94	1.1	0.88	0.973333	2.868	0.956	0.195421
8	0.7	700	0.5	0.5	0.52	0.54	0.52	0.812	0.2707	5.675652
9	0.7	900	1	0.58	0.6	0.56	0.58	1.01	0.3367	4.727999

III. 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 criterion is employed to determine the optimal cutting condition. By following the criteria of smaller surface roughness and larger S/N ratio, figures (2-3) used to determine the optimal set of parameters from the experimental design.

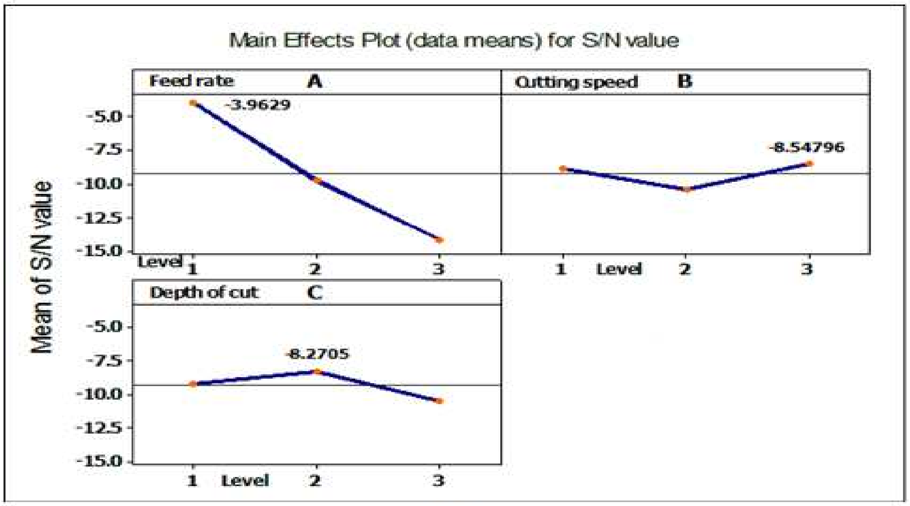

Figure (2) Means of S/N (Nose radius 0.8mm)

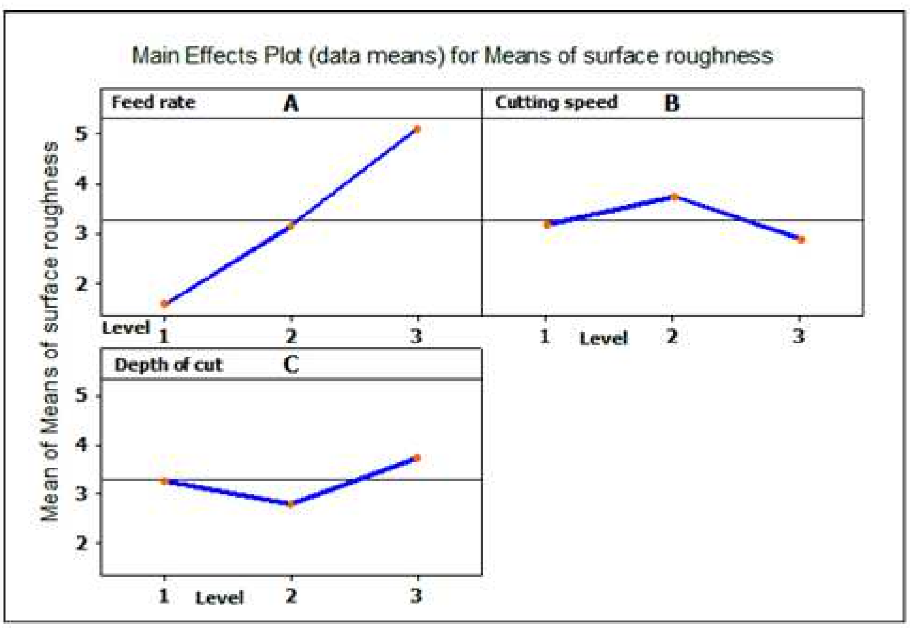

Figure (3) Means of surface roughness (Nose radius 0.8mm)

Figures (2&3) showthe control factor of feed rate (A) at level one (0.3mm/rev) 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. Besides, the lower surface roughness value had a better machining performance, and shows the control factors of cutting speed (B) at level three (900rpm), and depth of cut (C) at level two (1.0mm), provided the best results. Therefore, the optimum cutting condition will be; feed rate=0.3mm/rev (A1), cutting speed=900rpm (B3), and depth of cut=1.0mm (C2). The comparison of the optimal set of parameterswith data in the table (3) which represents the experimental design, new parameters arise and obtained and these parameters do not exist in table (3). To predict the mean for the treatment condition average of the result for the trail set, at this particular level is calculated by the following equation:

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

Where:

η_{calc}: The calculated S/N ratios at optimal machining conditions.

$\overline{\eta}_{avg}$: The average S/N ratios of all control factors.

$\overline{A}_i$: The average S/N ratio when the factor A (feed rate) is at level i.

$\overline{B}_i$: The average S/N ratio when the factor B (cutting speed) is at level i.

$\overline{C}_i$: The average S/N ratio when the factor C (depth of cut) is at level i.

The expression for surface roughness value is:

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

The average S/N ratios for all control factors $\overline{\eta}_{avg}$ and the average S/N ratio for each control factor $\overline{A}_1$, $\overline{B}_3$ and $\overline{C}_2$ can be obtained from the table (4) and from the figure (2).

Then the values of S/N ratios are substituted in Equation (2) and the calculated S/N ratios at optimal machining conditions will be:

$$\eta_{calc} = -9.30653 + (-3.9629 - (-930653)) + (-8.54796 - (-9.30653)) \\ + (-8.2705 - (-9.30653))$$

$$\eta_{calc} = -2.16827 \quad \text{dB}$$

Substituting this value in Equation (3) will give the surface roughness value as:

$$Ra_{calc} = 1.28355 \, \mu\text{m}$$

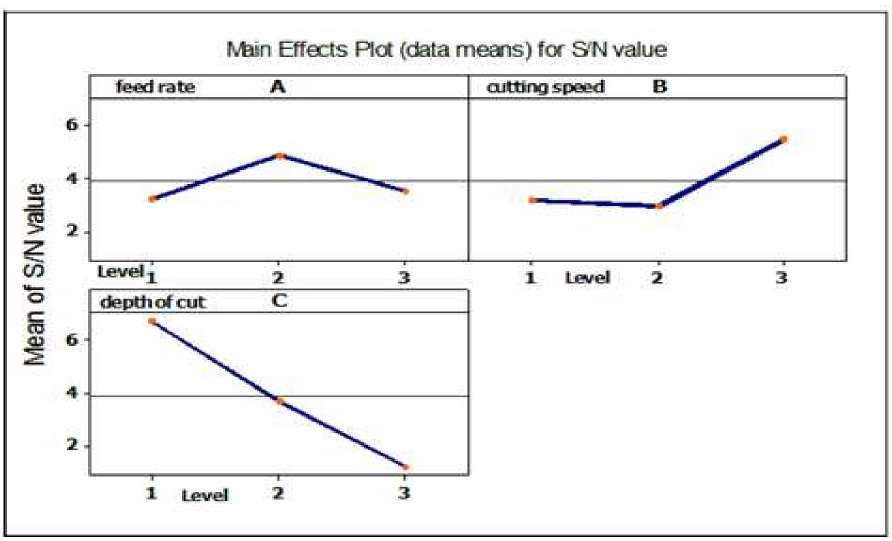

Figure (4) Means of S/N (Nose radius 1.2 mm)

Figure (5) Means of surface roughness (Nose radius 1.2mm)

Figures (4&5) show the control factors of feed rate (A) at level two (0.5mm/min), cutting speed (B) at level three (900rpm), and depth of cut (C) at level one (0.5mm), provided the best results. Therefore, the optimum cutting condition will be; feed rate=0.5mm/min (A2), cutting speed =900 rpm (B3), and depth of cut=0.5mm (C1). The comparison of the optimal set of parameters with the data in table (4) which represents the experimental design, these parameters are exist in the experiment number six and it is the optimal set of parameters.

Confirmation experiments are very important in validating the minimum surface roughness resulting from the optimum cutting conditions. The optimum cutting conditions were: feed rate 0.3mm/rev, cutting speed 900rpm and depth of cut 1.0mm. Two samples were cut under the optimal parameter set-up for the sake of confirmation. Surface roughness average for each sample; Ra=1.286μm and Ra=1.31μm were obtained. The mean of the surface roughness of thesetwo samples is Ra=1.298μm. It is very close to the predicted value of surface roughness (Ra_{calc}=1.28355μm). Therefore, the confirmation run indicated that the selection of the optimal levels for all the parameters produced the best surface roughness.

IV. CONCLUSIONS

The validity of Taguchi method in optimizing the cutting parameters for better surface roughness in turning operation is confirmed. The parameter under investigation is the surface roughness. This factor is studied using the method under the effect of three factors; feed rate, cutting speed, and depth of cut. The workpiece material was aluminium alloy 7075with the carbide cutting tools. Using Taguchi method, the optimum parameters for better surface roughness are obtained at a feed rate 0.5mm/rev, spindle speed 900rpm and depth of cut 0.5mm, (i.e., A2−B3−C1). Confirmation experiments at optimal conditions were carried out. The outcomes of experimental results are fairly close to the predicted values. The mean surface roughness of the two confirmation samples (1.298μm) was very close to the predicted value of surface roughness (1.28355μm). It can be concluded that better optimization of cutting parameters is necessary 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 found to be an efficient method for optimizing surface roughness in turning operations and it can obtain a remarkable saving in time and cost.

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