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Experimental investigation of cutting conditions parameters on surface roughness in aluminum alloys (AL-2024)

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ABSTRACT

The purpose of this search is to study the main factors on the surface roughness in (AL-2024) using a CNC milling machine for an HSS tool with flat end milling. And by using the Taguchi experience design method to conserve time and costs. To determine the optimal values of surface roughness using Taguchi optimization. We then performed an analysis of variance and regression. Confirmation tests were performed to verify work. The cutting process consists of two stages; the first stage is the cutting process in the upper direction of the cutting, using a coolant and dry cutting. The second stage is the cutting process in the lower direction of the cut, using a coolant and dry cutting the results show the best operating condition to obtain the best surface roughness of the product by using the bottom grinding, measuring the surface process surface roughness using the cutting conditions of the cutter (feeding) = 15 mm/min), (cutting depth = 1 mm) and (cutting speed = 37.68 (m/min) surface roughness (Ra = 0.17 µm) compared with the other value obtained.

1. Introduction

Surface roughness is one of the most important factors in determining product quality. The mechanism underlying surface roughness formation is highly dynamic, complex, and process count on. The factors that influence Finished surface roughness in CNC milling operation can be controlled factors (such as spindle speed, feed rate, and depth of cut) and cannot be controlled factor-like (material properties of performance, workpiece, and performance geometry) [1]. The surface roughness has a large role in fatigue strength and wears resistance, surface friction, light reflection, lubricant holding capacity, electrical and thermal contact resistance, appearance, cost, etc. As the high quality of the surface after final grinding and with further automated surface treatment is unnecessary, results in reduced energy consumption and environmental tolerance. However, surface roughness improvement constantly Challenges uncertainty in the foretelling model as well as the many impacts parameterized, which can be split into controlled and uncontrolled parameters. [2] Determine the appropriate processing conditions by checking the surface roughness of milling aluminum alloy 7075-T6. The Taguchi experimental design method was utilized to save time and cost. And to determine the optimal values of surface roughness using Taguchi optimization. Analysis of variance and regression analysis were performed. Affirmation tests were performed to work. From the results of confirmation tests, it was found that the improvement of surface roughness in milling aluminum alloy 7075-T6 has been swimmingly applied. (Neslihan ÖZSOY, 2019). [3] Studied the cutting conditions such as cutting feed, cutting depth, and spindle speed on milling of the end of 6061 aluminum to predict the surface roughness. He developed two mathematical models; the first for dehydration and the second for Minimum Quantity Lubrication (MQL) fabrication used multiple retreating analyses that predict the surface roughness of aluminum end milling in dry environments and Minimum Quantity Lubrication (MQL). An analysis of variance (ANOVA) is used to find the importance of the cut-off parameters on the surface roughness. Ojolo Sunday Joshua

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and et al. 2015. [4] A study was carried out to improve the surface roughness during processing in grinding Al6005A alloy. Taguchi-Gray relations and ANOVA were used to investigate the effects of the parameters. Billy Joe et al. 2018 [5]. Studied the improvement of surface roughness in the manufacture of GFRP composite. The experiments were planned according to the orthogonal matrix L27 and found the optimal levels of parameters by the method of Taguchi. Parida AK et al., 2015 [6]. Studied the cutting tool, cutting speed and feed rate on the surface roughness of AA7075-T6 in the grinding process. The results showed that there was an increase in the surface roughness rate with an increase in the feeding rate. But the surface roughness decreases when cutting speed increases. Tosun N, and et al, 2010 [7]. The processing of austenitic stainless steels is optimized for cut sizes FC, Ra, and Radius nose. Experiments were carried out using the Taguchi method. Günay M, 2013[8]. Studied the spindle speed, feed rate, axial/radial depth of cut-off radius and nose, and their bidirectional interactions on surface roughness. The Taguchi method is used to form AA5083-H36 alloy. They improved using the S/N ratio and ANOVA, Pinar AM, et al, 2016 [9]. The work aims to show the following points:

1. Study of the effect of Direction of Cutter Rotation on cutting conditions (feeding rate, cut cutting depth)
2. The Effect of Direction of Cutter Rotation on Work Surface Roughness with different cutting conditions

2. Experimental work

2.1 The direction of cutter rotation

The cutting direction, as there are two types of cutter movement in the Milling process, the first type is Up Cut Milling, which is the rotation of the cutter in the opposite direction to feed the table and is always used traditionally because it gets rid of the backlash between the leadscrew and the machine nut. The second type, is called Down Cut Milling, and the direction of rotation of the cutters is in the same direction as the table feed but it can only be used on machines equipped to be backslash remover or on a CNC milling machine.

2.2 Taguchi method

The Taguchi method was widely applied in the 1960s by Genichi Taguchi, where it proved to be very successful in improving the quality of industrial products. Where researchers increased their interest in this way day after day. Especially after reducing the experiments and the ease of application and evaluation. The Taguchi method is a method for designing and improving an experiment that depends on parameters design and system design. It is most ordinarily used in the Statistical Analytics of data composed by quality emphasis systems. Therefore, Taguchi's experimental design is an excellent method because it determines the optimal integration between different levels for different parameters.

Researchers have used these experiments to determine and understand a particular system or process. Monitoring and analyzing the outputs of this process or system, as well as modifying and analyzing them [11].

The purpose of the Taguchi method is to design and improve an experiment as it depends on design parameters. Optimization can be defined as the optimum use of the limited resource available. Improvement is very important in academic studies. Scientists used different methods intending to improve their work [12-14].

2.3 Workpiece material

Consist of an Aluminum alloy block, the dimensions of the block are as follows the length of 220mm, the width of 220mm, and the height of 4mm. Table (1) shows the composition chemical of the sample examined.

2.4 Machine model

A milling machine was used to perform the type of experiment (KNUTH) model (vector 610) in the university of technology /Training Center and Laboratories.

2.5 Cutting tool

One type of End milling cutter is used in this work: -

Flat End milling cutter (Four Flutes). With diameter (8mm) made from high-speed steel.

2.5.1 Up milling

A-Dry machine

B-Fluid machine

Figure 1. Cutting tools (a) dry machine (b) fluid machine

2.5.2 Down milling

A- Dry machine

B-Fluid machine

Figure 2. Cutting tool (a) dry machine (b) fluid machine

Figure 3. Cutting tool

Table 1. Chemical installation of the AL 2024

Si%	Fe%	Cu%	Mn%	Mg%
0.089	0.188	5.040	0.360	1.420
Cr%	Ni%	Zn%	Ti%	Al%
0.008	0.006	0.028	0.039	Bal.

Table 2. Geometry and properties of cutting tools

Cutting Tool	Material	Length of flute (mm)	All length (mm)
4 flutes	HSS	30	71

Table 3. The specifications of (Mar Surf PSI)

Term	Ra 0.03µm to 12.7µm
Probe	Head probe 20µm
Travelers length	1.75 mm, 5.6 mm, 17.5 mm, automatically

3. Results and discussions

3.1 Surface roughness measuring device

The American Mar Surf PS1 device shown in figure (5) has been used and according to the specifications listed in the table (5), It was used to measure the surface roughness. Where the parameter to be along the automatic motion (Ra) is special to specify because it is easy to use and is widely used as a surface roughness index parameter.

Figure 4. Surface roughness measuring device

3.2 Up-cut milling

The following are the up-cut milling of dry the machine, and fluid cases respectively.

Table 4. Conditions in the taguchi method experiments

Cutting Speed	Feed Rate	Surface Roughness	SNRA1	MEAN1
18.84	10	4.10	-12.2557	4.10
18.84	15	3.61	-11.1501	3.61
18.84	20	1.52	-3.6369	1.52
18.84	25	1.06	-0.5061	1.06
25.12	10	1.14	-1.1381	1.14
25.12	15	1.24	-1.8684	1.24
25.12	20	0.49	6.1961	0.49
25.12	25	0.49	6.1961	0.49
31.40	10	4.63	-13.3116	4.63
31.40	15	0.58	4.7314	0.58
31.40	20	1.60	-4.0824	1.60
31.40	25	0.87	1.2096	0.87
37.68	10	1.84	-5.2964	1.84
37.68	15	1.87	-5.4368	1.87
37.68	20	2.72	-8.6914	2.72
37.68	25	4.85	-13.7148	4.85

Table 5. ANOVA analysis of the signal-to-noise ratio of the surface roughness

Variance Source	Degree of Freedom,υ	Sum of Squares, ss	Variance, V	P (%)
Cutting Speed, VC (mm/min)	3	9.39	3.1	28.42
Feed Rate, f (mm/min)	3	4.37	1.1	13.24
Error,e	12	---	---	---
Total	16	33.02	---	---

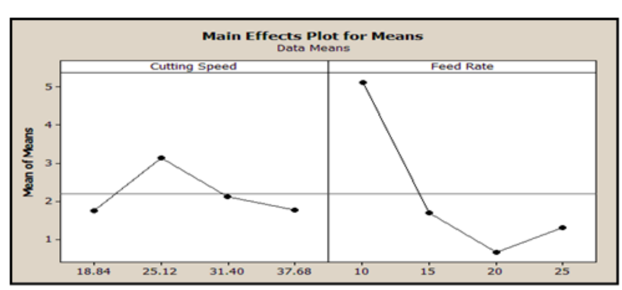

Figure 5. The influence of feed rate and cutting speed on surface roughness for UP cut milling on dry machine

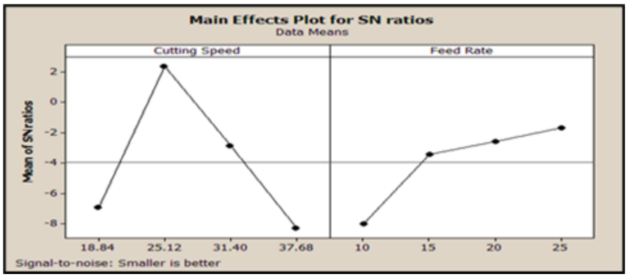

Figure 6. Main effects plot for S/N ratios on surface roughness for UP cut milling on the dry machine

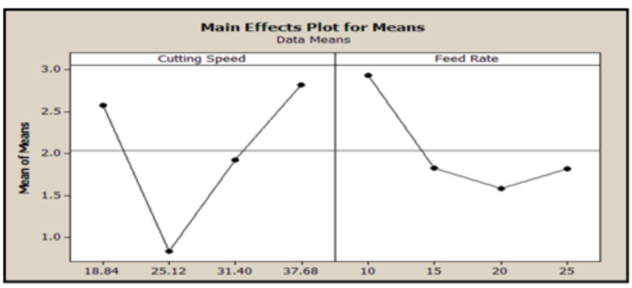

Figure. 7. The influence of feed rate and cutting speed on surface roughness for UP cut milling on fluid machines

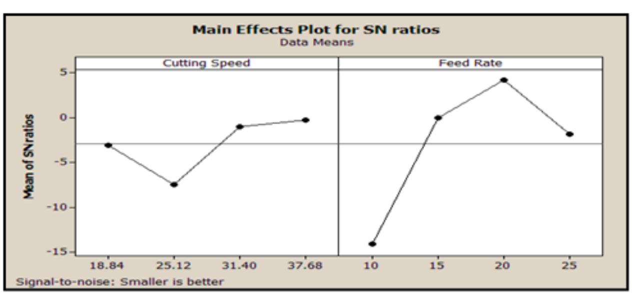

Figure. 8. Main effects plot for S/N ratios on surface roughness for UP cut milling on fluid machines.

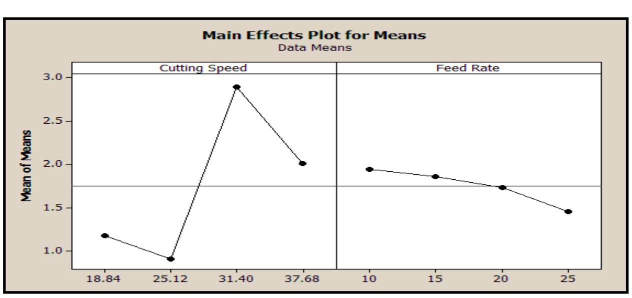

Figure 9. The influence of feed rate and cutting speed on surface roughness for down cut milling on dry machine

Table 6. Fluid machining conditions in the taguchi method experiments.

Cutting Speed	Feed Rate	Surface Roughness	SNRA1	MEAN1
18.84	10	3.91	-11.8435	3.91
18.84	15	1.40	-2.9226	1.40
18.84	20	0.90	0.9151	0.90
18.84	25	0.82	1.7237	0.82
25.12	10	5.75	-15.1934	5.75
25.12	15	4.62	-13.2928	4.62
25.12	20	0.87	1.2096	0.87
25.12	25	1.35	-2.6067	1.35
31.40	10	5.75	-15.1934	5.75
31.40	15	0.48	6.3752	0.48
31.40	20	0.29	10.7520	0.29
31.40	25	1.96	-5.8451	1.96
37.68	10	5.03	-14.0314	5.03
37.68	15	0.33	9.6297	0.33
37.68	20	0.63	4.0132	0.63
37.68	25	1.08	-0.6685	1.08

Table 7. ANOVA analysis of the signal-to-noise ratio of the surface roughness

Variance Source	Degree of Freedom,υ	Sum of Squares, ss	Variance, V	P (%)
Cutting Speed, VC (mm/min)	3	5.15	1.72	8.22
Feed Rate,f (mm/min)	3	47.40	15.80	75.71
Error,e	12	---	---	---
Total	16	62.60	---	---

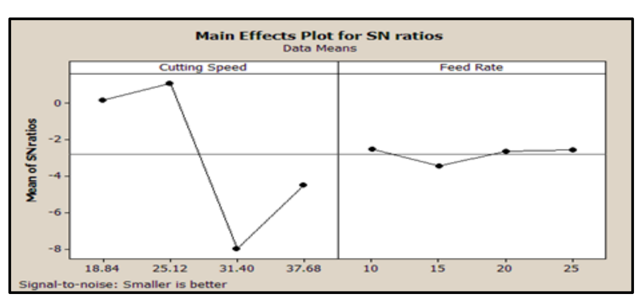

Figure 10. Main effects plot for S/N ratios on surface roughness for down-cut milling on dry machine

Table 8. Dray case: machining conditions in the taguchi method experiments

Cutting Speed	Feed Rate	Surface Roughness	SNRA1	MEAN1
18.84	10	0.60	4.4370	0.60
18.84	15	0.70	3.0980	0.70
18.84	20	0.38	8.4043	0.38
18.84	25	0.44	7.1309	0.44
25.12	10	0.87	1.2096	0.87
25.12	15	0.36	8.8739	0.36
25.12	20	0.49	6.1961	0.49
25.12	25	0.74	2.6154	0.74
31.40	10	0.66	3.6091	0.66
31.40	15	1.35	-2.6067	1.35
31.40	20	0.62	4.1522	0.62
31.40	25	0.22	13.1515	0.22
37.68	10	0.27	11.3727	0.27
37.68	15	0.17	15.3910	0.17
37.68	20	0.49	6.1961	0.49
37.68	25	0.33	9.6297	0.33

Table 9. Fluid case: ANOVA analysis of the signal-to-noise ratio of the surface roughness.

Variance Source	Degree of Freedom,υ	Sum of Squares, ss	Variance, V	P (%)
Cutting Speed, VC (mm/min)	3	9.62	3.21	37.93
Feed Rate,f (mm/min)	3	0.55	0.18	2.16
Error,e	12	---	---	---
Total	16	25.36	---	---

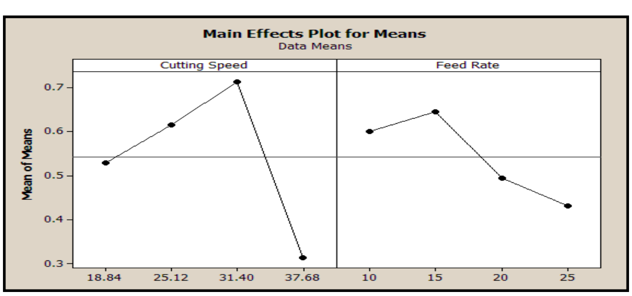

Figure 11. The influence of feed rate and cutting speed on surface roughness for down-cut milling on fluid machines

Table 10. Machining conditions in the taguchi method experiments

Cutting Speed	Feed Rate	Surface Roughness	SNRA1	MEAN1
18.84	10	0.53	5.5145	0.53
18.84	15	2.10	-6.4444	2.10
18.84	20	0.53	5.5145	0.53
18.84	25	1.56	-3.8625	1.56
25.12	10	1.11	-0.9065	1.11
25.12	15	0.59	4.5830	0.59
25.12	20	0.83	1.6184	0.83
25.12	25	1.12	-0.9844	1.12
31.40	10	5.05	-14.0658	5.05
31.40	15	1.07	-0.5877	1.07
31.40	20	3.11	-9.8552	3.11
31.40	25	2.35	-7.4214	2.35
37.68	10	1.08	-0.6685	1.08
37.68	15	3.69	-11.3405	3.69
37.68	20	2.48	-7.8890	2.48
37.68	25	0.79	2.0475	0.79

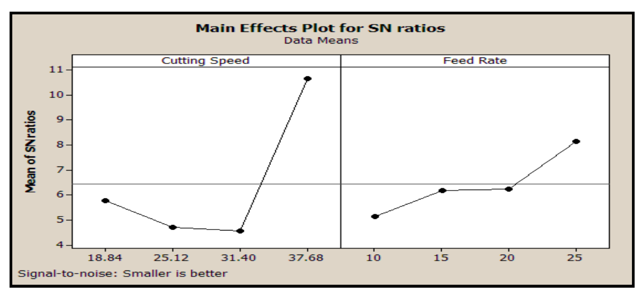

Figure 12. Main effects plot for S/N ratios on surface roughness for down-cut milling on fluid machines

Table 11. ANOVA for the signal-to-noise ratio analysis of surface roughness

Variance Source	Degree of Freedom,υ	Sum of squares, ss	Variance, V	P (%)
Cutting Speed, VC (mm/min)	3	0.3443	0.1148	26.81
Feed Rate, f (mm/min)	3	0.1127	0.0376	8.77
Error,e	12	---	---	---
Total	15	1.2841	---	---

Figures (6, 8, 10, and 12) indicate. The cutting conditions directly affect the surface roughness, as in the case of an increase in the feeding rate and a constant cutting speed, we notice that the average surface roughness increases, as well as in the case of an increase in the cutting speed and with a constant feeding rate, we also notice that there is an increase in the surface roughness rate. Through Taguchi Method, the best cutting conditions were predicted to obtain the best surface roughness results, The best surface roughness is in down cut milling, by using fluid, measuring the surface roughness of the operating surfaces using cutting conditions for the cutter (feed = 15 mm/rev, depth of cut = 1 mm and Cutting speed = 37.68 (m/min)) the surface roughness (Ra) was = (0.17 µm) compared with other values obtained. And that the most influential factor through the ANOVA is the cutting speed. It is worth mentioning that in down milling, the cutting tool is fed with the trend of rotation.

4. Conclusion

1. The best surface roughnesses are in down cut milling cut, using fluids, and at a higher cutting speed, where we notice an improvement in the surface roughness values.
2. In down milling, the thickness of the chips decreases from the beginning of cutting, gradually reaching zero at the end of cutting. These forbid the edge prevents rubbing and polishing on the surface before engaging in cutting.
3. The best surface roughness results were obtained, and the best shipping conditions were predicted by the Taguchi method. This is done by designing experiments based on special design criteria. Therefore, Taguchi's method is excellent because it determines the optimal integration between different levels for different parameters.
4. Using ANOVA, it was shown to us that cutting speed is the most influential factor in surface roughness.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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