Academic Platform Journal of Engineering and Science 8-2, 222-229, 2020

Academic Platform Journal of Engineering and Science

journal homepage: http://apjes.com/

Influence of Dry-Wet Machining Conditions on Surface Roughness of 6082-T6 Aluminum Alloy in Milling Process

*[1]Neslihan Ozsoy, [2]Murat Ozsoy

[1] Sakarya University, Department of Mechanical Engineering, Sakarya, Turkey, nerken@sakarya.edu.tr,

[2] Sakarya University, Department of Mechanical Engineering, Sakarya, Turkey, ozsoy@sakarya.edu.tr,

Research Paper | Arrival Date: 19.07.2019 | Accepted Date: 11.12.2019

Abstract

In present study the optimum processing conditions were detected by exploring the surface roughness of the 6082-T6 aluminum alloy during milling, depending on the feed per tooth (0.03, 0.05, 0.07, 0.09 mm/tooth), spindle speed (1000,1500, 2000, 2500 rpm) and cooling type (air, liquid) parameters. Experiments designed according to Taguchi's L16 orthogonal array. With the help of Signal/Noise ratios, the appropriate levels of the parameters have been determined to reduce the surface roughness value to the smallest value. The optimized machining conditions for surface roughness were observed 0.03 mm/tooth of feed per tooth and 2500 rpm of spindle speed and cooling by liquid. Variance and regression analysis were also made in the study. It was obtained that feed per tooth was the dominant parameter on surface roughness according to the analysis results. As last step, confirmation tests were carried out to check the success of the study.

Keywords: Optimization, Surface roughness, Taguchi method, ANOVA, Milling of Aluminum Alloy

1. INTRODUCTION

Due to the demand for more precise and complex products in the areas of volume molding, automotive and aerospace, machinability becomes even more important. Especially the high speed CNC machine tools, the flexibility of CAD/CAM software and the developments in cutting tool technology show that the studies in this area are distributed in a wide range.

Aluminum alloys with high strength/weight ratios, good corrosion/fatigue resistance and high metal removal rates constitute a large part of the workability of milling operations. Surface roughness is one of the most important quality components seen after the machining process. Therefore, researchers focus on this issue. The effects of variables such as cutting parameters (axial cutting depth, cutting speed, feed rate and radial depth), cutting tool geometry or material, tool temperature, vibration and workpiece material, tool wear on surface roughness are investigated [1-7].

When examining the quality of a product, many factors are looked at. Surface roughness is very important in terms of technological quality. It is also a factor affecting the production cost [8]. The basis for the formation of surface roughness is a complex mechanism. Therefore, it is quite difficult to calculate with theoretical analyzes. The trial plan is produced in the Taguchi method using standard orthogonal arrays. The experimental results are then analyzed using the mean analysis of the influencing factors and variance analysis (ANOVA).

Researchers' interest in the Taguchi method is increasing day by day, especially due to the low number of experiments, ease of application and easy evaluation of qualitative variables [9].

Experimental working needs to spend too much time so it is hard. Taguchi method is useful to avoid this. Many researchers have used this method [10-15].

Researches in literature show that many factors affect the surface roughness, such as the type of material, cutting tool, cutting speed and progress, cutting depth, coolant and machine construction [16-19]. However, the effects of the factors causing change can be different and independent or they may be related to each other. In this study, the surface roughness was evaluated statistically by using ANOVA in the milling of 6082-T6 aluminum alloy with uncoated cemented carbide by using the Taguchi method, which has gained considerable importance in the last 10 years.

*Sorumlu Yazar: Sakarya Üniversitesi, Mühendislik Fakültesi, Makine Mühendisliği Bölümü, nerken@sakarya.edu.tr, +90 264 295 57 96

Doi: 10.21541/apjes.594277

Unlike the literature, the Taguchi method was used to select the parameters and levels that were not previously used together and their effects on surface roughness were investigated.

2. MATERIALS AND METHODS

This section provides information about the work piece material, machine, cutting tool, method and experimental plan used in the study.

2.1. Taguchi Method

Experiments are used by researchers to identify and understand a system or a specific process [20].

The Taguchi design method used in this study is a design process developed by Genichi Taguchi. It is a set of methodologies that take account of the difference in material and production processes at the design stage. Taguchi design lets researchers more factors to take into consider easily. In this method, not only control factors but also noise factors are taken into consideration. The Taguchi design, as compared to the experimental design (DOE), executes only combinations of balanced (orthogonal) experiments. This makes the Taguchi design more effective than the fractional factor design. Thanks to the Taguchi technique, the product development cycle for both design and production can be greatly reduced in the industry, thus increasing costs and profits. In addition, Taguchi design considers ignored noise factors in the traditional experimental approach [9].

With the orthogonal sequences used in this method, the number of tests is significantly reduced and the effects of uncontrollable factors are minimized. On the other hand, it creates an easy, efficient and systematic method to identify the most appropriate parameters in production [21-25].

2.2. Work Piece Material, Machine and Cutting Tool

The work piece material selected for investigation is 6082-T6 aluminum alloy with the compositions as shown in Table 1. The alloy has 95 HB hardness, yield strength of 250 Mpa, tensile strength of 310 MPa and elongation of 10%. The dimensions of the work piece used in experimentation are 20x150x70 mm^3.

Table 1. Chemical components of the workpiece

Element	Fe	Si	Cu	Mn	Mg	Zn	Cr	Other	Al
Weight (%)	0.5	0.7-1.3	0.1	0.4-0.1	0.6-1.2	0.2	0.15	0.15	Rest

All experiments were carried out at dry and wet conditions in TAKSAN vertical machining center which has three axis machining capability in Sakarya University laboratory. Three flute uncoated cementitious carbide end mill cutter with a 45° helix angle manufactured by ISCAR, was used for trajectory milling with a 1 mm depth of cut the specimen AA6082 T6 at 150x70x20 mm^3. Each test was repeated three times at dry and wet machining conditions, then surface roughness was measured and averaged.

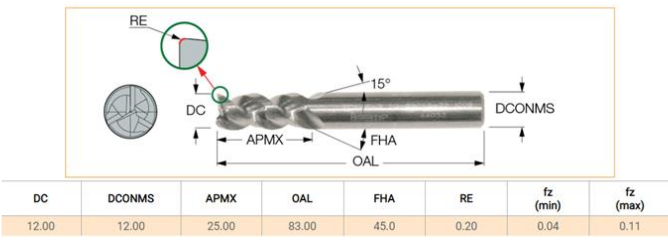


Figure 1. ECA-B-3 10-22C-72 Item numbered cutting tool

The diameter of the end mill was selected as 10 mm. The cutting tool used during the test is mainly used for aluminum and high temperature alloys at low and medium cutting speeds. The image of the cutting tool is shown in Figure 1 and trajectory milling process applied specimens are shown in Figure 2.

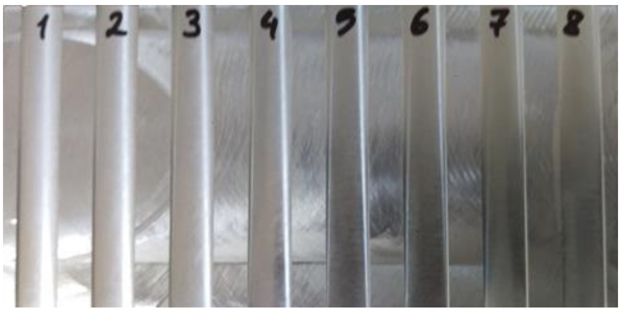


Figure 2. Machined part of 1 to 8 experiments

2.3. Experimental Plan and Procedure

Three different parameters as feed per tooth, spindle speed cooling type were chosen in the experiment design. Selected parameters and levels are specified in Table 2. According to full factorial experiment design 4x4x2=32 experiments were required. In Taguchi method orthogonal array is used to decrease experiment numbers. The most suitable orthogonal array L16 (mixed level) was selected to determine optimum conditions and analyze the parameters [26]. Thus Taguchi method reduced the experiment number to 16. All statistical analyses were performed using the Minitab 17 statistical package program at 95% confidence level.

MAHR-MARSURF PS1 model desktop roughness measurement instrument was used to measure surface roughness values. Measurements were taken at room temperature. The instrument measures according to DIN EN ISO 3274 standards. Measurements were taken from the workpiece on the same axis at one point. The cutting length (Lc) was chosen as 0.8 mm and the sampling length (Lt) as 5.6 mm for the measurement of the surface roughness values which occurred during machining on the workpiece.

Table 2. Selected parameters and levels

Symbol	Parameters	Level1	Level2	Level3	Level4
A	Feed per tooth, mm/tooth	0.03	0.05	0.07	0.09
B	Spindle speed, rpm	1000	1500	2000	2500
C	Cooling type	Air	Liquid		

3.RESULTS AND DISCUSSIONS

In this section, signal/noise analysis, variance analysis, regression analysis, surface graphs, probability analysis and confirmation tests are given.

3.1. S/N Ratio Results

The average surface roughness (µm) measurements made and their average values are given in Table 3. Optimization was done with the help of the results obtained. In this optimization process, there are three different convenient functions known as the Taguchi loss function, also referred to as the signal to noise ratio (S/N-Signal/Noise) function. These are “the higher the better”, “the nominal is the best”, “the lower the better”. We want to decrease surface roughness. So “the lower the better” approach was used and shown in equation (1) below.

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

where: y_i=observed data at the i_{th} experiment, n=the number of observations of the experiment [11].

“S/N response table” shows the effect of each parameter on the surface roughness in Table 4. S/N analysis made by Taguchi method provides to find out optimal levels for the optimal surface roughness.

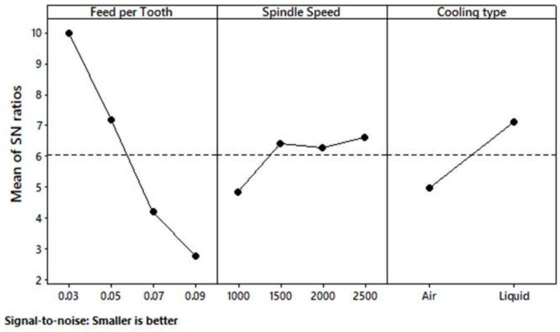
Table 3. The results of the experiments

Experiment no	Feed per tooth, mm/tooth	Spindle speed, rpm	Cooling type	Surface Roughness, R_a, µm	S/N ratio for R_a, dB
1	0.03	1000	Liquid	0.37725	8.4674
2	0.03	1500	Liquid	0.26250	11.6174
3	0.03	2000	Air	0.32100	9.8699
4	0.03	2500	Air	0.31350	10.0752
5	0.05	1000	Liquid	0.39100	8.1565
6	0.05	1500	Liquid	0.36325	8.7959
7	0.05	2000	Air	0.52925	5.5268
8	0.05	2500	Air	0.48775	6.2361
9	0.07	1000	Air	0.81350	1.7928
10	0.07	1500	Air	0.67000	3.4785
11	0.07	2000	Liquid	0.50750	5.8913
12	0.07	2500	Liquid	0.52450	5.6051
13	0.09	1000	Air	0.89200	0.9927
14	0.09	1500	Air	0.81675	1.7582
15	0.09	2000	Liquid	0.64450	3.8155
16	0.09	2500	Liquid	0.59300	4.5389

Table 4. S/N response table

Level	A	B	C
1	10.007	4.852	4.966
2	7.179	6.413	7.111
3	4.192	6.276	-
4	2.776	6.614	-
Delta	7.231	1.761	2.145
Rank	1	3	2

Mean of S/N ratio graphs are shown in Figure 3. The optimum level of each parameter was determined according to the highest signal to noise ratio of these control factor levels. Hence, the levels for the parameters giving the best R_a value were detected as factor A (Level 1, S/N=10.007), factor B (Level 4, S/N=6.614) and factor C (Level 2, S/N=7.111). That means an optimum R_a value can be measured with these levels of factors [11].



,

Figure 3. S/N graphs for surface roughness

3.2. ANOVA Results

With Variance Analysis (ANOVA), the effects of which factors are effective on the process are determined statistically. In the analysis of variance, the aim is to determine the extent to which the factors examined affect the output values selected in order to measure the quality and how the different levels effect the results.

In addition, the statistical reliability of the results obtained is also tested. With the help of ANOVA the effects of feed per tooth, spindle speed and cooling type on surface roughness were found. Table 5 shows the ANOVA results for the surface roughness. In the variance analysis (ANOVA) performed in this study, the confidence interval was 95% and significance level was 5%.

The effects of parameters in ANOVA is calculated by comparing the F ratio of each parameter. The last column of the table gives the contribution rate of each parameter, defining the degree of impact on measurements.

The contribution rates of the A, B and C factors on the surface roughness were found to be 74.13%, 7.93% and 15.4% respectively. From these results effective parameter on the surface roughness were feed per tooth (factor A, 74.13%). This results are in consistincy with literature [27, 28].

Table 5. Analysis of variance results for surface roughness

Source	Degree of freedom	Sum of squares	Mean square	F ratio	Contributi on rate (%)
A	3	0.418961	0.139654	78.14	74.13
B	3	0.044844	0.014948	8.36	7.93
C	1	0.087062	0.087062	48.71	15.4
Error	8	0.014299	0.001787	-	2.53
Total	15	0.565165	-	-	100

3.3. Regression Analysis of Surface Roughness

Regression analysis is the analysis method used to measure the relationship between two or more variables [29]. Because of the different parameters in the study, regression analysis can be performed for surface roughness [30]. In this study, the dependent variable is surface roughness, whereas the independent variables are feed per tooth (ft), spindle speed (ss) and cooling type (ct). For the surface roughness, the estimated equations (2) and (3) given below are obtained by regression analysis.

$$R_a = 0.1813 + 7.200\ f/t - 0.000089\ ss\ (ct=liquid) \qquad (2)$$

$$R_a = 0.3288 + 7.200\ f/t - 0.000089\ ss\ (ct=air) \qquad (3)$$

R-sq=95.76% R-sq (adj)=94.70%

where: R_a=surface roughness, f/t=feed per tooth, ss=spindle speed and ct=cooling type.

Equation (2) was used when the cooling type had been liquid and equation (3) was used when the cooling type had been air. The actual test results obtained with the linear regression model and the estimated values are compared in Figure 4. R^2

for the linear regression model for R_a was calculated as 95.76%.

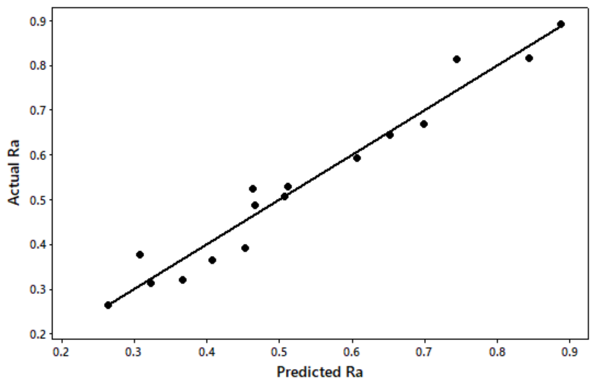


Figure 4. Comparison of predicted R_a found by linear regression model with actual R_a

3.4. Surface Graphs

3D surface graphics are used to see a response variable in relation to two predictive variables. A 3D surface plot is a three-dimensional graph that is used for investigating desired response values and operating conditions. Surface graphics serve to see the optimum junction point between two data sets.

In Figure 5 plot shows the relationship between the spindle speed and feed per tooth over the surface roughness. As the spindle speed increased, surface roughness decreased. Moreover, when feed per tooth increased, surface roughness increased too.

This is because, at a higher feed rate, the surface quality decreases as the tool passes through the workpiece too rapidly, while at the higher cutting speed, the temperature during the cutting increases, resulting in a softening of the material, leading to a reduction in surface roughness. These graphs indicate that the minimum surface roughness is obtained at low feed level, high speed and high nose radius [31].

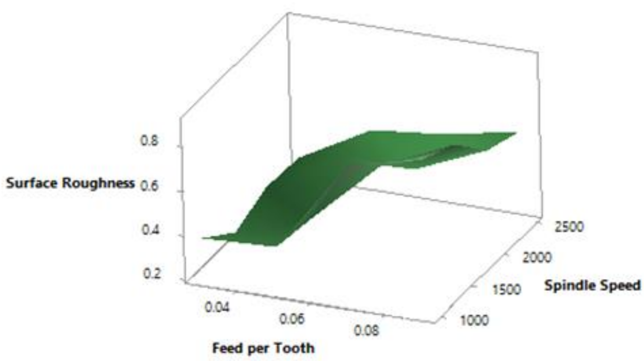


Figure 5. Surface plot of surface roughness vs feed per tooth, spindle speed

In Figure 6 plot shows the relationship between the cooling type and feed per tooth over the surface roughness. Process with liquid as cooling type created lower surface roughness. As the feed per tooth increased, surface roughness measured higher.

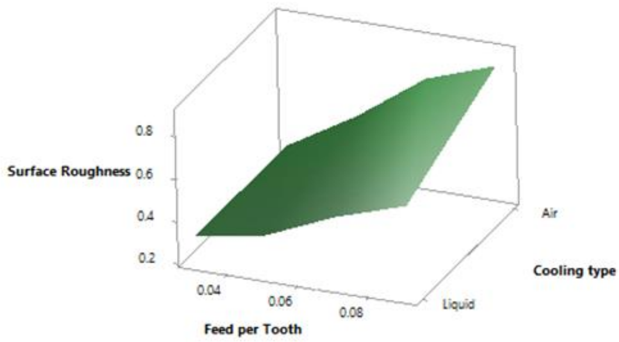


Figure 6. Surface plot of surface roughness vs cooling type, feed per tooth

In Figure 7 plot indicates the correlation between the spindle speed and cooling type over the surface roughness. A rise in the spindle speed caused surface roughness to be lower. When air used as liquid type resulted as rougher surfaces.

All these comments support the S/N ratio results.

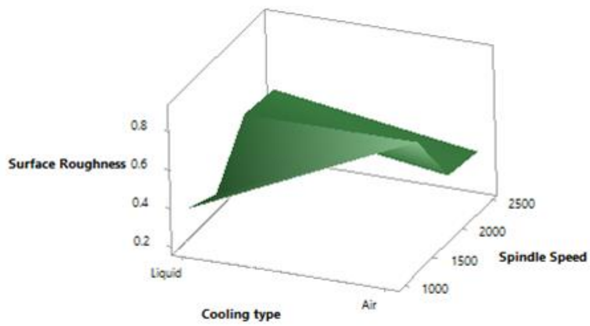


Figure 7. Surface plot of surface roughness vs cooling type, spindle speed

3.5. Confirmation Tests

The last step in Taguchi method is verification tests. Accuracy of the optimization is confirmed by this tests. Therefore, confirmation tests were performed at optimum levels of parameters. In the optimization of ideal surface roughness equation (4) was used.

$$R_{aopt} = (\overline{A}_1 - \overline{T_{Ra}}) + (\overline{B}_4 - \overline{T_{Ra}}) + (\overline{C_2} - \overline{T_{Ra}}) + \overline{T_{Ra}} \quad (4)$$

Here, ($\overline{A}_1$, $\overline{B}_4$, $\overline{C_2}$) are the optimal level mean values of surface roughness (R_{aopt}) and $\overline{T_{Ra}}$ states the mean of all of the R_a values gained from the experiments. The calculated values are: $\overline{A}_1 = 0.3185$ µm, $\overline{B}_4 = 0.480$ µm, $\overline{C_2} =$

0.458 μm and $\overline{T_{Ra}} = 0.5317$ μm. By giving them in equation (4), the mean optimum value of the surface roughness has been predicted as $Ra_{opt} = 0.1931$.
Finally, a validation test was required to confirm the optimized state. When the reliability of the situation is 95%, the confidence interval (CI) is calculated by equations (5) and (6) [32]:

$$CI_{Ra} = \sqrt{F_{\alpha,1,f_e} V_e \left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \quad (5)$$

and

$$n_{eff} = \frac{N}{1+T_{dof}} \quad (6)$$

Here F (α, 1, f_c) is the F-ratio at 95% confidence interval, f_e=8 DOF for error, V_e=1.787E^{-03} the error variance from Table 5, R=3 the number of replications and N_{eff} is effective number of replication, N=48 (16×3) total number of experiments and T_{dof} =7 the total degrees of freedom associated with the mean optimum, from standard statistical table, the required F ratio for α = 0.05 is found F (0.05,1,8)=5.32

By substituting equations (5) and (6), n_{eff}=6 and CI=± 0.0688. So, 95% confidence level range predicts optimum surface roughness =0.0688± 0.1931 μm so the verification result should be 0.1243μm< R_{aexp}<0.2619 μm [30].

The R_a obtained from confirmation experiment was R_{aexp}=0.231 μm remained within the confidence interval. We can say that, system optimization for surface roughness was achieved at a significant level by using the Taguchi method.

3.6. Probability Analysis

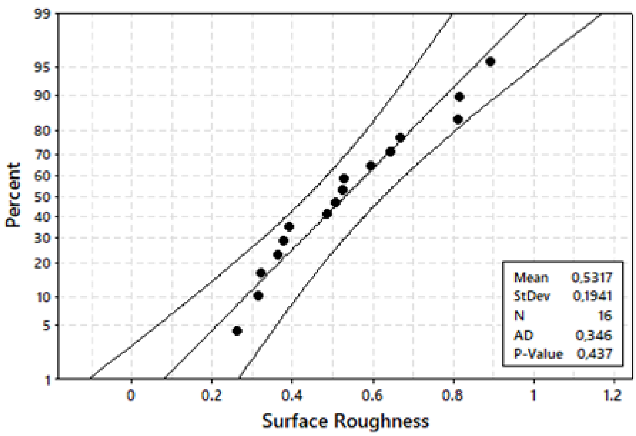


Figure 8. Probability plot of surface roughness

In order to check the distribution of the measured/calculated values of the results, the values given in Table 4 were confirmed by the probability graph in Figure 8. The plots were drawn for a confidence interval (CI) of 95%. It is proved that the data points are roughly aligned with the middle straight line, P value is greater than 0.05 and AD statistics are low, so the drawn data is distributed normally [33]. Therefore, these data can be used for optimization and experimental research.

4. CONCLUSION

In this paper, the effects on the average surface roughness of the feed per tooth, spindle speed, cooling type parameters in the milling of the AA6082-T6 aluminum alloy were evaluated by the Taguchi test design method. Accordingly, the following results were obtained:

The optimum levels of the parameters were found by using S/N ratios. The optimum status of surface roughness were occured at A1B4C2 (feed per tooth:0.03, spindle speed:2500, cooling type:liquid).

From the results of analyses of variance, it was discovered that feed per tooth was the dominant factor for surface roughness with a contribution rate of 74.13% and t the cooling type was the second factor with a contribution rate of 15.4% and spindle speed was the third parameter with a percentage contribution of 7.93%

The improved linear regression model showed a very good relationship. R^2 for the linear regression model for R_a was calculated as 95.76%. The measured values remained within the 95% confidence interval according to the validation test results.

From these results we can say that the Taguchi method is a confidential technique for surface quality optimization in milling of the 6082-T6 aluminum alloy. These results can be applied in literature and industry.

Acknowledgment

The author would like to express their gratitude Secil Yildirar for experimental help and ISCAR Turkey for cutting tools.

REFERENCES

[1].I. Asilturk, S. Neseli, M.A. Ince, "Optimization of parameters affecting surface roughness of Co28Cr6Mo medical material during CNC lathe machining by using the taguchi and RSM methods", Measurement, vol.78, pp. 120-128, 2016.
[2].S. Ozturk, "Application of theTaguchi method for surface roughness predictions in the turning process", Materials Testing, vol. 58, no.3, pp. 782-787, 2016.
[3].A. Uysal, "Surface roughness in nano fluid minimum quantity lubrication milling of AISI 430 ferritic stainless steel", Journal of Testing and Evaluation, vol. 45, pp. 933-939, 2017.
[4]. F. A. Akhavan, S. Safian, A. S. Alizadeh, I. M. Hasbullah, "Statistical analysis, modeling and optimization of thrust force and surface roughness in high-speed drilling

of Al–Si alloy", Proc IMechE, Part B: J Engineering Manufacture, vol. 227, no.6, pp. 808-820, 2013.
[5].R. Junxue, Z. Jinhua, Z. Jingwen, "Analysis and optimization of cutter geometric parameters for surface integrity in milling titanium alloy using a modified grey–Taguchi method" Proc IMechE, Part B: J Engineering Manufacture, vol. 230, no.11, pp. 2114-2128, 2016.
[6].M. Jebaraj, M. P. Kumar, N. Yuvaraj, G. M. Rahman, "Experimental study of the influence of the process parameters in the milling of Al6082-T6 alloy" Materials and Manufacturing Processes, vol. 34, no. 12, 1411–1427, 2019.
[7].J. U. Pillai, I. Sanghrajka, M. Shunmugavel, T. Muthuramalingam, M. Goldberg, G. Littlefair, "Optimisation of multiple response characteristics on end milling of aluminium alloy using Taguchi-Grey relational approach", Measurement, 124, 291-298, 2018.
[8].T. Somkiat, T. Prae, R. Suthas, "A wavelet approach to predict surface roughness in ball-end milling", Proc IMechE, Part B: J Engineering Manufacture, vol.231, no.14, pp. 2468-2478, 2017.
[9].Z. Zhang, C. Chen, D. Kirby, "Surface roughness optimization in an end-milling operation using the Taguchi design method", Journal of Materials Processing Technology, vol.184, pp.233-239, 2007.
[10]. M. Nalbant, H. Gokkaya, G. Sur, "Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning", Materials and Design, vol. 28, pp.1379-1385, 2007.
[11]. T. Kıvak, "Optimization of surface roughness and flank wear using the taguchi method in milling of hadfield steel with PVD and CVD coated inserts", Measurement, vol.50, pp.19-28, 2014.
[12]. M. Gunay, "Optimization with Taguchi method of cutting parameters and tool nose radius in machining of AISI 316L Steel", Journal of the Faculty of Engineering and Architecture of Gazi University, vol.28, no.3, pp.437-444, 2013.
[13]. R. Cakiroglu, A. Acir, "Taguchi optimization method of tool chip interface temperature depending on the cutting parameters in drilling operations" Electronic Journal of Machine Technologies, vol.10, pp.73-86, 2013.
[14]. N. Tosun, C. Kuru, E. Altintas, O. E. Erdin, "Investigation of surface roughness in milling with air and conventional cooling method" Journal of the Faculty of Engineering and Architecture of Gazi University, vol. 25, no.1, pp. 141-146, 2010.
[15]. G. Basmacı, "Optimization of Processing Parameters of AISI 316 Ti Stainless Steels", Academic Platform Journal of Engineering and Science 6-3, 01-07, 2018.
[16]. F. Kahraman, "Optimization of cutting parameters for surface roughness in turning of studs manufactured from AISI 5140 steel using the Taguchi method", Materials Testing, vol.59, no.1, pp.77-80, 2017.
[17]. Ö. Asal, "Optimization of Surface roughness in turning of AZ31 Magnesium Alloys with Taguchi method", Gazi University Journal of Science Part A: Engineering and Innovation, vol:6(1), pp.25-32, 2019.
[18]. A. V. Vishnu, M. V. Ramana, K.B.G. Tilak, "Experimental investigations of process parameters influence on surface roughness in turning of EN-353 alloy steel under different machining environments", Materials Today: Proceedings, vol.5, pp.4192-4200, 2018.
[19]. D. Behnam, T. Ahmadreza Hosseini," Cutting forces and surface roughness in wet machining of inconel alloy 738 with coated carbide tool" Proc IMechE, Part B: J Engineering Manufacture, vol.230, no.2, pp. 215-226, 2016.
[20]. K. Emel, B. Ozcelik, "Optimization of machining parameters during micro-milling of Ti6Al4V titanium alloy and inconel 718 materials using Taguchi method", Proc IMechE, Part B: J Engineering Manufacture, vol.230, no.2, pp.228-242, 2017.
[21]. A. M. Pinar, S. Filiz, B. S. Unlu, "A Comparison of cooling methods in the pocket milling of AA5083-H36 alloy via Taguchi method", The International Journal of Advanced Manufacturing Technology, vol.83, pp.1431-1440, 2016.
[22]. D. C. Mongomery, Design and analysis of experiments, 5th. Arizona: John Wiley&Sons, 2001.
[23]. K. Palanikumar, "Experimental investigation and optimization in drilling GFRP composites", Measurement, vol. 44, pp. 2138-2148, 2011.
[24]. I. Asilturk, H. Akkus, "Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method", Measurement, vol.44, pp.1697-1704, 2011.
[25]. K. R. Roy, A primer on the Taguchi method. 1th. New York: Van Nostrand Reinhold, 1990.
[26]. ISO 1302:2002. Geometrical Product Specifications (GPS)-Indication of surface texture in technical product documentation.
[27]. A. M.Pinar., E. Atik,U. Çavdar, "AA 7075 Alaşımının Frezelenmesinde Kesme Hızı, İlerleme Oranı, İşleme Deseni Ve Talaş Derinliği İşlem Parametrelerinin Yüzey Kalitesi Üzerindeki Etkilerinin İncelenmesi", 2. Ulusal Tasarım İmalat ve Analiz Kongresi, Balıkesir, 11-12 Kasım 2010.
[28]. Ö. Erkan, E. Yücel, "Optimization of the surface roughness of the end milled AA 7075 material with respect to cutting parameters and tool geometry", International Eurasian Conference on Science, Engineering and Technology (EurasianSciEnTech 2018), Ankara, Turkey, November 22-23 2018.
[29]. M.H. Cetin, B. Ozcelik, E. Kuram, E. Demirbas, "Evaluation of vegetable based cutting fluids with extreme pressure and cutting parameters in turning of AISI 304L by Taguchi method", Journal of Cleaner Production, vol.19, pp.2049-2056, 2011.
[30]. F. Kara, "Taguchi optimization of surface roughness and flank wear during the turning of DIN 1.2344 tool steel", Materials Testing, vol.59, no.10, pp.903-908, 2017.
[31]. B. Bhuvnesh, R. Kumar, K. S. Pradeep, "Effect of machining parameters on surface roughness in end milling of AISI 1019 steel", Proc IMechE, Part B: J Engineering Manufacture, vol.228, no.5, pp.704-714, 2014.
[32]. N. Mandal, B. Doloi, B. Mondal, R. Das, "Optimization of flank wear using zirconia toughened alumina (ZTA) cutting tool Taguchi method and regression analysis", Measurement, vol.44, pp.2149-2155, 2011.
[33]. G.H. V. Babu, K. Venkatarao, C.H. Ratnam, "Multi-response optimization in orthogonal turn milling by

analyzing tool vibration and surface roughness using response surface methodology" Proc IMechE, Part B: J Engineering Manufacture, vol.231, no.12, pp.2084-2093, 2017.