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Optimization of the Effect of Processing Parameters on Surface Roughness and Cutting Energy in CNC Milling of Al-7075 Material

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Abstract

In this study, it is intended to determine the most suitable process parameters for surface roughness and cutting energy of the 7075 series aluminum material in dry environment conditions by using Taguchi method in CNC milling. The process parameters were determined as, cutting speed, feed rate and cutting depth and the effects of these parameters on surface roughness, current flow through the grid and the energy consumed were examined. As a result, optimum process parameters were determined and the results were analyzed by graphs. It was observed that the most effective parameter on the surface roughness was the feed rate, while the most effective parameter on the current drawn from the network was the cutting depth. As a result of the experiments, the best surface roughness value was found to be 0.39 µm and the lowest current value was 0.9 A. In addition, considering the determined current amount and processing time, the lowest energy amount consumed was calculated as 7089.28 J.

Keywords: Milling process, Taguchi method, Cutting parameters, Surface roughness, Energy

Al-7075 Malzemenin CNC Frezelenmesinde İşlem Parametrelerinin Yüzey Pürüzlülüğüne ve Kesme Enerjisine Etkisinin Optimizasyonu

Öz

Bu çalışmada, CNC frezeleme prosesinde 7075 serisi alüminyum malzemenin kuru ortam şartlarında yüzey pürüzlülüğü ve kesme enerjisi için en uygun işlem parametrelerinin Taguchi yöntemi kullanılarak belirlenmesi amaçlanmıştır. İşlem parametreleri ilerleme hızı, kesme hızı ve kesme derinliği olarak belirlenmiş olup bu parametrelerin yüzey pürüzlülüğüne, şebeke üzerinden çekilen akım miktarına ve tüketilen enerji üzerindeki etkileri incelenmiştir. Sonuçta optimum işlem parametreleri belirlenmiş ve sonuçlar grafiklerle analiz edilmiştir. Yüzey pürüzlülüğüne en çok etki eden parametre ilerleme hızı iken, şebekeden çekilen akıma en çok etki eden parametrenin kesme derinliği olduğu gözlemlenmiştir. Deneyler sonucunda en iyi yüzey pürüzlülük değeri 0,39 µm, en düşük akım değeri 0,9 A olarak bulunmuştur. Ayrıca, belirlenen akım miktarı ve işlem süresi göz önüne alınarak tüketilen en düşük enerji miktarı 7089,28 J olarak hesaplanmıştır.

Anahtar Kelimeler: Frezeleme işlemi, Taguchi metodu, Kesme parametreleri, Yüzey pürüzlülüğü, Enerji

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1. INTRODUCTION

Energy is one of the important inputs for the economic and social development of countries. In order to prevent energy from being an obstacle to development and industrialization, efficient use has become important in our country where 70% of the demand is met by import. Studies indicate that efficient use of energy will save 30% on annual final energy consumption. The rapid depletion of fossil fuels that meet a major portion of the world's energy needs is one of the most important problems of our time. Mechanical processing, which is widely applied in the manufacturing industry, is used to give the desired shape to the materials. Therefore, the demand for energy increases. However, energy use has not been considerably optimized. Reduce the energy consumption of machines can significantly improve energy efficiency [1]. The surface quality is of paramount importance in the milling process. Product quality index commonly used in the finishing process is surface roughness [2]. Surface roughness is a key factor that greatly affects the technological quality and production cost of a product [2,3]. Machining conditions, workpiece material and tool geometry are factors that influence surface roughness. For this reason, optimum machining parameters and tool geometry must be selected to achieve a better surface quality in a milled product [4]. A powerful analysis tool such as experimental design is needed to model and analyze the effect of control factors on performance output. The traditional experimental design deals with a large number of experiments and is difficult to use because the number of processing parameters increases. The Taguchi method is a powerful method recently used to improve productivity during research and development [5]. The Taguchi method is a useful and efficient that optimizes experimental design [6,7]. This technique can be used to determine which factor has the most impact. It can also significantly reduce the time spent during experimental research [7-9]. This enables high quality products to be produced quickly and at low cost [5]. Bensouilah et al. [10] using the Taguchi method, coated and uncoated hard turning process surface roughness and shear force analysis performed. They found that surface roughness was better at coated ceramic tools, while shear force was lower at uncoated ceramic tools. Noordin et al. [11] subjected AISI 1040 steel material to a coated insert turning operation and investigated the effect of cutting parameters on surface roughness. They found that the most important parameter was feed rate. Ucun and Aslantaş [12] examined cutting parameters influence on surface roughness in rough turning. As a result, they observed that carbide cutting tools are not suitable for high cutting values in rough turning. Niranjan et al. [13] optimized the surface roughness using the Taguchi method with machining parameters for turning aluminum alloy 6061 T6 cylindrical bars. The optimum value of surface quality was obtained with cutting speed of 429 (m.min-1), feed rate of 0.05 (mm.min-1) and cutting depth of 1 (mm). They considered these process parameters to be optimal process parameters. Camposeco [14] has optimized the cutting parameters for minimum energy consumption during rough turning of the AISI 6061 T6. Zhou et al. [15] proposed a multi-purpose cutting parameter optimization model aimed at minimizing the processing time per unit of material and energy consumption. Kant and Sangwan [16] used gray relational analysis. They aimed to obtain optimum machining parameters to minimize power consumption and surface roughness. Hanafi et al. [17] used gray relational theory and Taguchi optimization methodology. TiN tools have optimized the process parameters to achieve minimum strength and best surface quality during the processing of PEEK-CF30 under dry conditions. Fratila and Caizar [18] applied the Taguchi methodology to obtain optimum cutting conditions that provide the best surface roughness and minimum power consumption during milling with $AlMg_3$ material HSS tool. Sarıkaya and Güllü [19] investigated the effect of process parameters in the turning of AISI 1050 steel using Response Surface Methodology (RSM). According to ANOVA results, they observed the highest effect on the surface roughness and the cooling condition. Çetin et al. [20] investigated the effect of plant based cutting fluids and cutting parameters on reducing surface roughness, cutting and feeding forces during turning of AISI 304L austenitic stainless steel using carbide cutting tool. Lee et al. [21] proposed a simulation-based method to reduce the energy consumption of a three-axis milling machine. Okwudire and Rodgers [22] have proposed a hybrid system to obtain high-performance and energy efficiency in processing. Abele et al. [23] proposed a machine tool simulation model during a production process and aimed to estimate energy consumption.

Figure 1. Test setup. a) Experiment samples, b) CNC vertical machining center, c) Surface roughness tester d) Clamp meter

Hazir and Koc [24] developed two mathematical models to optimize the surface roughness for the processing condition of Lebanese Cedar pine (Cedrus libani). For the optimization process, they have adopted the combined approach of the L27 vertical sequence based simulated angling algorithm. Bhosale et al. [25] conducted experiments using the L9 Taguchi orthogonal array, selecting three different parameters to achieve optimal surface roughness in the turning process. Kumar et al. [26] used the Taguchi L18 mixed type orthogonal array experimental design to determine the parameters affecting EN 19 stainless steel material's surface roughness and MRR (Material removal rate) in CNC turning.

In this study, the experimental design method Taguchi method was used to determine the effect of process parameters on surface roughness and cutting energy and to find optimum values in CNC milling of Al7075 series aluminum part. Unlike the literature, it was investigated what parameter is the most influential on the current drawn from the network. In addition, the results are examined and explained in detail.

2. EXPERIMENTAL PROCEDURE

2.1. Materials and Methods

Traditional experimental design is difficult to use, especially when dealing with a large number of experiments and when the number of processing parameters increases. Taguchi experimental design, developed by Dr. Genichi Taguchi, is an accepted method in the manufacturing sector, considering the variability inherent in the material and manufacturing processes at the design stage. The Taguchi method uses statistically designed orthogonal arrays to achieve the best results with a minimum number of experiments. In this way, the number of experiments is reduced, saving time and cost.

In this study, Al7075 series aluminum material (Figure 1a) DAHLIH MCV-1020BA CNC milling machine (Figure 1b) using the coolant closed milling process was performed. ISCAR H490 E90AX D16-2-C16-09 double-sided rectangular inserts with 4 helical cutting edges was used the cutting tools for heavy applications in experiments. Then, TR100 instrument was used to for the surface roughness (Figure 1c) and the influence on surface roughness of process parameters in the milling was examined and analyzed using Taguchi test design method, which is a quality improvement technique. It is also aimed to achieve optimum surface roughness with minimum energy. Energy calculations were made for this purpose and TENON DT 266 brand clamp meter (Figure 1d) was used to measure the current drawn over the network.

In this study, 9 pieces of 7075 series aluminum material with 50x40x10 (mm) dimensions were used. The 7075 series aluminum are commonly used in the aerospace, arms and defense industries due to light weight, high strength properties and good machinability [27-29]. Table 1 shows the mechanical properties of aluminum material, Table 2 shows the chemical properties.

Table 1. Mechanical properties of Al 7075 series

Maximum tensile strength (MPa)	Maximum yield strength (MPa)	Elongation (%)
280	140	9-10

Table 2. Chemical composition of 7075 series Aluminum material

Element	Contribution percentage (%)
Al	89.79
Zn	5.66
Mg	2.15
Cu	1.32
Si	0.35
Fe	0.45
Mn	0.08
Ti	0.05
Cr	0.10
Others	0.05

In this study, the experimental process parameters are determined as 3 levels are defined for each parameter as shown in Table 3. The experiments were applied under dry conditions. Separate tools were used for each experiment.

Table 3. Process variables, experimental design levels (L) used

Notations	Parameters	L1	L2	L3
A	Feed rate ($mm.min^{-1}$)	150	200	250
B	Cutting speed ($rev.min^{-1}$)	1000	1500	2000
C	Cutting depth (mm)	0.5	1	1.5

3. RESULTS AND DISCUSSION

Taguchi L_9 orthogonal index was chosen as the most suitable design for the experiment to examine how surface roughness was affected by process parameters. The ‘smaller is better’ method was used to calculate the S/N ratio, and all values were calculated using the MINITAB 17 program. Table 4 shows the Taguchi L_9 test design.

Table 4. Taguchi L_9 test design

Exp. No.	A	B	C	Surface Roughness R_a(μm)	S/N Ratio (dB)
1	1	1	1	0.42	7.53501
2	1	2	2	0.53	5.51448
3	1	3	3	0.40	7.95880
4	2	1	2	0.91	0.81917
5	2	2	3	1.89	-5.52924
6	2	3	1	0.39	8.17871
7	3	1	3	0.81	1.83030
8	3	2	1	0.53	5.51448
9	3	3	2	0.55	5.19275

In the graph given in Figure 2, the S/N ratios which are formed according to the process parameters for surface roughness are given. According to Taguchi experimental design, the best surface roughness (Ra) was obtained from experiment 6 corresponding to the largest S/N ratio.

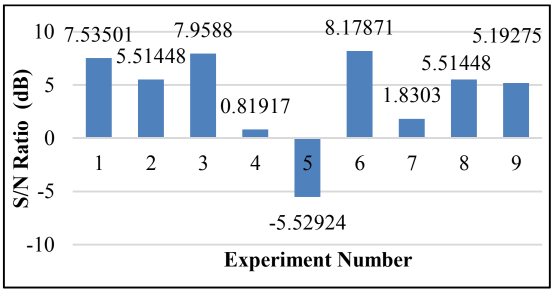

Figure 2. S/N ratio graph belonging to surface roughness

In Figure 3, the lowest surface roughness value (Ra) was obtained from the experimental parameters $A_2B_3C_1$ with a value of 0.39 (μm). The highest surface roughness value (Ra) was obtained from the test parameters $A_2B_2C_3$ with test value of 1.89 (μm).

In the light of these graphs, the best surface roughness value is obtained from the optimum process parameters in experiment 6 (Figure 2). Table 5 shows the S/N analysis of each control factor on surface roughness. From this table, the most effective factors are feed rate, cutting depth and cutting speed, respectively.

Table 5. Surface roughness S/N response table

Level	Feed rate (A)	Cutting speed (B)	Cutting depth (C)
1	7.891	3.395	7.076
2	1.156	2.721	4.730
3	4.179	7.110	1.420
Delta	6.735	4.389	5.565
Rank	1	3	2

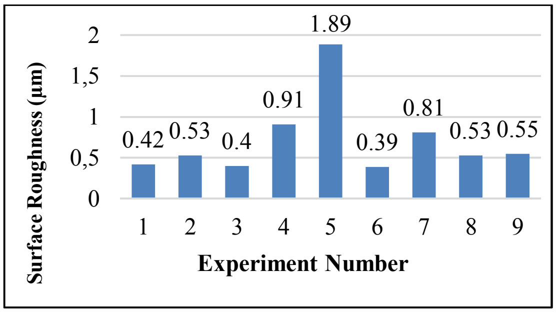

Figure 3. Surface roughness value graph of process parameters

According to the Figure 4, the surface roughness increases to a certain level as the feed rate increases and then starts to decrease. Increasing the depth of cut also caused the surface roughness to increase to a certain level. However, this increase was not as effective as the feed rate parameter.

In Figure 5 the effect of feed rate and cutting speed is shown. According to the given graph, the surface roughness is highest in the middle levels of both parameters. The lowest surface roughness was obtained when the feed rate was level 2 and the cutting speed was level 3.

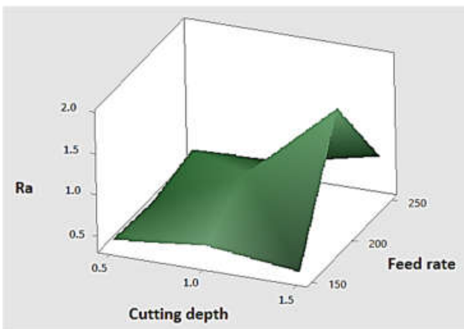

Figure 4. Graph of the effect of feed rate and cutting depth on surface roughness

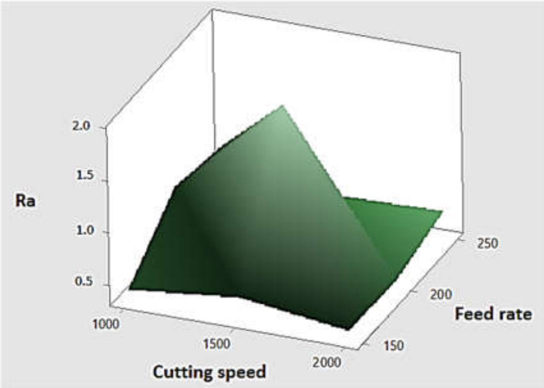

Figure 5. The effect of feed rate and cutting speed on surface roughness

According to the Figure 6, when the cutting speed increases, surface roughness increased to a certain level and then decreased. In addition, the surface roughness is the lowest in the 3rd level of cutting speed and 1st level of cutting depth.

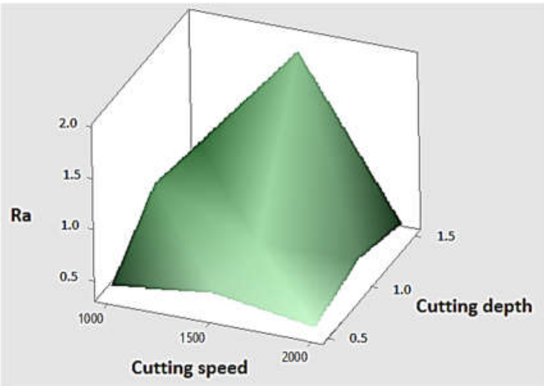

Figure 6. The effect of cutting speed and cutting depth on surface roughness

To obtain the effect of the determined variable parameters on the cutting energy, the amount of current drawn from the network during the processing of 9 test samples on the CNC Mill was measured with the clamp meter and the parameter affecting the current most was determined. Then, energy data were obtained by mathematical calculations. Table 6 shows the measured current values and the calculated S/N ratios in the Minitab 17 program. The minimum current was 0.9 (A) and the highest current was 1.43 (A).

In Figure 7, the S/N ratios generated according to the process parameters for the amount of current drawn are given. According to Taguchi experimental design, the optimum value was obtained from experiment 1 which corresponds to the largest S/N ratio.

In Figure 8, the lowest current value 0.9 (A) is obtained from test parameters $A_1B_1C_1$ in experiment 1. The highest current value 1.43 (A) was obtained from the test parameters $A_3B_3C_2$ in experiment 9.

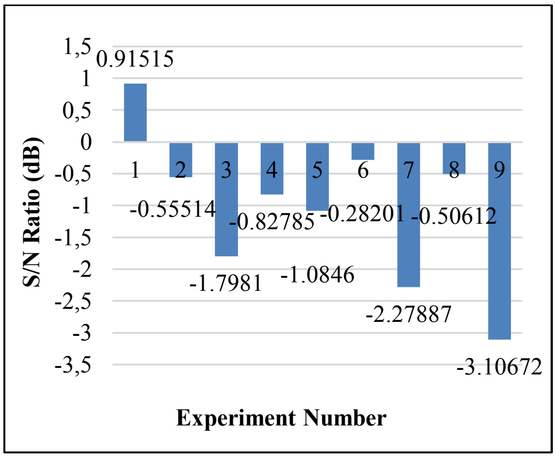

Figure 7. S/N ratio graph of the process parameters for the amount of current drawn

Table 6. Current and values of S/N ratio

Exp. No.	A	B	C	Current I (A)	S/N Ratio (dB)
1	1	1	1	0.9	0.91515
2	1	2	2	1.066	-0.55514
3	1	3	3	1.23	-1.79810
4	2	1	2	1.1	-0.82785
5	2	2	3	1.133	-1.08460
6	2	3	1	1.033	-0.28201
7	3	1	3	1.3	-2.27887
8	3	2	1	1.06	-0.50612
9	3	3	2	1.43	-3.10672

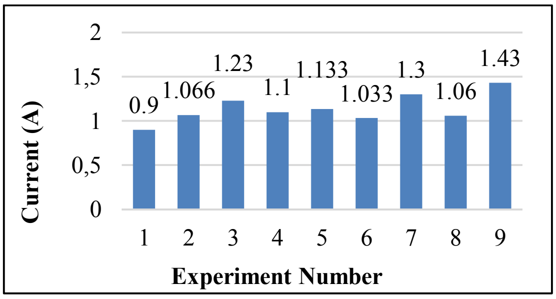

Figure 8. Current value graph of process parameters

Table 7 shows the S/N analysis of each control factor on the current. The most effective factors on the flow from this table are the cutting depth, feed rate and cutting speed, respectively.

Table 7. Current S/N response table

Level	Feed rate (A)	Cutting Speed (B)	Cutting depth (C)
1	-0.47937	-0.73052	0.04234
2	-0.73149	-0.71529	-1.49657
3	-1.96390	-1.72894	-1.72052
Delta	1.48454	1.01366	1.76286
Rank	2	3	1

In Figure 9, feed rate and cutting speed influences on the flow are examined. According to the given graph, the lowest current value was obtained at the 1st level of both parameters. The highest current value is obtained when both parameters are at the 3rd level.

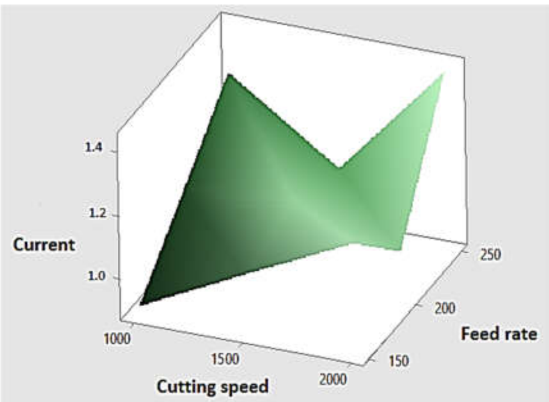

Figure 9. The cutting speed and feed rate influences on the current

In Figure 10, the cutting speed and cutting depth influences on the current are examined. According to the given graph, the lowest current value was obtained at the 1st level of both parameters. The highest current value is obtained when the cutting speed is level 3 and the cutting depth is level 2.

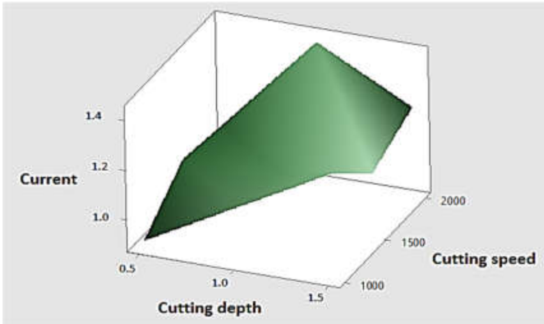

Figure 10. The effect of cutting depth and cutting speed on the current

In Figure 11, the feed rate and cutting depth influences on the current are examined. According to the given graph, the lowest current value was obtained at the 1st level of both parameters.

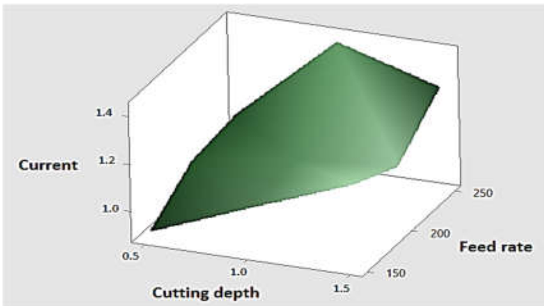

Figure 11. Graph of the effect of cutting depth and feed rate on the current

The amount of energy spent in milling operations is calculated by Equation 1.

$$E=P\times t \quad (1)$$

In Equation 1, E is the energy (Joule), P is the power (Watt) and t is the time (Second).

The amount of current drawn through the mains for each cutting operation was measured with a clamp meter. Measured values are put in place in Equation 8 and electrical power drawn from the grid is calculated.

$$P=V\times I\times \cos\varphi \qquad (2)$$

In Equation 2 *V* is voltage (V), *I* is current (A) and *cos φ* is power factor. The electrical power is directly proportional to the amount of current measured. Therefore, the amount of current measured in the experiment is high electrical power drawn from the network. The processing time of each workpiece and the amount of energy consumption during the operation of the machine with the help of electrical power values drawn from the network are calculated from Equation 1 and the results are presented in Figure 12.

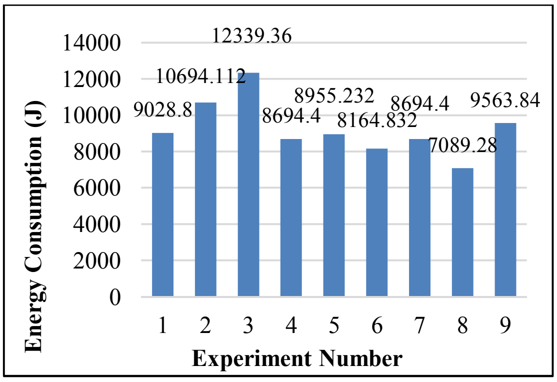

Figure 12. Energy value graph of process parameters

Accordingly, the maximum energy was spent in experiment 3 with 12339.36 (J) and the least energy was spent in experiment 8 with 7089.28 (J).

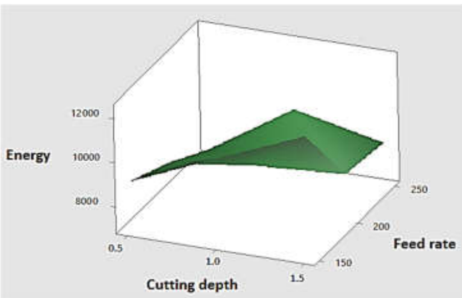

Figure 13. The effect of cutting depth and feed rate on the energy consumption

In Figure 13, it is seen that the energy consumed is maximum when the cutting depth is high and the feed rate is low.

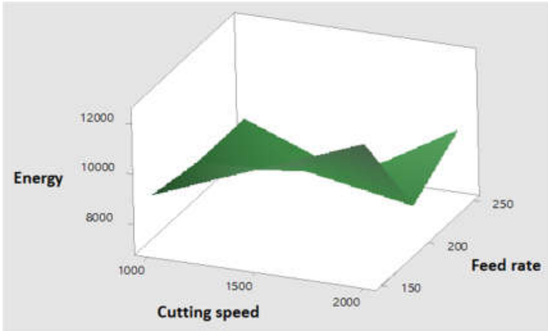

Figure 14. The effect of cutting speed and feed rate on consumed energy

In Figure 14, the energy consumed is maximum when the cutting speed is high and the feed rate is low. In addition, as the feed rate raised, the energy consumed decreased to a certain value and then continued to increase.

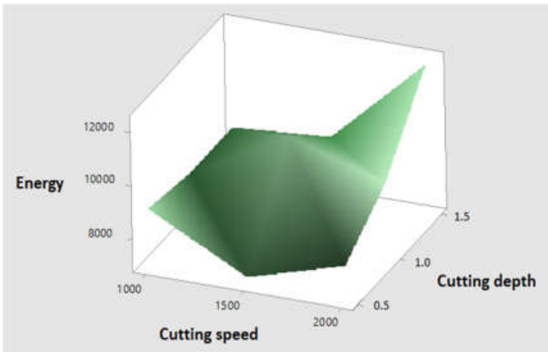

Figure 15. Graph of cutting speed and cutting depth effects on consumed energy

The Figure 15 shows that the consumed energy rises continuously as the cutting speed and cutting depth increases.

4. CONCLUSIONS

In this paper, the effects of machining parameters on surface roughness and cutting energy were examined by using 7075 series aluminum in CNC Milling process. And it was aimed to find the optimum values. 9 experiments were performed using Taguchi method and the effect values and optimum levels of the process parameters were determined. In this paper, the most suitable process parameters were determined by using fewer experiments with Taguchi method. Thus, a significant advantage was achieved both in terms of cost and time. After the experiments, it was observed that the feed rate was the most effective parameter on surface roughness and the cutting speed was the least effective parameter. As a result of the measurements, it was examined that the cutting depth was the most influential parameter on the amount of current drawn from the network and the cutting speed was the least influential parameter. As a result of the calculations, it is seen that when the cutting depth is high, the cutting speed is high and the feed rate is low, the amount of energy consumed during the process is maximum. In addition, it was found that the most influential parameter on the amount of energy consumed was the feed rate. This is because the amount of energy consumed is high due to the increased processing time when the feed rate is low. According to the results of the experiment, it was observed that keeping the cutting depth low provides low surface roughness and low energy consumption. As a result of the experiments, the best surface roughness value was found to be 0.39 µm and the lowest current value was 0.9 A. In addition, considering the determined current amount and processing time, the lowest energy amount consumed was calculated as 7089.28 J.

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