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Research Article

Optimization of Cutting Parameters Using Taguchi Method During the Face Milling of AISI 1040 with Coated and Uncoated Inserts

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ABSTRACT

AISI 1040 carbon steel is used in many different sectors such as mold sets, automobile components, transmission shafts, rails and gears. The use of this material in different sectors, its behaviors in the various machining operations have become important. In this study, face milling process was applied to AISI 1040 carbon steel material by using coated and uncoated cutting inserts. Experiments were performed on the basis of Taguchi's L18 orthogonal array (OA) at different levels of the cutting inserts (Uncoated carbide, CVD / TiN-TiCN-Al_2O_3 coated carbide and PVD/TiALN coated carbide), the cutting speeds (160, 180 and 220 m/min) and the feed rate (0.1, 0.15 and 0.3 mm/tooth) and depth of cut (0.3 and 0.6 mm). The obtained values at the end of the experiments were evaluated through the signal to noise (S/N) ratios and Analysis of Variance (ANOVA). The end of the confirmation experiments, the surface roughness of 2.90 µm could be significantly improved to 1.42 µm with an enhanced performance of 51.03%.

Keywords: Surface Roughness, Taguchi Method, Optimization, AISI 1040 face milling

AISI 1040 Çeliğinin Kaplamalı ve Kaplamasız Kesici Uçlarla Yüzey Frezemele Esnasında Kesme Parametrelerinin Taguchi Metodu Kullanılarak Optimizasyonu

ÖZET

AISI 1040 çeliği kalıp setleri, otomobil unsurları, transmisyon milleri, raylar ve dişliler gibi birçok farklı sektörlerde kullanılmaktadır. Bu malzemenin farklı sektörlerde kullanımı çeşitli işleme operasyonlarındaki davranışlarını önemli hale getirmektedir. Bu çalışmada, kaplamalı ve kaplamasız kesici uçlar kullanılarak, AISI 1040 karbon çeliğine yüzey işleme işlemi uygulanmıştır. Deneyler, farklı tipte kesici uçlar (kaplamasız karbit, CVD/ TiN-TiCN-Al_2O_3 kaplamalı karbit, PVD/TiALN kaplamalı karbit), kesme hızları (160, 180, 220 m/dak), ilerleme oranı (0.1, 0.15, 0.3 mm/diş) ve iyi bir yüzey kalitesi için bütün deneylerde 0.3 ve 0.6 mm kesme derinlikleri kullanılarak Taguchi L18 ortogonal dizi ile yürütülmüştür.

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Deneyler sonunda elde edilen değerler, sinyal-gürültü oranı ve varyans analizi (ANOVA) kullanılarak değerlendirilmiştir. Doğrulama deneyleri sonucunda %51.03 oranında bir performans artışıyla işleme doğruluğu 2.90 µm'dan etkili bir şekilde 1.42 µm'a iyileştirilmiştir.

Anahtar Kelimeler: Yüzey Pürüzlülüğü, Taguchi Metodu, Optimizasyon, AISI 1040 yüzey frezeleme

I. INTRODUCTION

Forming of the metals with metal cutting methods underlies on manufacturing sector. Metal cutting methods in machine industry are preferred because of good surface quality of machined parts, reducing the cost, and improving quality of manufacturing. Surface roughness is significantly effective on bearings, gears, especially in piston-cylinder mechanism, working as machine parts rubbing against each other [1]. The treated surface, using different machining manufacturing processes are directly or indirectly affected from machining parameters. The undistinguishable processing parameters cause rapid wear of the cutting tool, in addition to the losses as break, economic losses such as deterioration of workpiece or the low surface quality [2]. Kahraman studied his work, he developed a quadratic equation for statistical analysis and prediction of relationship between cutting parameters and surface roughness in turning of AISI 4140 steel [3]. Özel and Karpat, investigate with regression analysis cutting parameters effect on surface roughness in machining of AISI H-13 steel with CBN (cubic boron nitride) cutting tools. In their work, the best surface roughness was obtained with the reduction of feed rate, and they reported that tool wear increased [4]. Zain et al. and in their studies, they estimated the effect of cutting parameters on surface roughness in milling process using artificial neural network model [5]. Çakır et al. studied the effect of cutting parameters on surface roughness, and they stated mathematical model relation between surface roughness and cutting parameters. They used in AISI P20 cold process tool steel as material [6]. Özler et al. studied in their work, they machined austenitic manganese steel using cutting speed, feed rate, cutting depth and heating temperatures. Surface roughness values were measured end of their study. The surface roughness values were mathematically modelled with regression analysis using the obtained values. At the end of the study, it was made firm the obtained values with analysis were close to experimental values [7]. Güllü and Özdemir in their study, AISI 1050 steel was machined using cutting parameters such as different cutting speed, feed rate and cutting depth. Surface roughness values which was measured from the machined work piece face were analyzed by AXUM software using regression analysis according to cutting parameters [8]. Asiltürk and Çunkaş in their study, they measured surface roughness values during turning process using different cutting parameters as revolutions per minute, feed rate and cutting depth. They used artificial neural network and multiple regression analysis for the increasing confidence interval and the reliability of experimental values. The model was created with this analysis for surface roughness values of the AISI 1040 steel. Multiple regression and artificial neural network models were compared using statistical methods [9]. Brezocnik et al. were estimated with genetic algorithm the surface roughness values obtained from machining of the aluminum 6061 material using end-milling process [10]. Altınkaya and Güllü investigated the effect of the chip breaker form over the used cutting insert on surface roughness machining stainless steel with end-mill cutting inserts tool. For this reason constant to cutting depth, they used three different chip breaker form tool and three different cutting speeds (180, 225, and 270) [11]. Topal researched the effect of cut increment in estimation of the surface roughness in end mill operations. In his study, AISI 1040 steel was machined with end-mill tool using different cutting parameters as cutting speed, feed rate, cutting depth and cut increment, and surface roughness values were measured by Mitutoyo surface roughness device. The measured surface roughness values were used in training and testing artificial neural networks (ANNs), and he evaluated their performance used ANN models [12]. In other study, Çolak et al. used evolutionary programming methods in CNC milling for the testing surface roughness [13]. In high speed end-mill milling process, Özçelik and Bayramoğlu used AISI 1040 steel for statistical modelling of surface roughness. In their study; revolutions per minute, feed rate, cutting depth and cut increment were used as cutting parameters [14]. Zain et al. used in genetic algorithm to optimize cutting parameters reducing surface roughness values [15].

Taguchi technique is widely employed by many researchers since the effects of many factors on the responses and their optimal levels can be obtained with a few trials easily. Pinar [16] investigated the optimization of surface roughness in pocket milling of AA5083-H36 alloy via Taguchi method. In this study, the effects of cutting speed, feed rate, tool path pattern and depth of cut process parameters and their two-way interactions on the roughness are determined by using ANOVA. Following this study, Pinar et al. [17] studied the pocket machining of the same material in terms of different cooling strategies (vortex tube and classical cooling). Different from the other, they observed the effects of radial depth of cut and tool nose radius on the roughness. The aim of this study is to obtain optimum cutting conditions using the Taguchi method and Taguchi's L18 OA to minimize the surface roughness in the face milling AISI 1040 material. The obtained values for this aim were evaluated by the signal to noise (S/N) ratios, ANOVA and 3D graphics method. At the end of the study, the confirmation experiments were performed, and how to reduce the loss of quality parameters determined and the performance of optimization on machining process were tested. Besides with this study, implementation of the Taguchi method for the face milling on material AISI 1040 will benefit both the manufacturing industry and the similar studies in academic environment.

II. EXPERIMENTAL DETAILS

A. FACE MILLING METHOD

THM-U coded uncoated carbide (Widia, Germany), TN5515 coded TiN-TiCN-Al_2O_3 coated carbide CVD grade and TN6525 coded TiALN (Nano layer) coated carbide PVD grade cutting inserts with twelve cutting edges were used in experiments. Beside the Victory M1200 coded face milling tool (Widia, Germany) was selected as the tool holder (Figure1).

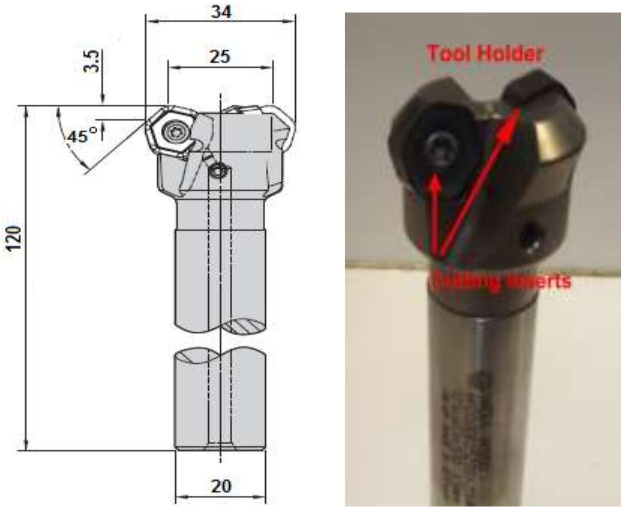

Figure 1. *Tool holder detail used experiments*

In this study, AISI 1040 steel blocks were used as the work pieces material. Steel is an iron-base alloy whose strength is due primarily to its carbon content. Small amounts of manganese, and frequently silicon and a trace of aluminum, are also present in steel [18]. An AISI 1040 steel is a plain–carbon steel with 0.40% C [19]. In this study, dimensions of the work piece were 80x65x30 mm. The chemical composition, physical and mechanical properties of AISI 1040 steel are given in Table 1.

Table 1. *Properties of AISI 1040 steel*

Chemical Properties					
%C	%Mn	%P	%S	%Fe	
0.37-0.44	0.60-0.90	0.60-0.90	0.05	98.6-99	
Physical Properties					
Density	Creep strength	Hardness Rockwell	Tensile Strength	Modulus of elasticity	
7.845 g/cm3	290 MPa	149	525 MPa	200 GPa	

Before the experiments, workpieces were created the three different machining faces and two channels in accordance with ISO 8688-1 using the end mill tool. Test specimens were prepared by Jetco JVM-2 milling machine. The face milling experiments were performed using a First model MCV-300 three-axis CNC vertical machine centre (Fanuc Oi mate MC) having 8000 rpm maximum spindle speed, 5.5 bar pneumatic pressure and 12 kW drive motor (Figure 2).

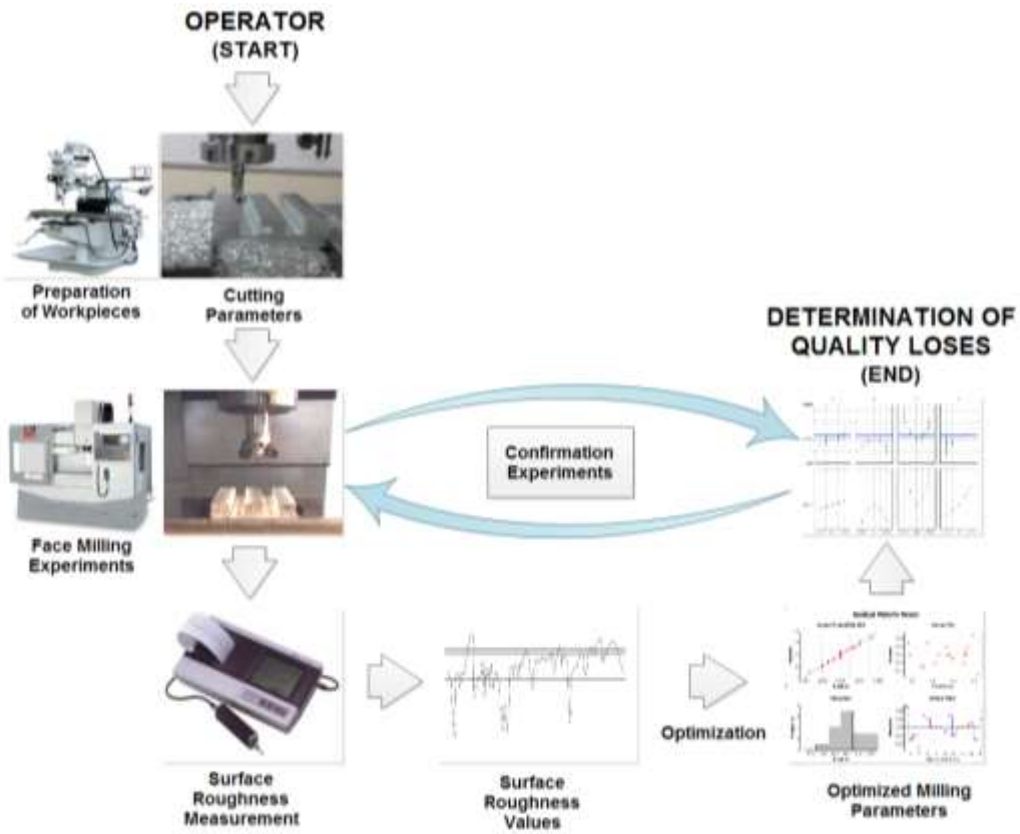

Figure 2. *The flowchart of experimental setup and optimization*

Determining the cutting parameters, cutting tools manufacturer's data and the recommendations contained in the ISO 8688-1 standard were taken into consideration [20]. The experiments were performed at two cutting depths (0.3 and 0.6 mm), three cutting tools, three cutting speeds (160,180 and 220 m/min) and three feed rates (0.1, 0.15 and 0.3 mm/tooth). The cutting inserts for each experiment were also replaced with a new one, and all face milling experiments were conducted under dry cutting conditions.

B. SURFACE ROUGHNESS MEASUREMENT

The surface roughness of the machined faces was measured using a Mitutoyo portable surface roughness tester (Mitutoyo Surftestest SJ-301. Product no. 99MBB035A1, Series No. 178, Mitutoyo Corporation, 20-1, Sakado 1-chome, Takatsu-ku, Kawasaki, Kanagawa 2002; 213-0012, Japan) and the average roughness values of the surface roughness were received for consideration. Surface roughness measurements are conducted with a cutoff and traversing length of 0.8 and 15 mm, respectively along centerline of sampling [17]. Three surface roughness values were measured for each machining condition and the mean of three roughness values was considered for evaluation. Surface roughness measurement and the workpiece are shown in Figure 3.

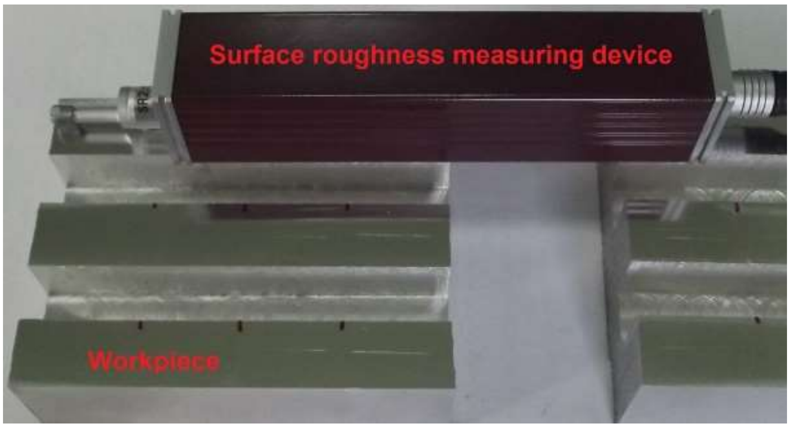

Figure 3 *Surface roughness measurement of workpiece*

III. EXPERIMENTAL DESIGN AND OPTIMIZATION

A. TAGUCHI METHOD

Taguchi method is a simple and robust technique for optimizing the process parameters involving reducing of process variation. The aim of the analysis is to investigate how different process parameters affect the mean and variance of process performance characteristics, and which variable contribute significantly [21]. Taguchi suggested that the design process consists of three phases: system design, parameter design, and tolerance design. In the system design phase, the basic concept is decided to use theoretical knowledge and experience to calculate the basic parameter values to provide the performance required [22]. As a consequence of detailed analysis and assessments performed by the Taguchi method before carrying out experiments, it is possible to significantly reduce the number of experiments. The Taguchi method is an experimental design technique that extremely beneficial for high-quality system design [23].

The Taguchi method uses a loss function to determine the quality characteristics. Loss function values are also converted to a signal-to-noise (S/N) ratio (η). In general, there are three different quality characteristics in S/N ratio analysis, namely "nominal the best", "larger the better", and "smaller the better". For each level of process parameters, the S/N ratio is calculated based on S/N analysis.

Nominal the best: $\eta = S / N_T = 10 \log \left(\frac{\bar{y}}{s_y^2} \right)$ (1)

Larger the better: $\eta = S / N_L = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y^2} \right)$ (2)

Smaller the better: $\eta = S / N_S = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right)$ (3)

Where $\bar{y}$ is the average of the observed data, s_y^2 is the variance of y, n is the number of observations, and y is the observed data [24, 25].

B. DETERMINING OF CONTROL FACTORS AND ORTHOGONAL ARRAY (OA) SELECTION

Taguchi created several special orthogonal arrays and to analyze the results and his method introduced the use of the signal-to-noise ratio (S/N ratio) to provide a design that is exempt to the effect of uncontrollable factors [26]. Moreover, compared to traditional experimental designs, the Taguchi method makes use of a special orthogonal array (OA) design to examine the quality characteristics through a minimal number of experiments. The choice of OA is critical, as it depends on the number of factors to be studied for optimization, the number of interactions to be examined, the number of levels required for each factor, the objective of the experiment, and of course the experimental budget and availability of resources. In order to guarantee that the chosen OA design will provide sufficient degrees of freedom for the proposed experiment, the following inequality must be fulfilled: the number of degrees of freedom of the OA ≥ number of degrees of freedom required for studying the main effect and interaction effect [27, 28]. In this study, the surface roughness values for face milling process were measured. The cutting parameters selected as control factors and their levels were determined as shown in Table 2.

Table 2. *Cutting parameters selected as control factors and their levels for face milling*

Symbol	Control factors	Levels		
		1	2	3
A	Cutting depth (a)	0.3	0.6	-
B	Cutting Tools (t_i)	Uncoated	TiN-TiCN-Al_2O_3	TiALN
C	Cutting Speed (V-m/min)	160	180	220
D	Feed Rate (f-mm/tooth)	0.1	0.15	0.3

The first step of the Taguchi method is to select an appropriate OA based on the selected cutting parameters as control factors. The most appropriate mixed OA [L_{18} ($3^3 \times 2^1$)] is selected to determine the optimal cutting parameters and to analyse the effects of these determined parameters [29]. The cutting parameters used for the selected mixed OA are assigned to each column and 18 combinations of cutting parameters were placed as shown in Table 3.

Table 3 *The Selected orthogonal array of Taguchi* L_{18} (3^3x2^1)

	Control factors			
	A	B	C	D
	Column no.			
Trial no.	1	2	3	4
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

In the performed experiments according to the obtained eighteen trials, each combination of the control factors was considered. Besides, the instead of the fifty-four full factorial experimental design, it was only carried out the number of eighteen trials using the Taguchi's L18 orthogonal array (OA), and thus the experiments provided savings from time and resources. At the end of the experiments conducted, optimization of the measured values and determination of the quality characteristics was provided with S/N ratios.

IV. Analysis And Evaluation of Experimental Results

A. OPTIMIZATION OF THE EXPERIMENTAL RESULTS USING THE S/N RATIO

The S/N ratio can reflect the variability of the system's quality characteristic. In addition, it is not dependent on the adjustment of the mean. That is, if the target value is changed, the S/N ratio would still be useful to predict the quality [30, 31]. Since minimum values of surface roughness obtained from experimental results were desired in point of the most affect product quality. Therefore, the "smaller the better" equation has been selected (Eq. 3) for the calculation of the S/N ratio. S/N ratios of surface roughness calculated by using Eq. 3 are shown in Table 4. As shown in Table 4, the cutting parameters expressed as control factors are discriminated by considering different levels and their possible effects according to the selected OA. After the 18 experimental trials performed, the average value of surface roughness was calculated as 1.80 µm and the average S/N ratio for the surface roughness value was 5,78 dB.

Table 4. *S/N ratios of experimental results for surface roughness*

Trial No	Control factors				Signal to Noise (dB)	
	A Cutting Dept (a)	B Cutting inserts (t)	C Cutting Speed (V)	D Feed Rate (f, mm/tooth)	Ra	S/N
1	0.3	Uncoated	160	0.10	1.02	0.172
2	0.3	Uncoated	180	0.15	1.12	0.984
3	0.3	Uncoated	220	0.30	0.995	0.043
4	0.3	TiN-TiCN-Al_2O_3	160	0.10	2.90	9.248
5	0.3	TiN-TiCN-Al_2O_3	180	0.15	2.60	8.299
6	0.3	TiN-TiCN-Al_2O_3	220	0.30	1.54	3.750
7	0.3	TiALN	160	0.15	2.57	8.198
8	0.3	TiALN	180	0.30	2.17	6.729
9	0.3	TiALN	220	0.10	0.26	11.70
10	0.6	Uncoated	160	0.30	2.24	7.005
11	0.6	Uncoated	180	0.10	1.66	4.402
12	0.6	Uncoated	220	0.15	1.83	5.249
13	0.6	TiN-TiCN-Al_2O_3	160	0.15	2.85	9.096
14	0.6	TiN-TiCN-Al_2O_3	180	0.30	1.85	5.343
15	0.6	TiN-TiCN-Al_2O_3	220	0.10	2.23	6.966
16	0.6	TiALN	160	0.30	3	9.542
17	0.6	TiALN	180	0.10	1.08	0.668
18	0.6	TiALN	220	0.15	0.47	6.558

Table 5. *Average S/N ratios (dB) and means of control factors*

Control Factors	Surface Roughness (Ra)			
	Level 1	Level 2	Level 3	Max-Min
S/N ratios (dB)				
A	2.8487	4.6350	-	1.7864
B	4.635	7.1174	1.1467	5.9707
C	7.2105	4.4045	0.3894	7.5999
D	1.6260	4.2117	5.3878	3.7618
Means (μm)				
A	1.686	1.912	-	0.226
B	1.478	2.328	1.592	0.851
C	2.430	1.747	1.221	1.966
D	1.525	1.907	1.966	0.441

The S/N ratio is a statistic that combines the mean and variance, and it depends on the kind of quality characteristic [32]. Moreover, effects of the level of each factor on the quality characteristic can be analysed using S/N ratios. These effects can be defined and evaluated according to total mean values of experimental results or S/N ratios. Therefore, the optimum surface roughness values were calculated by means of total mean values of experimental trial results of the surface roughness. Another requirement in the calculation of optimum values is to determine the optimum levels. The optimum levels can be determined by evaluating different levels of the control factors according to the results from combinations generated by the mixed L18 OA. As a result, the levels of control factors are determined for surface roughness shown in Table 5. These levels are used to plot the surface roughness values and their S/N ratios (Figure 4).

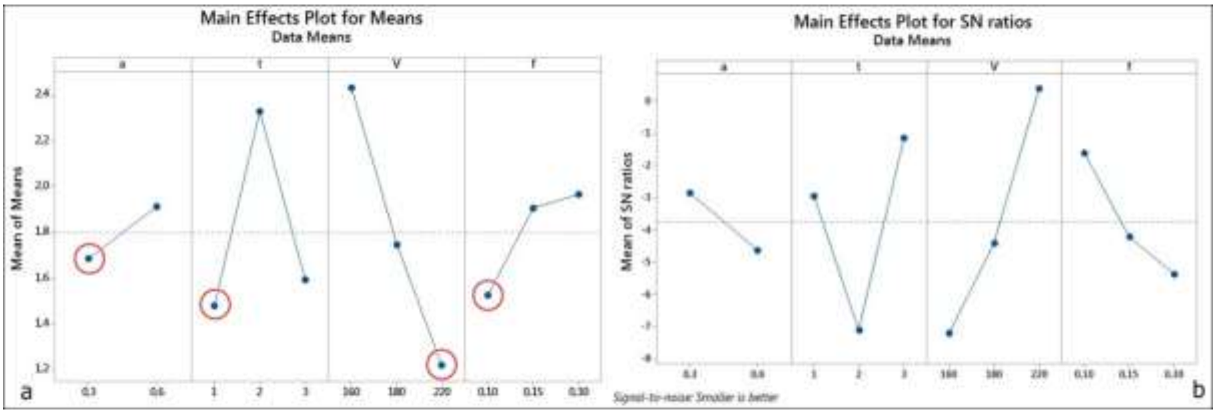

Figure 4. *Mean effects plot for control factors*

The calculated S/N ratios and means distributions for surface roughness according to control factors and their levels are shown in Figure 5. Because the "smaller the better" characteristic was selected, the lowest values of means for all the levels were considered to determine the optimal combination of control factors. Similarly, the high S/N ratios can be considered to determine the optimum combination, as well. Optimal values calculated were recommended for 18 trials and their 54 possible combinations (18 from $3^3 \times 2^1 = 54$). Therefore, optimum combination of the face milling parameters was determined as $A_1B_1C_3D_1$ (A_1 = 0.3 mm, B_1 = Uncoated tool, C_3 = 220 m/min, D_1=0.1 mm/tooth).

B. EVALUATION OF EXPERIMENTAL RESULTS

Variations of surface roughness values obtained from the experimental study of milling process depending on control factors and their variations are shown in Figure 5. Figure 5a shows that the effects of the cutting depth and cutting inserts on the surface roughness. In Figure5a, despite the surface roughness values obtained from both cutting depths are close to each other, when the depth of cut is increased the surfaced roughness values are also increased. The practical value of depth of cut varies from practitioner to practitioner and from one tool manufacture to another for the milling process. It is also customary to increase the tool nose radius with increase of depth of cut to obtain the best surface quality [20]. Therefore, the cutting depth of 0.3 mm is low value according to tool radius, and for this reason the surface quality is reduced depending on the cutting depth. In the same graph, the best surface quality is obtained from uncoated carbide inserts. These inserts are followed by TiN-TiCN-Al2O3 and TiALN coated carbide inserts. In Figure 6b, the effects of the cutting depth and the cutting speed on the surface roughness are shown, and here the minimum surface roughness values are obtained with a cutting speed of 220 m/min.

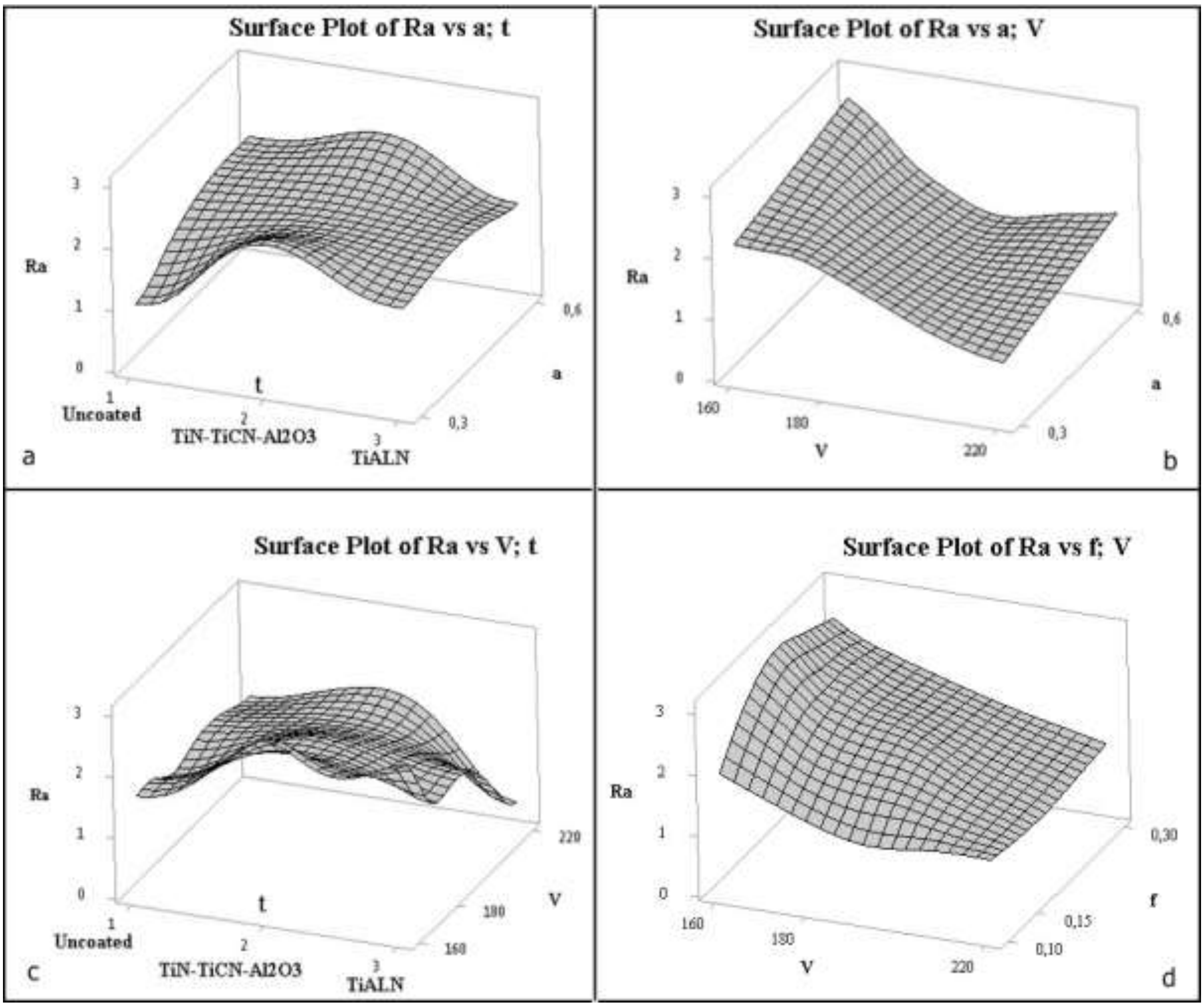

Figure 5. *Effect of the cutting parameters on surface roughness*

Figure 5c shows that the effects of the cutting inserts and the cutting speed and the minimum surface roughness value is achieved at the cutting speed of 220 m/min and uncoated carbide inserts. In Figure5c, when the cutting speed increase, the surface roughness values decrease. Decreasing the feed rate in the improvement of the surface roughness is a common practice in such studies [34]. In addition, this situation shows that there is very close relation between feed rate and surface roughness (Figure 5d). The effects of the cutting speed and the feed rate are shown in Figure 5d. It is shown that the surface roughness values increase with the increase of feed rate and the best surface quality is achieved at the cutting speed of 220 m/min. In Figure 5, the most effective parameter is the cutting speed according to other cutting parameters, and this parameter is efficiently changed to Figure 5b, Figure 5c and Figure 5d. On the other hands, the effects obtained from 3D graphs show parallelism with the means effect plots (Figure 4), and the effects of parameters affected on the surface roughness values achieved from experimental results are effectively verified by Taguchi method.

C. DATA ANALYSE USING ANOVA

Analysis of Variance (ANOVA) is a statistical method that is used to determine and analyse individual interactions of all control factors in Taguchi Method. In this study, cutting depth, cutting inserts, cutting speed, and feed rate was investigated their effects on surface roughness using ANOVA method. In addition, the multiple regression method was used to derive quadratic equation as mathematical model of the cutting parameters and their interactions. In the analysis, the percentage distributions of each control factor were used to measure the observed effects on the quality characteristics. Experimental results were evaluated at a confidence level of 95%. ANOVA values for experimental results are shown in Table 6, and the S/N ratios for the smaller the better characteristic are shown in Table 7.

In consequence of the pooling the percentage contributions of factors A, B, C and D are 1.92 %, 21.38%, 36.85%, and 5.73% respectively, and the error is 13.55% (Table 6). Therefore, control factor C (cutting speed) is the most significant factor in affecting surface roughness. These factors are followed by the factor B (21.38), factor two level interaction AxB (7.75), AxC (5.97) and AxD (6.85) respectively. On the other hand, the error on the ratio is small for the response model. According to ANOVA, because the percentage contribution of the error (e) is as small as only 13.55%, the error can be reduced that no further important factors were missed in the Taguchi method, and thus the collocation of the eighteen experimental trials given in this study is successful. In addition, because the variance caused by the cutting depth is too small, and it is regarded as noise in this study [35].

Table 6. *Results of ANOVA for control factors and interactions*

Variance Source	Degree of freedom (DF)	Sum of squares (SS)	Mean square (MS)	F	Contribution (%)
Surface roughness (Ra-μm)					
A	1	0.2301	0.2301	0.57	1.92
B	2	2.5593	1.2796	3.16	21.38
C	**2**	**4.4111**	**2.0962**	**5.18**	**36.85**
D	2	0.6870	0.2108	0.52	5.73
AxB	2	0.9280	0.4640	1.15	7.75
AxC	2	0.7146	0.3573	0.88	5.97
AxD	2	0.8199	0.4100	1.01	6.85
Error (e)	4	1.6191	0.4048		13.55
Total	17	11.9691			100

Moreover, Table 7 shows the ANOVA results obtained using S/N ratios of surface roughness values. It was observed that factor C (cutting speed) was the most significant factor (31.80%), followed by factor B (cutting tool) is 20.17%. The percentage contribution of error is 10.61%. These factors are followed by the factors two level interaction AxD (14.58), AxC (7.64) and AxB (4.65) respectively.

Table 7. *Results of ANOVA for S/N ratios and factor interactions*

Variance Source	Degree of freedom (DF)	Sum of squares (SS)	Mean square (MS)	F	Contribution (%)
Signal-to-noise ratios (S/N-dB)					
A	1	14.36	14.36	0.97	2.577
B	2	112.43	56.21	3.81	20.17
C	**2**	**177.23**	**100.58**	**6.83**	**31.80**
D	2	44.44	27.19	1.84	7.97
AxB	2	25.94	12.97	0.88	4.65
AxC	2	42.59	21.30	1.45	7.64
AxD	2	81.26	40.63	2.76	14.58
Error (e)	4	58.95	14.74		10.61
Total	17	557.19			

According to ANOVA values in Table 7, the error is small, and the both tables are similar to each other in terms of the percentage contribution. The results of the experimental trials for surface roughness are quite satisfactory.

D. CONFIRMATION EXPERIMENTS AND DETERMINATION OF QUALITY LOSSES

Confirmation experiments and determination of quality losses are the final step of the Taguchi method, and aim of these applications is to analyse the quality characteristics. The purpose of the confirmation experiment is to validate the conclusions drawn during the analysis phase. The confirmation experiment also serves the purpose of testing that specific combination of factors and levels, and it is defined by the total effect generated by the control factors [36, 37]. These factors are equal to the sum of each individual effect. In the Taguchi optimization technique, it was necessary to conduct a confirmation experiment to validate the optimized condition [38]. Minimum surface roughness is obtained by considering that the effective factors within the evaluated optimal combination. Therefore, in consideration of the individual effects of the control factors A_1, B_1, C_3 *and* D_1 (A_2 = 0.3 mm, B_1 = Uncoated, C_3 = 220 m/min, D_1=0.1 mm/tooth), minimum surface roughness value (Ra_c) is calculated as follows:

$$Ra_c = A_1 + B_1 + C_3 + D_1 - 2SRa_m \quad (5)$$

where, *A1, B1, C3 and D1* are the means of experimental trials with different levels of factors. According to these values, the minimum surface roughness (Ra_c) was computed as 2.30 µm. To verify the quality characteristic of the conformation experiment, the confidence interval (CI) is employed. In addition, the confidence interval is a maximum and minimum value between which the true average should fall at stated percentage of confidence. The CI for the predicted optimal values is calculated as follows [35, 38]:

$$CI = \sqrt{F_{\alpha:1,Ve} x V_{ep} x \left(\frac{1}{n_{eff}} + \frac{1}{r} \right)} \quad (6)$$

where $F_{\alpha:1,}v_e$ is the F-ratio of the significance level α, α is the significance level, $1\text{-}\alpha$ is the confidence level, V_e is the degrees-of-freedom of error, V_{ep} is the error variance, *r* is the number of confirmation experiments, and n_{eff} is the number of effective measured results defined as [32]:

$$n_{eff} = \frac{total \quad \exp rimental \quad trials}{1 + total \quad \deg rees \quad of \quad freedom \quad associated \quad with \quad items \quad used \quad in \quad estimate} \quad (7)$$

In this study, three confirmation experiments were performed to evaluate the performance of experimental trials conducted using optimal conditions (A_1 = 0.3 mm, B_1 = Uncoated, C_3 = 220 m/min, D_1=0.1 mm/tooth). With a 95% confidence level for surface roughness, that is, α = 0.05 and V_e = 4, $F_{\alpha:1,}v_e$ = 7.71 was found based on the look-up the table. The CI is calculated as 1.56 µm using Eq. 6 and Eq. 7. The three confirmation tests performed in terms of the optimal levels ($A_1B_1C_3D_1$) were found as 1.4, 1.53, and 1.33 µm, and the mean of these measurements was calculated as 1.42 µm in the determined confidence interval (0 < 1.42 < 2.98). Therefore, the result of the confirmation tests conducted for the surface roughness is expected to be located in the range of (1.42 ± 1.56) µm or (0-2.98) µm, with a 95% level.

__Table 8.__ Comparison of combinations in terms of means and S/N ratios

	Level	Ra (µm)	S/N (dB)
Initial			
Combination	$A_1B_2C_1D_1$	2.90	9.247
Surface roughness (Ra_m)			
Optimal combination (Experimental)	$A_1B_1C_3D_1$	1.42	3.045
Optimal combination (Prediction)	$A_1B_1C_3D_1$	2.30	7.234

In Table 8, surface roughness values are compared according to optimal combinations obtained by means of experimental and prediction. At the same time, the combination $A_1B_2C_1D_1$ is selected from eighteen trials as initial combination. According to Table 8, the values of the surface roughness are reduced from 2.90 µm to 1.42 µm, and the accuracy improved by the optimal combination is increased up to 51.03% ((0.52-0.24)/0.52) for surface roughness.

In Table 9, the performance comparisons between the initial and the optimal conditions are listed. Because the mean of the confirmation experiments is 1.42 µm, which is located in the predicted range of 0-2.98 µm, this range means that the control factors considered in this study are both significant and accurate. As a result of the eighteen experimental trials are considered to be successful [32]. The quality characteristic of this experiment is improved from 2.90 µm ($A_1B_2C_1D_{1,}$ initial combination) to 1.42 µm ($A_1B_1C_3D_{1,\text{ the}}$ optimal combination) as referred in Table 9.

__Table 9.__ The performance comparison between initial and optimal combination

	Initial combination	Optimal combination	
		Prediction	Confirmation
Level	$A_1B_2C_1D_1$	$A_1B_1C_3D_1$	$A_1B_1C_3D_1$
Ra_m (µm)	2.90	2.30±1.56	1.42
Quality loss			23.8 %

The quality losses between initial and optimal combinations for surface roughness can be calculated the ratio of quality loss function. This function refers the relation that every 3 dB in quality improvement will cut half of the quality loss. The quality loss function is indicated as follows [34]:

$$\frac{L_{opt}(y)}{L_{ini}(y)} \approx \left(\frac{1}{2}\right)^{\Delta\eta/3} \tag{8}$$

Where $L_{opt}(y)$ and $L_{ini}(y)$ are optimal and initial combinations respectively. Δ_η is the difference between the S/N ratios of optimal and initial combinations. The differences in S/N ratios that can be used to evaluate the quality loss of the optimal combination for confirmation experiments is found to be 6.202 [Δ_η = 6.725 (= 9.247 – 3.045)]. The quality loss of the confirmation test is calculated as 0.238 by means of Eq. 8. In this way, the quality loss of the optimal combination becomes only 23.8% of the initial combination. Therefore, the quality loss for the surface roughness has been reduced to 76.2% using the Taguchi method.

V. CONCLUSIONS

In this study, the parameter design of Taguchi method was presented, and 3D plots and ANOVA method were applied to evaluate the effects of cutting parameters on surface roughness. Moreover, the Taguchi method was used to obtain optimal control factors and to evaluate quality characteristic in face milling of AISI 1040 steel under dry cutting conditions. The obtained results using these methods are as follows:

- According to experimental results, the optimized control factors settings for surface roughness are: A_1 (a, cutting depth 0.3 mm), B_1(t, Uncoated cutting tool), C_3 (V, 220 m/min), D_1 (f, 0.1 mm/tooth).
- The experimental results indicated that the main effect of the cutting speed is the most significant factor on surface roughness (Ra) with the percent contribution of 36.85%. This factor is followed by the factor cutting tool (21.38%).
- According to ANOVA results, means and S/N table values are similar to each other. The confirmation test results showed that the observed values are within the calculated confidence interval for a significance level of 5% (or 95% confidence level).
- The quality loss of the surface roughness performed under the optimal combination is reduced to 76.2%. It is obtained from experimental studies that uncoated inserts have positive effects on better surface roughness.
- The machining accuracy of 2.90 μm could be significantly improved to 1.42 μm with an enhanced performance of 51.03% in the end of the confirmation experiments.

As shown in this study, Taguchi method was successfully applied to determine optimal combinations of the cutting parameters, and to minimize the machining costs and time in the face milling of AISI 1040 steel which is commonly used in the mold sets, automobile components, transmission shafts, rails and gears. The method presented in this study can be applied to various applications of machining of steels. Further research works could consider more parameters such as number of tooth of tool holder, different cutting inserts and cutting conditions of pocket and slot machining.

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