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Research Article

Investigation of Drilling Performance of CuZn15 Brass Material

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Abstract

Brass is basically a copper-zinc alloy. Zinc increases the strength of the brass, adding hardness and wear resistance to it. Brass is a copper alloy that is easy to produce and highly capable of forming. Therefore, it has found widespread and long-term use in many sectors. Drilling is one of the widely used machining methods with its simple structure and economy. In this study, CuZn15 brass alloy has been subjected to drilling tests in terms of two quality characteristics (cutting force and cutting tool temperature) considering four control factors (cutting speed, feed rate, drill bit angle and coating state). The effects of control factors on quality characteristics were modeled by regression analysis and optimum drilling conditions were tried to be determined by Taguchi method. For 95% confidence interval, the effect rates of control factors were calculated by variance analysis. Optimization was also tested by verification experiments. As a result of the experiments, it was observed that the order of importance of the control factors affecting the cutting force was the feed rate, the bit angle, the cutting speed and the coating state respectively, and the order of importance of the control factors affecting the cutting tool temperature was the cutting speed, the bit angle, the feed rate and the coating state. According to these results, optimization made at the level of 0.05 significance in terms of cutting force and cutting tool temperature was found appropriate.

Keywords: Brass; Drilling; Cutting parameters; Taguchi method; Regression analysis.

CuZn15 Pirinç Malzemenin Delinme Performansının İncelenmesi

Öz

Pirinç temelde bir bakır çinko alaşımıdır. Çinko, pirinçin mukavemetini arttırarak ona sertlik ve aşınma direnci katar. Pirinç, üretilmesi kolay ve şekillendirilebilme kabiliyeti yüksek bir bakır alaşımdır. Bu nedenle birçok sektörde yaygın ve uzun soluklu kullanım imkânı bulmuştur. Matkapla delik delme basit yapısı ve ekonomikliği ile halen yaygın olarak kullanılan imalat yöntemlerinden biridir. Bu çalışmada, CuZn15 pirinç alaşımı dört kontrol faktörü (kesme hızı, ilerleme miktarı, matkap uç açısı ve kaplama durumu) dikkate alınarak iki kalite karakteristiği (kesme kuvveti ve kesici takım sıcaklığı) açısından delme deneylerine tabi tutulmuştur. Kontrol faktörlerinin kalite karakteristikleri üzerindeki etkileri regresyon analizi ile modellenmiş ve Taguchi metodu ile optimum delme şartları belirlenmeye çalışılmıştır. %95 güven aralığında varyans analizi yapılarak kontrol faktörlerinin etki oranları hesaplanmıştır. Doğrulama deneyleri ile de optimizasyon test edilmiştir. Deneyler sonucunda kesme kuvveti üzerinde etkili olan kontrol faktörlerinin önem sıralamasının sırasıyla ilerleme miktarı, uç açısı, kesme hızı ve kaplama durumu olduğu, kesici takım sıcaklığı üzerinde etkili olan kontrol faktörlerinin önem sıralamasının ise kesme hızı, uç açısı, ilerleme miktarı ve kaplama durumu olduğu görülmüştür. Elde edilen bu sonuçlara göre, kesme kuvveti ve kesici takım sıcaklığı açısından 0,05 anlamlılık düzeyinde yapılan optimizasyonun uygun olduğu görülmüştür.

Anahtar Kelimeler: Pirinç, Delik delme, Kesme parametreleri, Taguchi metodu, Regresyon analizi.

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1. Introduction

Brass is an alloy formed by the combination of copper and zinc. Zinc increases the strength, hardness and wear resistance of brass. Brass alloys are relatively easy to manufacture as zinc can easily mix homogeneously in the copper melt. Brass is widely used due to its easy formability, production, high corrosion resistance and visual appeal. Brass alloys are commonly used in machine parts, fittings and plumbing projects [1-4].

Despite the development of modern manufacturing methods, classical turning, milling and drilling are still up to date. Due to its economy and simplicity, the commonly used hole drilling is one of the manufacturing methods that are widely used in many industries such as aerospace and automotive [5]. During the forming process by chip removal, the workpiece will resist not to get cut by cutting tools. In order for the cutting event to take place, this resistance must be overcome. This force which is necessary for the cutting to take place, is defined as "cutting force". The cutting force is one of the parameters showing the machinability of a material. [6-9]. The cutting force is one of the leading parameters that have an effect on the cutting tool life, and therefore on the surface quality. For these reasons, it is desirable to minimize the cutting forces [9, 10]. The efficiency of machining processes largely depends on increasing the cutting and feed rates. With the rising rates, the heat generated in the cutting zone will increase; therefore, the tool life and quality of the parts produced will be adversely affected [11-12]. Providing the temperature control is very important to increase cutting performance. Most of the heat generated during cutting is expected to be removed together with the chip. For this reason, it is necessary to quickly and easily evacuate the chip from the cutting zone [11-13].

In drilling forged brass material with carbide drills, Timata et al. investigated the effects of cutting speed and feed rate on the hole end burr height and hole diameter with variance analysis. They stated that the cutting speed and feed rate on results were statistically significant at 0.05 significance level [14]. Iwata et al. carried out high speed drilling experiments with 0.1 mm diameter carbide drills on stainless and brass materials. In the experiments performed using cutting fluid, they examined the effects of changes in cutting speed and feed rate on cutting tool wear and hole quality [15]. In another study conducted again by Iwata et al., they put stainless steel and brass materials with drill diameters ranging from 0.1-0.9 mm to high-speed machining experiments. They examined the cutting force, cutting torque, cutting tool wear and burr formation [16]. Vergara et al. put copper and brass materials to hole drilling experiments by friction stir welding method. They evaluated their hole quality in terms of sheet thickness, spindle speed, feed rate and TFD tool diameters. They explained that high spindle speeds and low feed rates are more effective than other parameters to produce sufficient quality holes [17].

Kato et al. investigated the effects of drill geometry on high-speed drilling of integrated circuits made of brass material. They stated that the longest tool life is in cutting tools with a 15º helix angle. They expressed that the newly developed drill geometry with a notch opened perpendicular to the cutting edge relatively reduces the cutting forces and that the chip can be evacuated more easily [18]. Boopathia et al. investigated the driving force and temperature distribution in the friction drilling method for brass, aluminum and stainless-steel materials for varying feed rates [19]. Rahman et al. put the brass material to drilling experiments via micro hole drilling by HSS cutting tools. In the experiments, they examined the material removal rate, surface roughness, dimensional accuracy and burr formation. They stated that with increasing cutting speed and feed rate, surface roughness and dimensional accuracy would decrease and tool wear and burr formation would increase [20]. Imai et al. made drilling experiments in dry conditions on high strength brass material (Cu-40Zn) produced by powder metallurgy method. They examined the effects of changes in material production method (sintering temperatures, protective atmosphere) on machinability [21]. Balout et al. investigated the cutting forces and chip formation in dry drilling of AA6061 forged, AA356 aluminum and 70-30 brass alloys, which were exposed to preheating and precooling. They stated that precooling reduces cutting forces depending also on cutting conditions and the chip can be evacuated more easily by breaking [22]. Gaitondea et al. examined the effects of minimum lubricant method of brass material on the turning process with carbide cutting tools using the Taguchi method [23].

In this study, the performance of CuZn15 brass alloy was modeled by multiple linear regression method in terms of cutting force and cutting tool temperature (2 quality characteristics) criteria by taking into account 4 different cutting speeds, 4 different feed rates, 4 different drill bit angles and 2 different coating conditions (4 control factors) with HSS cutting tools, and the optimum machining conditions were pursued by Taguchi method. In order to determine the impact rates of selected control factors on the quality characteristics, variance analysis (ANOVA) was applied to the test data at 95% confidence interval, and finally the validity of optimization was tested by verification experiment.

2. Material and Method

2.1. Materials

CuZn15 brass alloy was obtained by cutting Ø60 mm cylindrical material with a thickness of 17 mm. After that, levelling process was done by reducing the total thickness to 15 mm for the hole drilling test standards (plate thickness ≥ drill diameter x 3). The chemical composition and some mechanical properties of the test material are given in Table 1.

Table 1. Some properties of brass material [24].

Specification	Unit	Brass
Chemical Composition	%	84-86 Cu, 15 Zn, <=0.05 Fe, <=0.06 Pb
Density (at 20ºC)	g/cm^3	8.75
Melting Point	ºC	990-1025
Rockwell Hardness	HR	56
Yield Strength	MPa	69
Tensile Strength	MPa	270
Elasticity Modules	GPa	115
Poison Ratio	-	0.307
Thermal Conductivity Coefficient (20ºC)	[W/(mK)]	159

2.2. Machining Experiments

A through-hole drilling process (15 mm) was applied to CuZn15 brass test material using different cutting parameters by HSS cutting tools. Cutting forces (Fc) and cutting tool temperatures (T) were determined as performance criteria (quality characteristics). During the experiments carried out without using cutting fluid; 4 different cutting speeds (Vc), 4 different feed rates (f), 4 different drill bit angles (β) and 2 different coating states (CS) (uncoated and coated) were selected in order to determine the best values of control factors in terms of determined quality characteristics. Control factors, levels of control factors and abbreviations used are given in Table 2.

Table 2. Control factors and their levels.

Control Factors	Unit	Code	Levels			
			1	2	3	4
Cutting Speed (Vc)	m/min	A	10	20	30	40
Feed Rate (f)	mm/rev	B	0.025	0.050	0.075	0.100
Drill Bit Angle (β)	º	C	90	105	118	140
Coating State (CS)	-	D	Uncoated and Coated			

By Taguchi method, the optimum values of control factors for quality characteristics were pursued. The experimental design was made using the Taguchi L16 (4 ** 3 2 ** 1) vertical array. For the related material, the studies proposed in cutting tool catalogues and included in the literature were taken into consideration. Preliminary experiments were carried out at the highest levels of cutting parameters recommended in catalogues and literature.

2.3. Machine Tools, Cutting Tools and Measuring Devices

In the experiments, HSS cutting tools with Ø 5 mm diameter, 30° helix angle, 90º - 105º - 118° - 140º end angles, uncoated and coated (CVD - AlTiN - coating thickness: 5 µm) were used. In the selection of cutting tools, the manufacturer's recommendations and previous studies were taken into consideration. The cutting tools used in the experiments are connected to the tool holder with a collet that can tighten Ø5 mm diameter cutting tools.

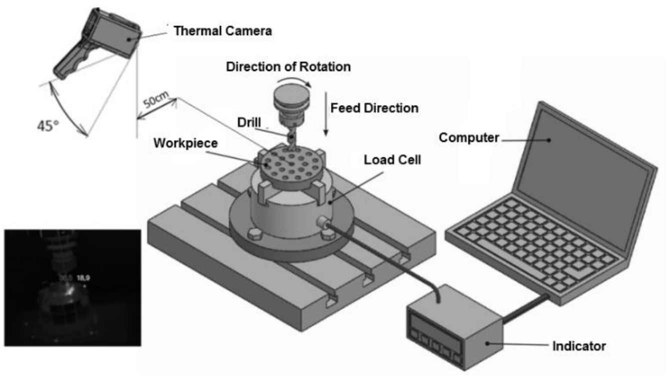

Figure 1. 3D model of experimental setup.

Drilling experiments were carried out using Arion IMM-600 CNC vertical machining center. Cutting forces were measured with a force gauge based on the load cell [25]. In Figure 1, it was attempted to present the design of the established experimental setup. The cylindrical prepared workpiece was connected to the workbench with a 4-legged chuck and the holes were drilled thoroughly. The temperatures formed in the tool and workpiece during machining were measured by Fluke Ti200 brand / model thermal camera.

2.4. Regression Analysis

Regression analysis is a model that includes dependent (quality characteristic) and independent (control factors) variables and allows the dependent variable to be expressed with independent variables [26]. The coefficient of determination (determination coefficient, R^2) obtained as a result of the equation gives the expressibility rate of independent variables with dependent variables. The closer the R^2 value to 1, the more accurate results can be obtained from the regression model. Regression analysis is a well-known statistical tool which is widely used by scientists as well.

Karaca examined the effect of drilling parameters such as cutting speed, feed rate and drill bit angle on the deformation factor formed during the drilling process of glass fiber reinforced plastic composites. He tried to identify the most appropriate drilling parameters using multiple regression analysis [27]. Bayraktar and Turgut have investigated the drilling process of fiber reinforced polymer matrix composite materials by considering factors such as surface damage at the entrance and exit of the hole, cutting tool, cutting parameters and cutting tool geometry. It was attempted to interpret the obtained data using methods such as taguchi, variance analysis, artificial neural networks and regression analysis. As a result of the studies, they emphasized that high cutting speed and low feed rates should be used [28].

Meral et al. modeled the feed forces and surface roughness obtained in the drilling of AISI 1050 material with linear regression, quadratic regression and exponential regression methods depending on the experimental parameters (drill type, drill diameter, feed rate and cutting speed) [10]. Yılmaz et al. drilled holes on the X10CrAlSi24 sheet material with 0.5mm diameter and 20mm length by electrical discharge machining method. In the experiments, they analyzed the values of workpiece machining speed and electrode wear rate for three different discharge currents, three different electrode speeds and two different electrode types. Then they obtained mathematical models with the help of multiple regression analysis by using experimental results [29]. Başak and Baday modeled the effects of cutting parameters on cutting forces and surface roughness by regression analysis in the machining of a spheroidized medium carbon steel. Significance testing was performed by ANOVA to determine the relationship between dependent variables and independent variables [30].

2.5. Taguchi Method

With the Taguchi method, in contrast to the traditional experiment design; the data obtained from the experiments are converted to Signal/Noise (S/N) ratio with the objective function suitable for the desired result in order to determine the effects of control factors on the quality characteristic. The S/N ratio is defined as the desired signal ratio for the undesired random noise value and shows the quality characteristics of the experimental data [31]. There are three basic functions for calculating the S/N ratio. These are "the smallest the best, the biggest the best and the nominal the best" purpose functions. The goal of all three functions is to maximize the S/N ratio [32, 33]. The Taguchi method is a method that allows the results to be obtained economically and in a shorter time by reducing the number of experiments, in contrast to the full factorial experiment design. For these reasons, the method is often preferred by scientists in different fields of study. Ghani et al. applied the Taguchi method to optimize milling parameters when machining AISI H13 tool steel with end mill. They chose cutting speed, feed rate and depth of cut as control factors, and cutting forces and surface roughness as quality characteristics. L27 orthogonal array was chosen for the experimental design. The experiments were carried out on AISI H13 tool steel workpiece material with TiN coated carbide tools. Low cutting forces and low surface roughness values were obtained in experiments with high cutting speed, low feed rate and low cutting depth [34].

Günay has optimized cutting tool tip radius and cutting parameters for the cutting forces and workpiece surface roughness values in the processing of AISI 316L austenitic stainless steel. For this purpose, Taguchi used the L9 vertical index and applied ANOVA analysis to determine their significance levels. It was found that the most important control factor affecting cutting force and surface roughness is the feed rate [35]. Farmer et al. optimized the cutting tool and cutting parameters with Taguchi L16 experimental design in machining of molybdenum alloys [33]. Canel et al. examined the impact of cutting parameters on surface roughness in laser cutting of Al 6082-T6 alloy with Taguchi method. [36]. Terzioğlu analyzed the impact factors on thermoelectric generator again using the Taguchi method [37]. Pınar et al. used the Taguchi method whilst examining the performance of the Ranque – Hilsch vortex tube [38]. Maiyar et al. optimized cutting parameters for milling of Inconel 718 super alloy with Taguchi-based gray relational analysis [39]. Gökçe et al. evaluated the milling process of commercial pure molybdenum in terms of cutting parameters using the Taguchi L16 experimental design [40].

In order to determine the appropriate levels of control factors, the situation with the smallest quality characteristic values should be determined (cutting forces and cutting tool temperatures are intended to be low). These goals were used to calculate the Signal/Noise (S/N) ratio, using the "the smallest the best" objective function given in Equation 1. Here; Yi: is the measured value (quality variable) of the quality characteristic and n: the total number of experiments (observations). In order to determine the effect of control factors on the quality characteristic values, ANOVA analysis was applied to the experiment results in 95% confidence interval. Taguchi method and ANOVA analysis were performed by Minitab17 program.

$$S/_N = -10 \log \left(1/_n \sum_{i=1}^{n} Y_i^2 \right) \quad (1)$$

Regression analysis is a model that includes dependent (quality characteristic) and independent (control factors) variables and allows the dependent variable to be expressed with independent variables [26].

3. Results and Discussion

Cutting forces and cutting tool temperatures measured in the through-hole (15mm) drilling experiments carried out using 4 different cutting speeds, 4 different feed rates, 4 different drill bit angles and 2 different coating states (uncoated and coated) on the CuZn15 brass alloy are given in Table 3. In addition, the S/N ratios and statistical calculations obtained with "the smallest the best" goal function given in Equation 1 in Table 3 are also shown in the coding used.

Table 3. Cutting forces, tool temperatures measured in experiments and calculated S/N ratios.

Test	Code	Vc (m/min)	Code	F (mm/rev)	Code	β (°)	Code	CS	Fc (N)	T (°C)	Fc S/N (dB)	T S/N (dB)
1	A1	10	B1	0.025	C1	90	D1	Uncoated	197.02*	37.10*	-45.8902	-31.3875
2	A1	10	B2	0.050	C2	105	D1	Uncoated	247.56	50.30	-47.8736	-34.0314
3	A1	10	B3	0.075	C3	118	D2	Coated	281.58	55.00	-48.9920	-34.8073
4	A1	10	B4	0.100	C4	140	D2	Coated	331.40	60.30	-50.4071	-35.6063
5	A2	20	B1	0.025	C2	105	D2	Coated	212.92	47.70	-46.5643	-33.5704
6	A2	20	B2	0.050	C1	90	D2	Coated	228.69	41.00	-47.1849	-32.2557
7	A2	20	B3	0.075	C4	140	D1	Uncoated	333.47	72.20	-50.4611	-37.1707
8	A2	20	B4	0.100	C3	118	D1	Uncoated	349.91	59.50	-50.8791	-35.4903
9	A3	30	B1	0.025	C3	118	D1	Uncoated	271.18	68.50	-48.6652	-36.7138
10	A3	30	B2	0.050	C4	140	D1	Uncoated	321.21	70.20	-50.1358	-36.9267
11	A3	30	B3	0.075	C1	90	D2	Coated	273.73	46.60	-48.7464	-33.3677
12	A3	30	B4	0.100	C2	105	D2	Coated	323.82	55.70	-50.2061	-34.9171
13	A4	40	B1	0.025	C4	140	D2	Coated	242.49	74.10	-47.6939	-37.3964
14	A4	40	B2	0.050	C3	118	D2	Coated	292.83	69.40	-49.3323	-36.8272
15	A4	40	B3	0.075	C2	105	D1	Uncoated	332.98	77.80**	-50.4484	-37.8196
16	A4	40	B4	0.100	C1	90	D1	Uncoated	351.03**	73.60	-50.9069	-37.3376
								Average	286.99	59.9		
* Minimum Value, ** Maximum Value												

The average cutting force obtained as a result of drilling the test material with the determined control factors was calculated as 286.99 N and the average cutting tool temperature value was calculated as 59.9ºC. When Table 3 is examined, it is seen that the highest values of control factors are 351.03 N for cutting force, 77.80ºC for cutting tool temperature value, and the lowest values of control factors are 197.02 N for cutting tool temperature value and 37.10ºC for cutting tool temperature value. These differences between the maximum and minimum results of the quality characteristics are an indication that the determined control factors significantly affect the drilling performance of the brass material.

3.1. Multiple Linear Regression Analysis Results

In order to calculate cutting forces and cutting tool temperatures, multiple linear regression equations are given in Equation 2 and Equation 3 respectively. In the equations, the values represented are A: Cutting speed, B: Feed rate, C: Drill bit angle and D: Coating state (Table 2 and Table 3).

$$Fc = 166 + 13.8\,A + 35.7\,B + 15.3\,C - 27.1\,D \quad (2)$$

$$T = 31.1 + 7.43\,A + 2.14\,B + 6.41\,C - 7.42\,D \quad (3)$$

In the regression equations, the increasing values of the control factors in the negative factor state will have a negative effect on the quality characteristic results, while the increasing values of the control factors in the positive factor state will have a positive effect. Coating state (D) was coded as 1 (uncoated) and 2 (coated) to achieve the regression equation.

The Table of coefficients found after obtaining the regression equation is given in Table 4. In this Table; Coef: indicates coefficients of values, SE Coef: standard error in coefficients, T: the result of test statistics, P: whether regression analysis is significant or not. P values less than 0.05 is a proof that the control factor is statistically significant.

In terms of cutting force, the feed rate has the highest coefficient, and it is an expected situation for cutting forces to rise at increasing values of the feed rate [41, 42]. Although the effect of coating state is seen as negative, the coated cutting tool will have the effect to decrease the cutting force since its code is 2 (negative coefficient). It is stated that coated cutting tools reduce cutting forces compared to uncoated tools [43]. It is also seen in Equation 3 and Table 4 that cutting speed is the cutting factor which the cutting tool temperature is affected the most.

Table 4. Coefficient table of regression equations.

	Cutting Force				Cutting Tool Temperature			
Predictive Element	Coef	SE Coef	T	P	Coef	SE Coef	T	P
Coefficient	165.66	11.27	14.70	0.000	31.113	5.714	5.45	0.000
Cutting Speed	13.756	2.016	6.82	0.000	7.430	1.022	7.27	0.000
Feed Rate	35.728	2.016	17.72	0.000	2.145	1.022	2.10	0.060
Drill Bit Angle	15.313	2.016	7.59	0.000	6.410	1.022	6.27	0.000
Coating State	-27.112	4.509	-6.01	0.000	-7.425	2.285	-3.25	0.008
R-Sq (R^2)	%97.6				%90.7			
R-Sq (adj) (R^2 adj)	%96.8				%87.3			

Table 5. Variance analysis of regression equations.

Cutting Force					
Source	DF	SS	MS	F	P
Regression	4	36944.7	9236.2	113.58	0.000
Measurement Error	11	894.5	81.3		
Total	15	37839.2			
Cutting Tool Temperature					
Source	DF	SS	MS	F	P
Regression	4	2238.40	559.60	26.79	0.000
Measurement Error	11	229.81	20.89		
Total	15	2468.22			

When the values in Table 4 are examined, it can be concluded that almost all control factors are not statistically significant in drilling the brass material (P> 0.05). When the cutting force and cutting tool temperature R^2 and adjusted R^2 values are examined, we see that the regression equations can explain the experiments at a rate of 97.6% for cutting force and 90.7% for cutting tool temperature. In other words, a strong relationship can be mentioned between the variables.

Our adjusted R^2 value is 96.8% for cutting force and 87.3% for cutting tool temperature, and this value is not too far from R^2. Therefore, it can be said that the regression equation is applicable. In addition, variance analysis of the multiple linear regression equation we obtained in is given Table 5. Here, the P value is less than 0.05 so we have a statistically significant regression equation.

3.2. Optimization Results with Taguchi Method

According to the S/N ratios calculated for the cutting force and cutting tool temperature values, the main impact graphs are shown in Figure 2 and Figure 3. In addition, Table 6 gives the distribution of S/N ratios according to control factors and their order of importance.

When the main impact graphs in Figure 2 and the highest and lowest points of S/N ratios in Table 6 are examined, it is seen that the most important control factor affecting the cutting force is the feed rate. It is also seen in Table 6 that the order of importance for control factors affecting the cutting force is the feed rate, drill bit angle, the cutting speed and the coating state, respectively.

Similarly, when Figure 3 and Table 6 are reviewed, it is seen that the most important control factor affecting the cutting tool temperature is the cutting speed. In addition, the order of importance for control factors affecting the cutting tool temperature is the cutting speed, drill bit angle, feed rate and coating state, respectively (Table 6).

The interaction of feed rate and the change in the drill bit angle on cutting forces are shown on the graph in Figure 4. Fluctuations on the graph show that cutting forces are also affected by other control factors (cutting speed and coating state), and these results prove the accuracy of statistical results as well.

Figure 5 shows the effect of changes in cutting speed and drill bit angle on the cutting tool temperature. The curvature of color changes on the graph is an indication that other control factors (feed rate and coating state) also affect the cutting tool temperature values. With the variance analysis (ANOVA), the influence rates of cutting forces and cutting tool temperature values from control factors were determined, and the results were given in Table 7. In the schedule, SD: indicates Degree of freedom, KT: Sum of squares, KO: Average of squares, F: Test statistics, P: Level of significance, % contribution: Impact rate and R^2: Determination coefficient.

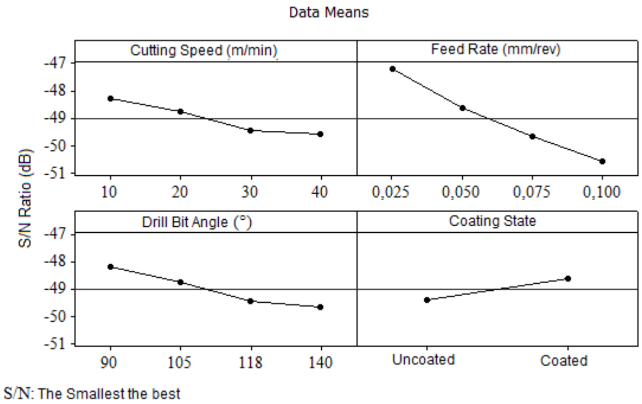

Figure 2. Main effect plots for the S/N ratios of the cutting force values.

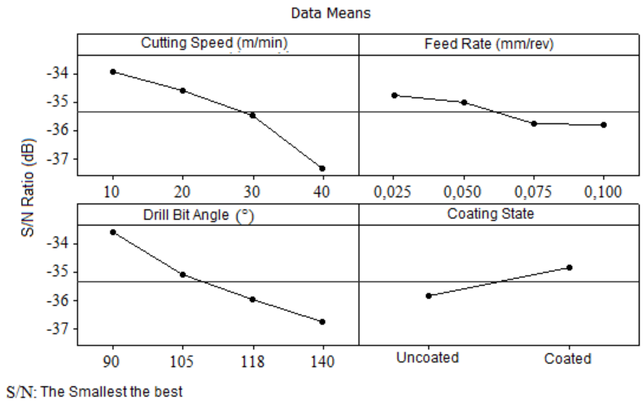

Figure 3. Main effect plots for the S/N ratios of the cutting tool temperature values.

Table 6. The order of importance of control factors for average S/N ratios of cutting force and cutting tool temperature values.

Level		Cutting Speed (dB)	Feed Rate (dB)	Drill Bit Angle (dB)	Coating State (dB)
Cutting Force	1	-48.29	-47.20	-48.18	-49.41
	2	-48.77	-48.63	-48.77	-48.64
	3	-49.44	-49.66	-49.47	
	4	-49.60	-50.60	-49.67	
	Difference	1.30	3.40	1.49	0.77
	Order	3	1	2	4
Cutting Tool Temperature	1	-33.96	-34.77	-33.59	-35.86
	2	-34.62	-35.01	-35.08	-34.84
	3	-35.48	-35.79	-35.96	
	4	-37.35	-35.84	-36.78	
	Difference	3.39	1.07	3.19	1.02
	Order	1	3	2	4

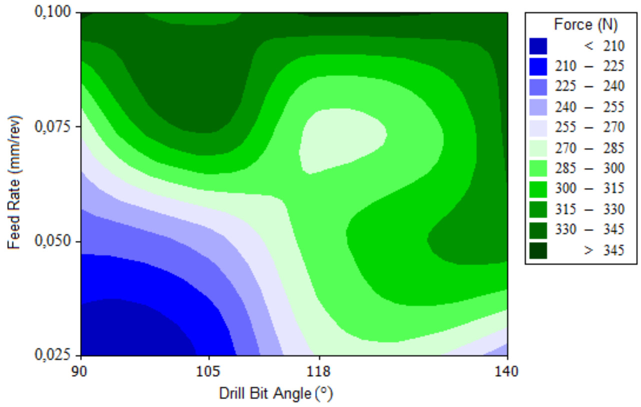

Figure 4. Interaction of change in feed rate and bit angle on the cutting force.

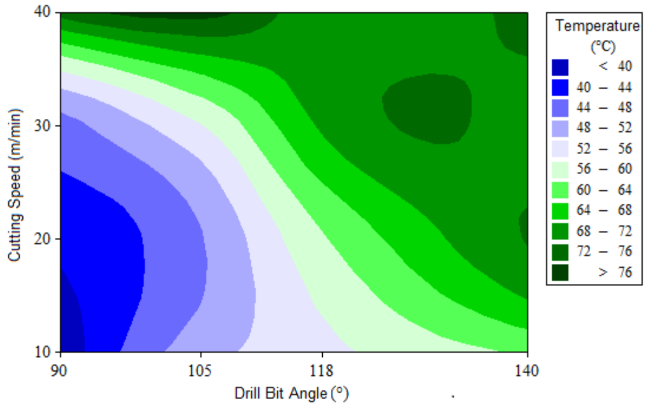

Figure 5. Interaction of change in cutting speed and bit angle on cutting tool temperature.

According to ANOVA results, as in regression analysis; the P value of less than 0.05 indicates that the effect of control factors on quality characteristics is statistically significant. When Table 7 is examined, the significance level for each control factor is less than 0.05 (P value < 0.05). Accordingly, all control factors are statistically effective on quality characteristics. Moreover, when the F rates in Schedule 7 are compared to value of the relevant F test table (α = 0.05 F distribution table), it is seen that the F rates are considerably larger than the α = 0.05 F distribution table value (F rates > 6.61). These results also support the accuracy of variance analysis. The fact that the determination coefficients (R^2) is 98.43% for cutting force and 95.72% for cutting tool temperature is an indication that there is a strong relationship between quality characteristics and control factors.

Table 7. ANOVA for cutting force and cutting tool temperature values S/N ratios.

Control Factors		SD	KT	KO	F Ratio	P value	% Contribution
Cutting Force	Cutting Speed	3	3888.9	1296.3	10.88	0.012	10.28
	Feed Rate	3	25613.1	8537.7	71.64	0.000	67.69
	Drill Bit Angle	3	4800.9	1600.3	13.43	0.008	12.69
	Coating State	1	2940.4	2940.4	24.67	0.004	7.77
	Residual Error	5	595.9	119.2			1.57
	Total	15	37839.2				100.00
	R^2	%98.43					
Cutting Tool Temperature	Cutting Speed	3	1197.55	399.18	18.87	0.004	48.52
	Feed Rate	3	114.67	38.22	1.81	0.263	4.65
	Drill Bit Angle	3	829.72	276.57	13.08	0.008	33.62
	Coating State	1	220.52	220.52	10.43	0.023	8.93
	Residual Error	5	105.75	21.15			4,28
	Total	15	2468.22				100.00
	R^2	%95.72					

It can be observed from the related table (Table 7) that the rates of cutting force values affected by the control factors are 67.69% for the feed rate, 12.69% for drill bit angle, 10.28% for the cutting speed and 7.77% for the coating condition. In addition, it is given in Table 7 that the rates of cutting tool temperature values affected by control factors are 48.52% for cutting speed, 33.62% for tip angle, 8.93% for coating state and 4.65% for feed rate, respectively.

By optimization with Taguchi method, the optimum levels of control factors were identified on the determined quality characteristics. According to this optimization, the optimum levels of control factors in terms of cutting forces were found as A1-B1-C1-D2 (10 m/min cutting speed-0.025 mm/rev feed rate-90º drill bit angle-coated drill) and in terms of cutting tool temperature values as A1-B1-C1-D2 (10 m/min cutting speed-0.025 mm/rev feed rate-90º drill bit angle-coated drill) (Figure 2 and Figure 3). The next step is to check the validity of optimization. For this purpose, verification experiments and predictive calculations should be made for the optimum levels of control factors. The results of the verification experiment, predictive calculations and comparisons are given in Table 8.

Equation 4 was used to calculate the predictive value (Fc_{tah}) of the cutting force, and Equation 5 was used to calculate the predictive value (T_{tah}) of the cutting tool. The levels of control factors at which optimum cutting force and cutting tool temperature can be achieved are the same (A1-B1-C1-D2). In Equality 4; Fc_{tah}: Arithmetic mean of Fc value for the optimum conditions of A1-B1-C1-D2 control factors and $\overline{Fc}_{tah}$: arithmetic mean of Fc values obtained as a result of experiments. In Equality 5; T_{tah}: Arithmetic mean of T value for the optimum conditions of A1-B1-C1-D2 control factors and $\overline{T}_{tah}$: arithmetic mean of T values obtained as a result of experiments.

$$Fc_{tah} = \overline{Fc}_{tah} + \left(\overline{A}_1 - \overline{Fc}_{tah}\right) + \left(\overline{B}_1 - \overline{Fc}_{tah}\right) + \left(\overline{C}_1 - \overline{Fc}_{tah}\right) + \left(\overline{D}_2 - \overline{Fc}_{tah}\right) \tag{4}$$

$$T_{tah} = \overline{T}_{tah} + \left(\overline{A}_1 - \overline{T}_{tah}\right) + \left(\overline{B}_1 - \overline{T}_{tah}\right) + \left(\overline{C}_1 - \overline{T}_{tah}\right) + \left(\overline{D}_2 - \overline{T}_{tah}\right) \tag{5}$$

The results of verification experiment carried out with the levels of optimum control factors were evaluated by considering the confidence interval (CI) value calculated by means of Equation 6.

$$CI = \sqrt{F_{0,05,(1,f_e)}\, Ve\, \left(1/\eta_{eff} + 1/r\right)} \tag{6}$$

$$\eta_{eff} = {}^{N}\!/_{1 + \upsilon_T} \tag{7}$$

In Equation 6 and Equation 7; the symbols are represented as $F_{0,05,(1,f_e)}$: The degree of error freedom from the test table F0.05, Ve: Error variance, η_{eff}: actual number of repetitions, r: Number of repetitions for verification experiment, N: total number of experiments and υ_T: sum of degrees of freedom for the control factors. Accordingly, the values for cutting force: $F_{0,05,(1,f_e)}$ (from F test table) and Ve = 119.2, and for cutting tool temperature: $F_{0,05,(1,f_e)}$ (from F test table) and Ve = 21.15 (Table 7) were obtained from the relevant tables.

After substituting the sum of degrees of freedom for the control factors which have a significant effect on calculating the number of repetitions of experiment, total number of experiments and cutting force in Equation 7, the actual number of repetitions (ɳeff) was calculated as 1.45 and the number of repetitions for verification experiment (r) was applied as 1.

When the relevant values were substituted in Equation 6, the Confidence Range (CI) was found as ± 32.91. If the same calculations are repeated for the cutting tool temperature; the values to be obtained are $F_{0,05,(1,f_e)}$ = 6.61, Ve = 21.15, ɳeff = 1.45, r = 1 and CI = ± 13.86.

The Fc value (Fc_{den} = 180.52 N) obtained as a result of the verification experiment was determined, and the S/N ratio (Fc S/N_{den} = -45.1305 dB) of this value was calculated with Equation 1. In addition, the predictive Fc_{tah} value (Fc_{tah} = 170.38 N) and S/N ratio (Fc S/N_{tah} = -45.2445 dB) calculated with Equation 4 were found by means of Equation 1. If the same operations are repeated for the cutting tool temperature, the results are found as T_{den} = 35.07 ºC, T S/N_{den} = -30.8987 dB, T_{tah} = 33.51 ºC and T S/N_{tah} = -31.1009 dB (Table 8).

Table 8. Comparison of the results of the verification experiment and predictive calculations.

Quality Characteristics	Verification Experiments		Predictive Calculations		Differences	
Cutting Force	Fc_{den} (N)	Fc S/N_{den} (dB)	Fc_{tah} (N)	Fc S/N_{tah} (dB)	Fc_{den}-Fc_{tah}| (N)	Fc S/N_{den}-Fc S/N_{tah} (dB)
	180.52	-45.1305	170.38	-45.2445	10.14	0.1140
Cutting Tool Temperature	T_{den} (ºC)	T S/N_{den} (dB)	T_{tah} (ºC)	T S/N_{tah} (dB)	T_{den}-T_{tah} (ºC)	T S/N_{den}-T S/N_{tah} (dB)
	35.07	-30.8987	33.51	-31.1009	1.56	0.2022

According to these results: the absolute difference between the ratio Fc S/N_{den} (-45.1305 dB) and the ratio Fc S/N_{tah} (-45.2445 dB) for cutting force resulted as 0.1140 dB, and the absolute difference between the ratio T S/N_{den} (-30.8987 dB) and the ratio T S/N_{tah} (-31.1009 dB) for the cutting tool temperature as 0.2022 dB. For both quality characteristics, these differences are seen to be smaller than the confidence interval (CI) values calculated with Equation 6 (0.1140 <32.91) and (0.2022 <13.86). That is to say; for cutting force,

$Fc\ S/N_{tah} - CI < Fc\ S/N\ den < Fc\ S/N_{tah} + CI$

$-45.2445 - 32.91 < -45.1305 < -45.2445 + 32.91 \rightarrow -78.1545 < -45.1305 < -12.3345$

Also, for cutting tool temperature:

$T\ S/N_{tah} - CI < T\ S/N_{den} < T\ S/N_{tah} + CI$

$-31.1009 - 13.86 < -30.8987 < -31.1009 + 13.86 \rightarrow -44.9609 < -30.8987 < -17.2409$ can be calculated.

4. Conclusion

In this study, drilling of the CuZn15 brass alloy with HSS cutting tools using 4 control factors as cutting speed, feed rate, drill bit angle and coating state was evaluated in terms of cutting force and cutting tool temperature quality characteristics. Results of the study were evaluated with the regression analysis and the Taguchi method statistical methods, and validity of the optimization performed with the validation experiments was tested. As a result of the study, the following conclusions were obtained.

- The order of importance for the control factors affecting cutting force was the feed rate, drill bit angle, cutting speed and coating state, respectively.
- The order of importance of the control factors affecting the cutting tool temperature was found to be cutting speed, drill bit angle, feed rate and coating state, respectively.
- It was calculated that the feed rate was effective on results at a rate of 67.69% in terms of cutting force while the cutting speed at 48.52% in terms of cutting tool temperature.
- Other control factors determined on the cutting force and tool temperature are also statistically significant.
- With increasing feed rate for each drill bit angle, cutting forces tend to rise. The lowest cutting forces were measured with drills with a low bit angle.
- Increased cutting speed resulted in more intense heat generation in the cutting zone. Increasing the drill bit angle also adversely affected the heat passing to the cutting tool.

The optimization made at the level of 0.05 significance in terms of cutting force and cutting tool temperature was found to be appropriate.

References

[1] Şentürk, B.S., "*Pirinç alaşımlarının ekstrüzyonunda meydana gelen üretim hatalarının tespiti, nedenleri ve çözüm yollari*" İTÜ Institute of Science, Master's Thesis, 2007.

[2] Brady, G.S., "*An encyclopedia for purchasing managers, engineers, executives and foremen*" McGraw-Hill Company Materials Handbook, New York, 1991.

[3] Gokce, H., "*Optimization of cutting tool and cutting parameters in face milling of custom 450 through the taguchi method*" Advances in Materials Science and Engineering, 2019.

[4] Ersümer, A., "*Bakır ve alaşımlarının dökümü ve ısıl işlemleri*" İTÜ Bookstore, İstanbul, 1976.

[5] Kurt, M., Kaynak, Y., Bakır, B., Köklü, U., Atakök, G., Kutlu, L. "*Experimental investigation and taguchi optimization for the effect of cutting parameters on the drilling of Al2024-T4 alloy with diamond like carbon coated drills*" International Advanced Technologies Symposium, Karabük, Turkey, 2009.

[6] Colligan, K. "*New tool drills both titanium and carbon composites*" American Machinist, 138(10): 56-58, 1994.

[7] Kim, D., Ramulu, M. "*Cutting and drilling characteristics of hybrid titanium composite laminate*" In Proceedings of Materials and Processing Technologies for Revolutionary Applications Fall Technical Conference, Seattle, Washington, 1-8, 2005.

[8] Lambert, B.K. "*Prediction of force, torque and burr length in drilling titanium composite materials*" SME Technical Paper MR79: 363, 1979.

[9] Bayraktar, Ş., Siyambaş, Y., Turgut, Y. "*Delik delme prosesi: bir araştırma*" Sakarya University Institute of Science, Master's Thesis, 21(2): 120-130, 2017.

[10] Meral, G., Dilipak, H., Sarıkaya, M., "*AISI 1050 malzemenin delinmesinde delme parametrelerinin delik kalitesi üzerindeki etkisinin çoklu regresyon metoduyla modellenmesi*" Electronic Journal of Machine Technologies, 8(1): 37-46, 2011.

[11] Dhar, N.R., Ahmed, N.T., Islam, S., "*An experimental investigation on effect of minumum quantity lubrication in machining AISI 1040 steel*" International Journal of Machine Tools & Manufacture, 47(1): 748-753, 2007.

[12] Çakır, A., Bahtiyar, O., Şeker, U., "*Farklı soğutma şartları ile farklı kesme parametrelerinin AA7075 ve AA2024 alüminyum alaşımlarında delik delme işlemlerine etkisinin deneysel olarak incelenmesi*" 16rd International Machine Design and Manufacturing Congress, İzmir, Turkey, 2014.

[13] Bahçe, E., Kılıçkap, E., Özel, C. "*AL5005'in delinmesinde delme parametrelerinin çapak oluşumuna etkisinin araştırılması*" 2rd National Design Machining and Analysis Congress, Balıkesir, Turkey 2010.

[14] Timata, M., Saikaew, C. "*Influences of spindle speed and feed rate on exit burr height and workpiece diameter in drilling forging brass*" Solid State Phenomena - Metallurgy Technology and Materials VI, 279(1): 67-71, 2018.

[15] Iwata, K., Moriwaki, T., Hoshi, T. "*Basic study of high-speed micro deep drilling*" CIRP Annals, 30(1): 27-30, 1981.

[16] Iwata, K., Moriwaki, T., Hoshikawa, T. "*Fundamental study of high-speed micro deep drilling*" Journal of the Japan Society of Precision Engineering, 49(2): 240-246, 1983.

[17] Vergara, J., Damm, S., Villanueva, J., Godoy, J.M., Tikal, F. "*Bush making by thermal flow drilling in copper and brass*" The International Journal for Manufacturing Science & Production, 4(2): 103-111, 2001.

[18] Kato, H., Nakata, S., Ikenaga, N., Sugita, H. "*Improvement of chip evacuation in drilling of lead-free brass using micro drill*" International Journal of Automation Technology, 8(6): 874-879, 2014.

[19] Boopathia, M., Shankara, S., Manikandakumara, S., Rameshb, R. "*Experimental investigation of friction drilling on brass, aluminium and stainless steel*" Procedia Engineering, 64(1): 1219-1226, 2013.

[20] Rahman, A.A., Mamat, A., Wagiman, A. "*Effect of machining parameters on hole quality of micro drilling for brass*" Modern Applied Science, 3(5): 221-230, 2009.

[21] Imai, H., Li, S., Kondoh, K., Kosaka, Y., Kojima, A., Atsumi, H., Umeda, J. "*Effect of chromium precipitation on machinability of sintered brass alloys dispersed with graphite particles*" Materials Transactions, 52(7): 1426, 2011.

[22] Balout, B., Songmene, V., Masounave, J. "*An experimental study of dust generation during dry drilling of pre-cooled and pre-heated workpiece materials*" Journal of Manufacturing Processes, 9(1): 23-34, 2007.

[23] Gaitondea, V.N., Karnik, S.R., Davimc, J.P. "*Selection of optimal MQL and cutting conditions for enhancing machinability in turning of brass*" Journal of Materials Processing Technology, 204(3): 459-464, 2008.

[24] Online http://www.matweb.com/search/DataSheet.aspx

[25] Gökçe, H., Yavuz, M., Karayel, M. "*İmalat süreçlerinde kesme kuvvetlerinin belirlenmesi amaçlı dinomometre tasarımı ve imalatı*" Gazi Journal of Engineering Sciences, 3(2): 27-32, 2017.

[26] Başar, G., Kahraman, F. "*Delik işleme prosesinde kesme parametrelerinin Taguchi metodu ve regresyon analizi kullanılarak modellenmesi ve optimizasyonu*" 2rd International Mediterranean Science and Engineering Congress, Antalya, Turkey, 2017.

[27] Karaca, F., "*Cam elyaf takviyeli plastik kompozitlerde delme parametrelerinin deformasyon faktörüne etkisinin araştırılması*" Science and Engineering Journal of Fırat University, 28(2): 23-27, 2016.

[28] Bayraktar, Ş., Turgut, Y. "*Elyaf takviyeli polimer kompozit malzemelerin delinmesi üzerine bir araştırma*" 3rd National Symposium on Machining Manufacturing, Ankara, Turkey, 2012.

[29] Yılmaz, V., Yılmaz, C.Y., Sarıkaya, M., Özdemir, M. "*Modelling of performance output in the hole drilling process with different electrodes to X10CrAlSi24 sheet material*" 3rd International Symposium on Innovative Technologies in Engineering and Science, Valencia, Spain, 1032-1041, 2015.

[30] Başak H, "*In processing of a spheroidized medium carbon steel, modelling with regression analysis of cutting forces and surface roughness affected by cutting parameters*" Pamukkale University Journal of Engineering Sciences, 22(4): 253-258, 2016.

[31] Aydemir, M.E. "*Bazı optimizasyon yöntemlerinin yama anten problemlerindeki performansı*" Journal of the Faculty of Engineering and Architecture of Gazi University, 29(3): 579-588, 2014.

[32] M., Saat, "*Kalite denetiminde taguchi yaklaşımı*" Gazi University Journal of Faculty of Economics and Administrative Sciences, 3(1): 97-108, 2000.

[33] Çiftçi, İ., Gökçe, H., "*Optimisation of cutting tool and cutting parameters in machining of molybdenum alloys through the taguchi method*" Journal of the Faculty of Engineering and Architecture of Gazi University, 34(1): 201-213, 2019.

[34] Ghani J.A., Choudhury I.A., Hassan H.H. "*Application of taguchi method in the optimization of end milling parameters*" Journal of Materials Processing Technology, 145(1): 84-92, 2004.

[35] Günay M., "*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, 28(3): 437-444, 2013.

[36] Canel, T., Zeren, M. and Sınmazçelik, T. "*Laser parameters optimization of surface treating of Al6082-T6 with taguchi method*" Optic & Laser Technology, 120(1): 1-15, 2019.

[37] Terzioğlu, H. "*Analysis of effect factors on thermoelectric generator using taguchi method*" Measurement, 149, 106992, 2020.

[38] Pinar, A.M., Uluer, O., Kirmaci, V. "*Optimization of counter flow ranque-hilsch vortex tube performance using taguchi method*" International Journal of Refrigeration, 32(6): 1487-1494, 2009.

[39] Maiyar, L.M., Ramanujam, R., Venkatesan, K. and Jerald, J. "*Optimization of machining parameters for end-milling of inconel 718 super alloy using taguchi based grey relational analysis*" Procedia Engineering, 64(1): 1276-1282, 2013.

[40] Gökçe, H., Çiftçi, İ. and Demir, H. "*Cutting parameter optimization in shoulder milling of commercially pure molybdenum*" Journal of the Brazilian Society of Mechanical Sciences and Engineering, 40(360): 1-11, 2018.

[41] Korkmaz, M.E., Çakıroğlu, R., Yaşar, N., Özmen, R., Günay, M. "*Al2014 alüminyum alaşımının delinmesinde itme kuvvetinin sonlu elemanlar yöntemi ile analizi*" El-Cezerî Journal of Science and Engineering, 6(1): 193-199, 2019.

[42] Çaydaş, U., Çelik, M. "*AA7075T6 alaşımının delinmesinde kesme parametrelerinin yüzey pürüzlülüğü, takım sıcaklığı ve ilerleme kuvvetine etkilerinin araştırılması*" Journal of Polytechnic, 20(2): 419-425, 2017.

[43] Bayraktar, Ş. "*Investıgatıng of effects on thrust force and burr height of cutting parameters in dry drilling of AL5083 alloy*" 16rd International Materials Symposium, Denizli, Turkey, 2016.