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Araştırma Makalesi / Research Article

Investigation of The Effect of Radial Width and Axial Depth Parameters on Surface Quality in Milling of White Marbles

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Abstract

In this study, surface quality and tangential cutting force and radial width (a_e) and axial deep (a_p) parameters were investigated in the processing of white marble, which is a natural building material. Five different white marbles were used in the experiments and the taguchi method was applied as the test method. Depending on the number and level of parameters, the L9 orthogonal array was chosen. Cutting forces and surface roughness data were collected for each marble. The optimal level and contribution percentage of each parameter was determined by applying the analysis of variance with the signal-to-noise (S/N) ratio. The Fr and Ra factors for all marbles were found to be ae:1 mm and ap:1 mm. Depending on the significance level, axial depth of cut (ap) was the primary effective parameter (65-86% for Fr; 42-78% for Ra), while radial depth of cut was the secondary effective parameter (3-24% for Fr; 16-35% for Ra). It can be said that the feed rate parameter was not an effective parameter in general.As a result of regression analysis, a significant relationship of 83% was observed between Ra surface roughness value and mineral grain size. Grain size has been the mineralogical-petrographic feature affecting the surface quality of marbles.

Keywords
Marble; Taguchi method; Surface roughness; Varyans analizi; Axial depth of cut; Radial depth of cut

Beyaz Mermerlerin Frezelemesinde Radyal Genişlik ve Eksenel Derinlik Parametrelerinin Yüzey Kalitesine Etkisinin Araştırılması

Öz

Bu çalışmada, doğal bir yapı malzemesi olan beyaz mermerin işlenmesinde yüzey kalitesi ve teğetsel kesme kuvveti ile radyal genişlik (a_e) ve eksenel derinlik (a_p) parametreleri araştırılmıştır. Deneylerde beş farklı beyaz mermer kullanılmış ve test yöntemi olarak Taguchi yöntemi uygulanmıştır. Parametre sayısı ve seviyesine bağlı olarak L9 ortogonal dizisi seçilmiştir. Her bir mermer için kesme kuvvetleri ve yüzey pürüzlülüğü verileri toplanmıştır. Her bir parametrenin optimum seviyesi ve katkı yüzdesi, sinyal-gürültü (S/N) oranı ile varyans analizi uygulanarak belirlenmiştir. Tüm mermerler için Fr ve Ra faktörleri, ae:1 mm ve ap:1 mm olarak bulundu. Anlamlılık seviyesine bağlı olarak, eksenel kesme derinliği (ap) birincil etkin parametre (Fr için 65-86%; Ra için 42-78%), radyal kesme derinliği ikincil etkin parametre (3-24% for Fr; 16-35% for Ra) olmuştur. İlerleme hızı parametresinin ise genel olarak etkin bir parametre olmadı söylenebilir. Regresyon analizi sonucunda Ra yüzey pürüzlülüğü değeri ile mineral tane boyutu arasında %83 oranında anlamlı bir ilişki gözlenmiştir. Tane boyutu, mermerlerin yüzey kalitesini etkileyen mineralojik-petrografik özellik olmuştur.

Anahtar kelimeler
Mermer; Taguchi yöntemi; Yüzey pürüzlülüğü; Varyans analizi; Eksenel kesme derinliği; Radyal kesme derinliği

1. Introduction

Marbles have been used throughout history in art and architecture in terms of durability and aesthetics. The use of CNC machine is increasing in the marble industry as it is more precise, faster, higher quality, and multidimensional than manual work. The most important difference of marbles from metal alloys is that they are produced directly from nature, and the natural structure content cannot be changed. The most important difference of natural stones compared to composite materials and metals is that they are heterogeneous. Therefore, due to the processing of materials with the homogeneous characterization of CNC machines, tool technology, and machinery have developed rapidly compared to metal materials. In the milling of marbles, the processing parameters change according to the characterization of the rocks. The texture of the rocks and the mineral grain sizes affect the surface roughness in face milling operations (Altıntaş 1994, Özkan and Öz 2020, Özkan and Öz 2021).

In the processing of marbles in CNC machines, factors affecting product quality such as milling tools, machine parameters, and rock properties. These factors are especially important factors that directly affect product quality (Polini and Turchetta 2004, Sarıışık ve Özkan 2017, Sarıışık ve Özkan 2018). In milling operations, the relationship between process parameters and cutting factors can be solved by performing the least number of experiments compared to the full factorial experimental design of the Taguchi experimental design (Liu *et al*. 2020, Taguchi and Phadke 1984).

In the studies carried out on natural stones with different properties; Kenda and Kopač (2009) researched the type of diamond grains, the hardness of the matrix, the structure of the diamond tools, the wear principles of the diamond tools, the product quality and efficiency of the water cooling and machining process in the machining of granites with diamond inserts. Gálos and Gyurika (2014) a quantitative measurement method and the effective applicability of this measurement method were investigated to determine the average edge chipping rate of ground granite surfaces. Gyurika (2018) a quantitative measurement to define the average edge comminution rate of ground granite surfaces and the effective applicability of this measurement method were studied. Gyurika and Szalay (2019) analyzed the changes in surface roughness and average edge chip ratios during the milling of granite surfaces at different cutting speeds. Arunramnath *et al*. (2019) TOPSIS method with different cutting parameters was applied in the grinding of epoxy granite composites, cutting forces and surface roughness were investigated.

Polini and Tuchetta (2004) analysed the relationship between the cutting force and energy parameters in stone forming with electroplated diamond milling. The relationship between cutting force and equivalent chip thickness (or MRR) is modeled with a power function for three different feed rates. Turchetta *et al*. (2009) tried to develop a model to describe the relationship between specific cutting energy and process parameters for machining five different stones using diamond milling cutters. Turchetta (2012), developed models for calculating cutting power and energy in studies on natural stones with a milling machine and diamond coated disc. Wang *et al*. (2020) investigated the effect of machining parameters on cutting forces and marble chips in high speed milling of marble with a carbide ball nose end mill. Özkan and Öz (2011) investigated the surface quality of the characterization of metamorphic marbles and sedimentary origin limestones depending on the optimum processing parameters.

The radial cutting force is related to the contact angle of the tool and is the force required of the tool against the workpiece. Since the radial cutting force is directly related to the radial cutting width, it affects the surface quality (Liu *et al*. 2020, Ma *et al*. 2020, Pham *et al*. 2020). The amount of radial cutting width changes the tool contact angle, which affects the size of the radial cutting force component. The radial cutting forces change due to the increase or decrease in the tool contact angle (Tien 2020).

Marbles can have different textural and mineral grain sizes due to their metamorphic origin. The interaction and bonding of minerals in tissues can differ in each marble. For this reason, unlike metal workpieces, the insert interacts with mineral grains of different sizes and tissue boundaries in the milling process. Carbide-coated inserts are commonly used for machining marbles, travertine, and many limestones. It has been observed that these carbide-coated tools are used more effectively and efficiently than other tools in metamorphic and sedimentary origin natural stones. Chip types in metal and marble workpieces are very different. While continuous or intermittent sawdust comes out in metal workpieces, different tools and processing parameters are used according to metals since marbles come out as sawdust.

When suitable machining parameters cannot be determined, it causes problems such as poor surface quality, poor workpiece quality, low productivity, and vibration associated with the dynamic interaction between the cutting tool and the marble workpiece.

Determining the parameters by trial and error in the grinding of marbles is time consuming and costly. The Taguchi experimental design method enables obtaining high surface quality products in less time and cost with appropriate processing parameters. In this study, an experimental setup was designed according to Taguchi design for radial depth of cut, axial depth of cut and feed rate parameters, considering previous studies (Özkan and Öz 2020, Özkan and Öz 2021, Pham *et al*. 2020) in the milling of marble with CNC. After the process, the radial cutting force (Fr) and Ra roughness values were measured, and the effectiveness of the parameters and their appropriate combinations were determined. No studies based on the effect of radial depth of cut, one of the machining parameters, were encountered in the processing of marbles. As a result of this study, it is recommended that the process parameters that provide the most suitable Fr force and surface roughness of the marbles processed in CNC should be used by the practitioners in the sector.

2. Taguchi Method

For businesses working with CNC machines, choosing the appropriate parameters for each material to be processed is time-consuming and costly. Taguchi method is an experimental design method applied in product quality improvement by using a special array called an orthogonal array with the best combination among selected parameters. With the Taguchi experimental design, less number of experiments were applied, the most suitable operating parameters were determined, and high quality products were produced at low cost in the enterprises, thereby increasing the production efficiency. Appropriate selection of processing factors is the most important step in experimental design. Because it is possible to obtain high quality products by minimizing the effect of uncontrollable factors (Taguchi 1984, Taguchi and Tsai 1995).

The signal/noise (S/N) ratio is a statistical method belonging to the Taguchi method, which is used to reduce the system's variation and bring the product closer to the desired values. Signal value (S) represents the actual value to be measured and given by the system, while the noise factor (N) represents the ratio of undesired factors to the measured value. In the study, calculations were made using the 'smaller-better' (equation 1) function of the S/N ratio analysis (Nagode and Fajdıga 1995, Taguchi and Chowdhury 2004).

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (1)$$

In this study, S/N analysis was performed for each marble sample. The purpose of choosing this S/N method; It is to improve the surface quality of the materials by determining the appropriate processing parameter combination to obtain a low surface roughness value in CNC milling (Taguchi and Phadke 1984, Teruo 2011, Turchetta *et al*. 2009).

3. Test Process

3.1 Marbles Used İn The Experiment and Their Properties

In the experimental studies, five different (Afyon White (WM1), Kemalpaşa White (WM2), Marmara White (WM3), Milas White (WM4) and Uşak White (WM5)) metamorphic origin white homogeneous real marbles) were used. The standards used in the experiments , mineralogical and petrographic descriptions, chemical analysis physical and mechanical properties (Table 1, 2, 3 and 4) and thin section images (Figure 2) of the samples are shown.

Table 1. Standards used in analysis physical and mechanical properties of marbles

Name:	**Standard No:**
Determination of knoop hardness	EN 14205:2003
Determination of real density and apparent density, and of total open porosity	EN 1936: 2006
Determination of unaxial compressive stregth	EN 1926: 2006
Determination of elemental composition by XRF	EN 15309:2007
Determination of water absorption at atmospheric pressure	EN 13755:2008
Determination of flexural strength under constant moment[8]	EN 13161: 2008
Determination of abrasion resistance	EN 14157 :2017

Table 2. Properties and petrographic descriptions of marbles

Natural rocks	Sample code	Photo	Texture	C/ Po /F (μm)	Minimum Particle Width (μm)	Maximum Particle Width (μm)	Average Particle Width (μm)
Afyon White Marble	WM1		Cyristalline	-/-/-	38,0	839,3	287,3
Bursa Kemalpaşa White Marble	WM2		Granoblastic	-/-/-	49,8	1615,9	332,1
Marmara White Marble	WM3		Cyristalline	-/-/-	7,0	186,9	60,9
Muğla White Marble	WM4		Granoblastic	-/-/-	212,9	1796,3	816,2
Uşak White Marble	WM5		Cyristalline	-/-/-	37,0	1601,8	524,7

Table 3 Chemical properties of marbles

Natural rock	Lol* (%)	Na_2O (%)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	P_2O_5 (%)	SO_3 (%)	Cl (%)	K_2O (%)	CaO (%)	MnO (%)	Fe_2O_3 (%)	SrO (%)	F (%)
WM1	44,2	0,01	0,18	0,13	0,13	0,01	0,01	0,00	0,02	55,2	0,01	0,03	0,01	-
WM2	43,8	0,02	0,76	0,10	0,09	0,00	0,01	0,01	0,01	55,0	-	0,07	0,02	0,09
WM3	47,3	0,02	14,40	0,05	0,06	0,01	0,01	0,01	0,00	38,0	-	0,02	0,02	-
WM4	44,0	0,02	0,35	0,05	0,06	0,00	0,01	0,01	-	55,5	-	0,03	0,02	-
WM5	44,4	0,03	0,88	0,05	0,05	0,00	0,01	0,03	-	54,5	-	0,03	0,03	-

Lol***:** Loss on ignition

Table 4. Physical and mechanical properties of marbles

Natural rock	OP (%)	AD (kg/m³)	WA (%)	HS	HK	AR (cm³/50cm²)	FS (MPa)	UCS (MPa)
WM1	0.23	2685	0.11	48.7	141.17	25.40	14.80	68.78
WM2	0.21	2650	0.07	46.1	144.15	20.52	13.32	94.10
WM3	0.13	2670	0.11	49.5	157.31	29.55	10.90	69.06
WM4	0.32	2720	0.22	42.7	140.40	32.40	5.25	58.88
WM5	0.22	2665	0.08	50.1	145.30	14.75	21.35	76.21

OP: Open porosity, AD: Apparent density, WA: Water absorption, HS: Shore hardness, HK: Knoop hardness, AR: Abrasion strength. FS: Flexural strength, UCS: Uniaxial compressive strength.

3.2 Milling Test Operations

Milling experiments were carried out on Megastone 2030 4 Axis Multifunctional CNC natural stone vertical machining machine. The different feed rates was emphasized by keeping the cutting speed constant. According to the selected parameters and levels, the L9 orthogonal model effectiveness of axial and radial cutting width at kept constant at 168 m/min (9000).

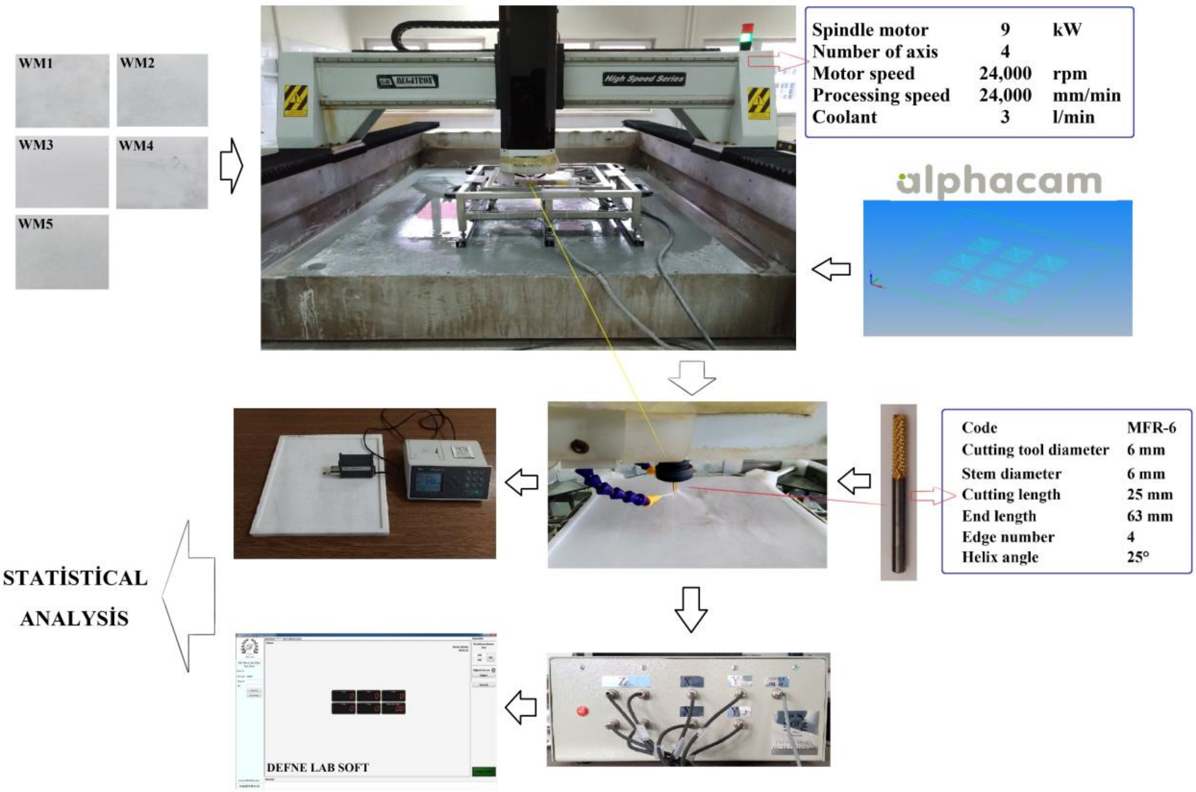


Figure 1. Test process

appearance and technical features of the CNC machine, the appearance of the carbide coated insert used in milling, and its technical features are shown in Figure 1.

Parameters and levels selected for the milling process; axial depth(mm) =1, 2, 3; radial width (mm)= 1, 1.5, 2; feed rate (mm/min)= 2000, 2500, 3000 are shown in Table 5. The cutting speed was In the study, the corresponding to the orthogonal index used in the Taguchi design was used. The L9 experimental model is shown in Table 6. By using the Alpha CAM program, the processes and parameters to be made on natural stones were programmed. Three square designs of 40x40 mm were created and modeled on marble samples of 300x300x20 mm.

Table 5. Factors and levels used in experiments

Factor	Symbol	Unit	Code	Level		
				1	**2**	**3**
Radial depth of cut	a_e	mm	a_e	1	1,5	2
Axial depth of cut	a_p	mm	a_p	1	2	3
Feed rate	f	mm/min	f	169	188	207

Table 6. Orthogonal array (L9)

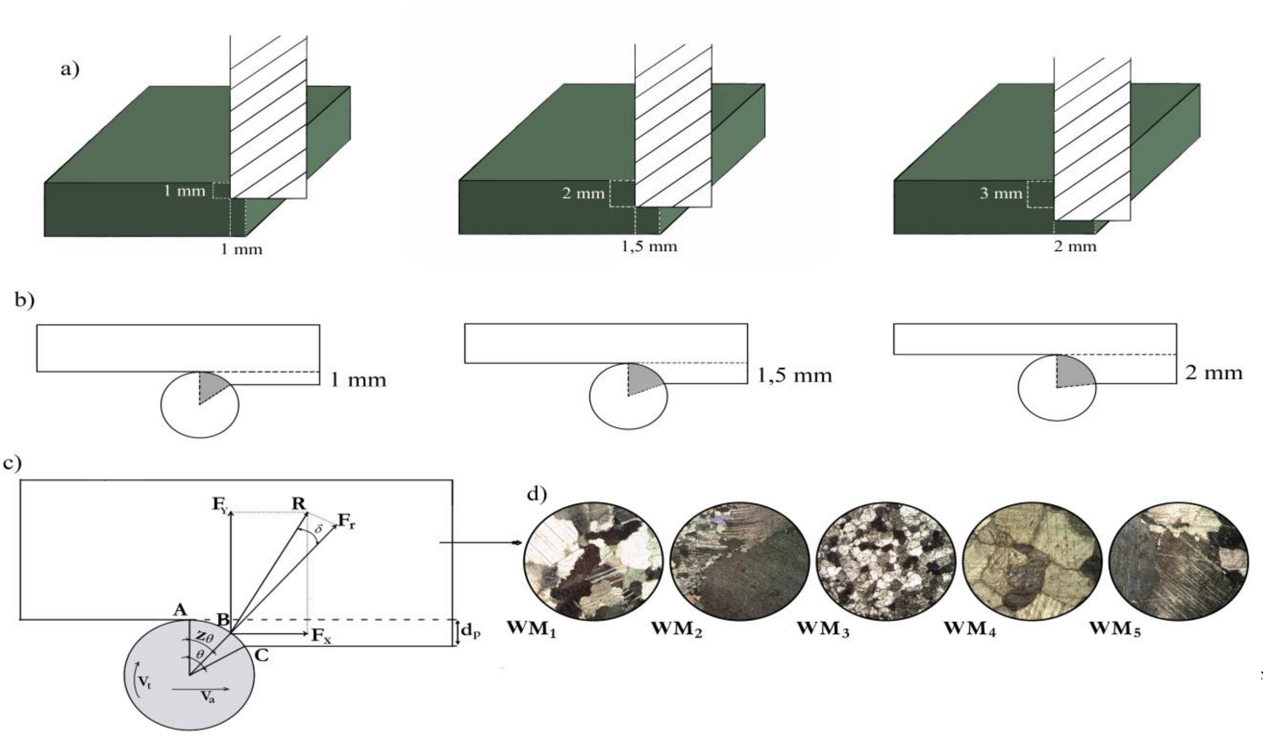
Experiment No:	Factor level			Assigned factor value		
	A	**B**	**C**	**f**	a_e	a_p
1	1	1	1	2000	1	1
2	1	2	2	2000	1,5	2
3	1	3	3	2000	2	3
4	2	2	1	2500	1	2
5	2	3	2	2500	1,5	3
6	2	1	3	2500	2	1
7	3	3	1	3000	1	3
8	3	1	2	3000	1,5	1
9	3	2	3	3000	2	2

The thickness differences that occur during the cutting process of the samples taken from the marble factories affect the surface quality. In this study, the thickness differences of the samples were eliminated by the milling process, and the surface qualities were brought to the same state. In order to prevent surface differences that may occur due to abrasion in the leveling process of marble samples, a separate carbide milling tool was used in each process. Machining direction inside-out lines are selected.

Finally, a straight surface was created in order to facilitate the measurement with the roughness device by leveling the places other than the processed square shapes.

During the milling process, force measurements were made with load measuring cells on three axes. Radial shear force (Fr) (Figure 2) values were calculated with force data taken along three axes.

Surface roughness measurements were made with the Marh Perthometer M2 model surface roughness unit. From 9 different square surfaces created according to the L9 index of Taguchi design, each square was divided into four equal parts and 24 Ra roughness values were measured for each square. The steps of all these processes are shown step by step in Figure 1.



parameter combinations determined from the S / N ratio, and the results are compared. Conditions based on estimates as a result of confirmation experiments should be close to the results obtained. If the test results are close to the predicted values, it confirms the experimental conditions' validity and the control factors' applicability. This indicates that the predicted combinations of parameters are

each factor

f = factor number

The approval test results for marbles are shown in Table 10. When the validation test results were compared, it was concluded that the parameter values were well-estimated and sufficient. It has been shown that the Taguchi method is applicable under real operating conditions in the milling operations of marbles.

Table 10. Confirmation test results

Samples (Fr)	WM1	WM2	WM3	WM4	WM5
Appropriate levels	f3: a_e1:a_p1	f1:a_e1:a_p1	f1:a_e1:a_p1	f1:a_e1:a_p1	f1:a_e1:a_p1
Estimated Fr values	6,54	5,05	10,63	6,29	8,02
Validation experiments	6,37	7,9	14,24	7,91	10,02
Samples (Ra)	**WM1**	**WM2**	**WM3**	**WM4**	**WM5**
Appropriate levels	f2: a_e1:a_p1	f3: a_e1:a_p1	f1:a_e1:a_p1	f3: a_e1:a_p1	f1:a_e1:a_p1
Estimated Ra values	4,06	4,01	3,38	4,92	4,72
Validation experiments	4,22	4,34	3,46	4,75	4,6

5. Results

The effects of radial and axial depth of cut on surface roughness were investigated. In order to obtain the lowest surface roughness value, statistical analyses were performed to determine the effectiveness of radial and axial cutting depth parameters on roughness and the most appropriate parameter combinations. S/N ratio analysis and variance analysis of the Taguchi method were used statistically.

With the “smaller-better” objective function in Equation 1, the parameter values and their effectiveness in affecting the surface quality were calculated according to the processing parameters with S/N ratios and variance analyses.

S/N ratios calculated for each marble sample are given in Table 7. The optimum processing parameters of marbles according to the effect degrees of the parameters according to the calculated S/N ratios are shown in Table 8. The parameter with the highest delta value has the greatest effect on the roughness value. The rank value indicates the order of the degree of influence. For example, for Afyon white marble with an M1 sample, the most influential parameter is the axial cutting depth, and the appropriate processing parameter combination is f2:a_e1:a_p1 (f2: 2500 mm/min feed rate, a_e: 1 mm radial depth, a_p: 1 mm axial depth) was determined. For example, for Afyon white marble with an WM1 sample, the most influential parameter is the axial cutting depth, and the appropriate processing parameter combination is f2:a_e1:a_p1 (f2: 2500 mm/min feed rate, a_e1: 1 mm radial cutting depth, a_p1: 1 mm axial cutting depth) was parameters determined. Fr-S/N response graphs are shown in Figure 3, and Ra-S/N responses are shown in Figure 4. In the S/N graphs here, the highest slopes show the levels where the parameters are effective.

Table 7. Ra, Fr and S/N ratio values

f	a_e	a_p	WM1				WM2				WM3			
m/min	mm	mm	Fr	S / N	Ra	S / N	Fr	S / N	Ra	S / N	Fr	S / N	Ra	S / N
2000	1	1	7,17	-17,11	5,28	-14,45	7,90	-17,95	4,58	-13,21	14,24	-23,07	3,46	-10,78
2000	1,5	2	10,05	-20,05	6,94	-16,82	30,02	-29,55	6,23	-15,88	35,42	-30,99	4,52	-13,10
2000	2	3	28,13	-28,98	7,47	-17,46	23,04	-27,25	7,38	-17,36	81,95	-38,27	5,18	-14,28
2500	1	2	9,56	-19,61	5,97	-15,51	26,52	-28,47	4,31	-12,68	27,41	-28,76	4,33	-12,72
2500	1,5	3	19,11	-25,63	7,21	-17,15	21,15	-26,50	8,34	-18,42	69,38	-36,82	5,22	-14,35
2500	2	1	7,60	-17,62	5,76	-15,20	14,36	-23,14	5,5	-14,80	22,21	-26,93	3,99	-12,01
3000	1	3	14,76	-23,38	6,7	-16,52	18,37	-25,28	6,61	-16,40	57,36	-35,17	4,94	-13,87
3000	1,5	1	6,56	-16,33	5,62	-14,99	12,32	-21,81	5,13	-14,20	19,41	-25,76	4,16	-12,38
3000	2	2	12,85	-22,18	7,14	-17,07	46,12	-33,28	4,96	-13,90	54,48	-34,72	5,29	-14,46

f	a_e	a_p	WM4				WM5			
m/min	mm	mm	Fr	S / N	Ra	S / N	Fr	S / N	Ra	S / N
2000	1	1	7,91	-17,96	4,81	-13,64	10,02	-19,56	4,6	-13,25
2000	1,5	2	18,69	-25,43	7,9	-17,95	18,02	-23,17	5,7	-15,11
2000	2	3	51,60	-34,25	7,55	-17,55	39,38	-29,07	6,93	-16,81
2500	1	2	17,86	-25,04	6,75	-16,58	15,93	-22,07	5,49	-14,79
2500	1,5	3	48,75	-33,76	7,82	-17,86	36,68	-27,53	6,88	-16,75
2500	2	1	11,53	-21,24	5,9	-15,41	16,52	-19,43	6,34	-16,04
3000	1	3	48,95	-33,79	6,42	-16,15	30,19	-26,03	6,77	-16,61
3000	1,5	1	9,51	-19,56	5,44	-14,71	16,35	-19,69	6,09	-15,69
3000	2	2	29,74	-29,47	6,79	-16,63	39,50	-23,56	6,74	-16,57

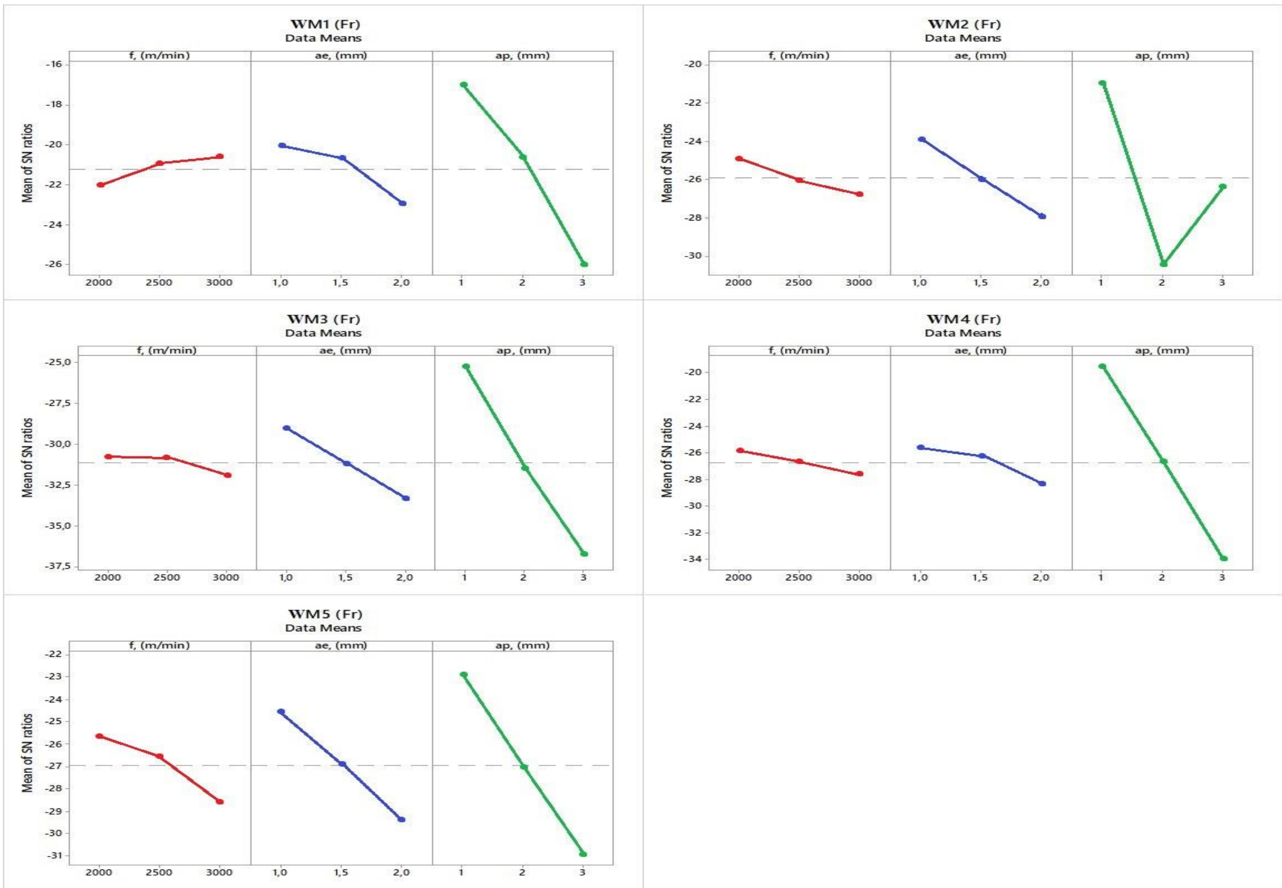


Figure 3. S/N ratio graph for Fr value

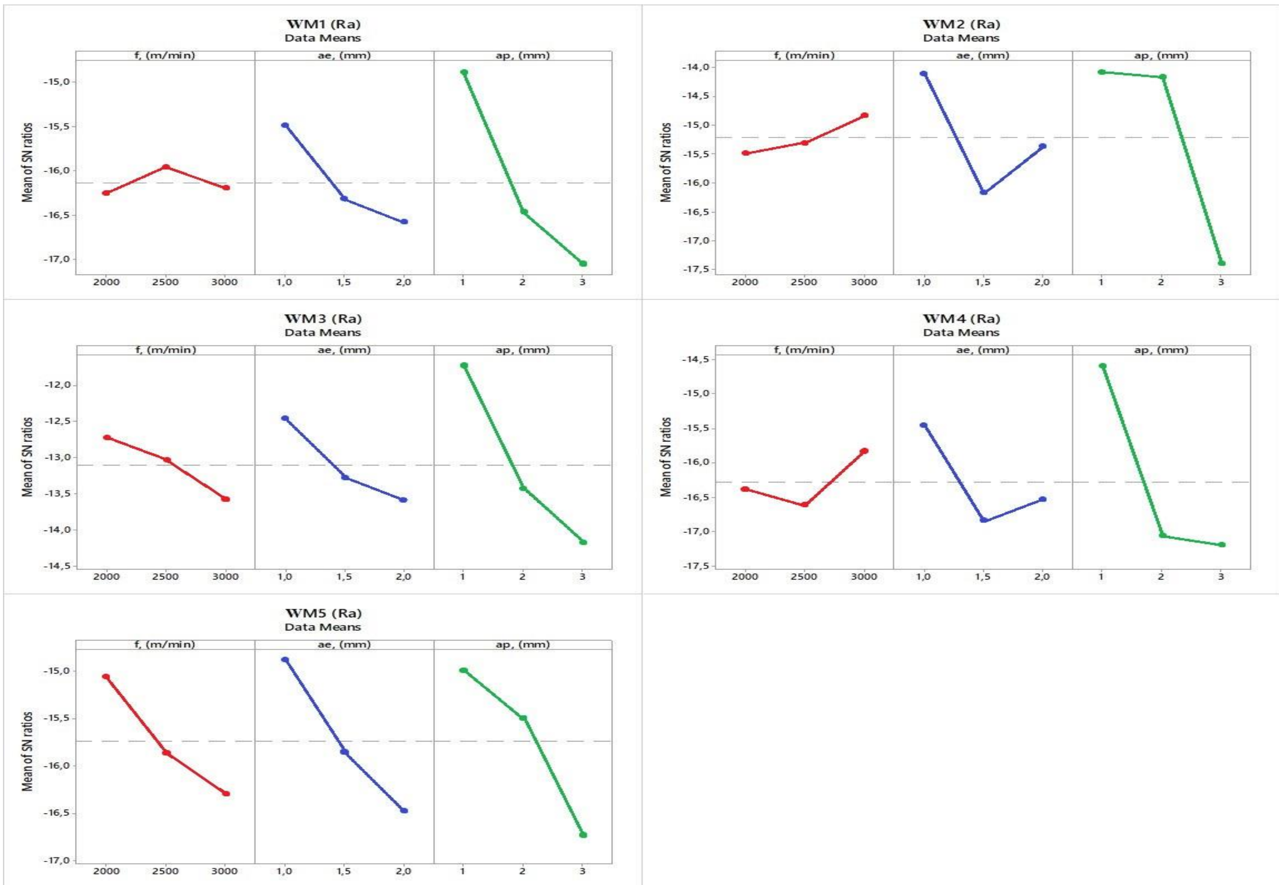


Fig. 4. S/N ratio graph for Ra value

Table 8. Response table for Fr and Ra factor

WM1 Level (Fr)	f	a_e	a_p
1	-22,05	-20,03	-17,02
2	-20,95	-20,67	-20,61
3	-20,63	-22,93	-26,00
Delta	1,42	2,89	8,98
Rank	3	2	1
Appropriate parameter f3:a_e1:a_p1			

WM1 Level (Ra)	f	a_e	a_p
1	-16,25	-15,50	-14,89
2	-15,96	-16,33	-16,47
3	-16,20	-16,58	-17,05
Delta	0,29	1,09	2,16
Rank	3	2	1
Appropriate parameter f2: a_e1:a_p1			

WM2 Level (Fr)	f	a_e	a_p
1	-24,92	-23,90	-20,97
2	-26,04	-25,95	-30,43
3	-26,79	-27,89	-26,35
Delta	1,87	3,99	9,47
Rank	3	2	1
Appropriate parameter f1: a_e1:a_p1			

WM2 Level (Ra)	f	a_e	a_p
1	-15,49	-14,10	-14,08
2	-15,31	-16,17	-14,16
3	-14,84	-15,36	-17,40
Delta	0,65	2,07	3,32
Rank	3	2	1
Appropriate parameter f3: a_e1:a_p1			

WM3 Level (Fr)	f	a_e	a_p
1	-30,78	-29,00	-25,25
2	-30,84	-31,19	-31,49
3	-31,89	-33,31	-36,76
Delta	1,11	4,31	11,5
Rank	3	2	1
Appropriate parameter f1: a_e1:a_p1			

WM3 Level (Ra)	f	a_e	a_p
1	-12,72	-12,46	-11,73
2	-13,03	-13,28	-13,43
3	-13,58	-13,59	-14,17
Delta	0,85	1,13	2,44
Rank	3	2	1
Appropriate parameter f1: a_e1:a_p1			

WM4 Level (Fr)	f	a_e	a_p
1	-25,88	-25,60	-19,59
2	-26,68	-26,25	-26,64
3	-27,61	-28,32	-33,94
Delta	1,73	2,72	14,35
Rank	3	2	1
Appropriate parameter f1: a_e1:a_p1			

WM4 Level (Ra)	f	a_e	a_p
1	-16,38	-15,46	-14,59
2	-16,62	-16,84	-17,06
3	-15,83	-16,54	-17,19
Delta	0,79	1,38	2,60
Rank	3	2	1
Appropriate parameter f3: a_e1:a_p1			

WM5 Level (Fr)	f	a_e	a_p
1	-25,68	-24,55	-22,88
2	-26,57	-26,89	-27,03
3	-28,60	-29,40	-30,93
Delta	2,92	4,85	8,05
Rank	3	2	1
Appropriate parameter f1: a_e1:a_p1			

WM5 Level (Ra)	f	a_e	a_p
1	-15,06	-14,89	-15,00
2	-15,86	-15,85	-15,49
3	-16,29	-16,48	-16,73
Delta	1,23	1,59	1,73
Rank	3	2	1
Appropriate parameter f1: a_e1:a_p1			

Analysis of variance was performed to determine the effectiveness ratios of machining parameters to surface roughness. Considering the P ratio value and the 95% confidence interval in the analysis of variance, it is concluded that the parameter is effective when P<0.05. The F value shows the effect value of each factor in the analysis according to the F hypothesis test. The degrees of freedom of the parameters correspond to $F_{0.05;2;8}$=4.46 according to the F hypothesis table. Parameters with F values greater than 4.46 effectively on radial cutting force and surface roughness. According to the F test results, the effects of the process parameters on the radial shear force (Fr) and Ra roughness value are shown in Table 9.

Table 9. Variance analysis results for Fr and Ra

Fr	**WM1**		**WM2**		**WM3**		**WM4**		**WM5**	
	Effect (%)	**F**	**Effect (%)**	**F**	**Effect (%)**	**F**	**Effect (%)**	**F**	**Effect (%)**	**F**
f	2,33	1,08	3,23	23,44	1,02	9,98	1,38	5,55	9,02	4,42
a_e	9,75	4,53	14,52	105,37	12,14	118,89	3,71	14,93	23,69	11,62
a_p	85,77	39,88	82,11	595,87	86,74	849,79	94,66	380,86	65,25	32,01
Error	2,15		0,14	23,44	0,10		0,25		2,04	
Total	100		100	105,37	100		100		100	
Ra	**WM1**		**WM2**		**WM3**		**WM4**		**WM5**	
	Effect (%)	**F**	**% Effect**	**F**	**Effect (%)**	**F**	**Effect (%)**	**F**	**Effect (%)**	**F**
f	1,49	0,97	2,24	0,49	9,01	20,62	5,68	3,10	20,92	10,68
ae	19,75	12,94	21,69	4,78	16,19	37,05	18,23	9,95	34,43	17,58
ap	77,23	50,59	71,53	15,76	74,36	170,13	74,26	40,56	42,69	21,81
Error	1,53		4,54		0,44		1,83		1,96	
Total	100		100		100		100		100	

The relationship between grain width and surface roughness in the processing of marbles with a CNC machine was investigated by regression analysis (Figure 5). The regression graph obtained between the surface roughness (Ra) values obtained after the surface treatment performed at the most appropriate cutting parameters determined in the Taguchi design for five White-colored marbles and the average grain width of the marbles is shown in Figure 4. The regression equation is given in equation 3. Accordingly, there is a significant 83% relationship between the average mineral grain size and the roughness. While the roughness values are lower in fine-grained marbles, surface roughness values are higher in coarse-grained marbles. Mineral grain size affects the quality of new surfaces formed as a result of surface treatment.

The interaction between the mineral and the cutter will increase as the cutting width increases, especially in the final milling process. While fine grains are easily cut, coarse grains will be more difficult to cut. Considering the blunting of the cutter for the duration the milling process, it will be difficult to cut the coarse grains and the mineral will continue to move forward by breaking the grains instead of cutting them. This will cause the milled surface to be rough.

$$y = 0{,}0016x + 3{,}6237 \quad R^2 = 0{,}8285 \tag{3}$$

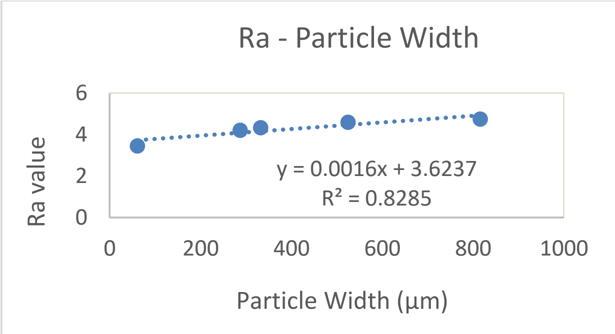


Fig. 5. Relationship between Ra-Particle width

As a result of the experiments carried out with the Taguchi method, the most suitable combination of the radial cutting force and the process parameters for increasing the surface quality of the white marbles was determined.

6. Conclusions

In this study, the effects of axial depth of cut and radial cutting width parameters on surface roughness are emphasized. Belonging to the marbles used in the experiments, Using the Taguchi test method and analysis of variance, the effectiveness of axial depth of cut and radial cutting width parameters on Ra surface roughness values and appropriate machining values were determined. Some results have been obtained for five different white-colored marbles in accordance with the working conditions performed on the CNC milling machine:

1. Radial cutting forces, S/N based on the analysis, WM1, WM2, WM3, WM4 and WM5 samples determined optimal process parameters,

respectively f3:ae1:ap1, f1: ae1:ap1, f1: ae1:ap1, f1: ae1:ap1and f1: ae1:ap1 were found.

2. For surface roughness, based on S/N analysis, the optimal process parameters determined in the WM1, WM2, WM3, WM4 and WM5 samples are f2: ae1:ap1, f3: ae1:ap1, f1: ae1:ap1, f3: ae1:ap1and f1: ae1:ap1 respectively.
3. According to the F test analysis result, the most effective parameter in the formation of radial cutting force and surface roughness is the axial depth of cut. In terms of radial cutting force, the effective values of cutting depth of WM1, WM2, WM3, WM4 and WM5 samples are 85.77%, 82.11%, 86.74%, 94.66% and 65.25%, respectively. The effect values for surface roughness are 77.23%, 71.23%, 74.36%, 74.26%, and 42.69%, respectively.
4. The secondary effective parameter is the radial depth of cut, and the radial cutting force effect values are 9.75%, 14.52%, 12.14%, 3.71%, and 23.69%, respectively. The effect values for surface roughness are 19.75%, 21.69%, 16.19%, 18.23%, 34.43%, respectively.
5. With the Taguchi method, the processing performance of CNC machines has been improved and the quality of the products obtained has been improved.
6. According to the analysis of variance, the axial cutting depth was the most influential parameter in the processing of marbles. The radial cutting width was the secondary effective parameter in the formation of surface roughness.
7. As the radial depth of cut increases, the surface to which the cutting tip will touch will increase, so rupture occurs instead of cutting, which increases the surface roughness. Average particle size is effective in the formation of surface roughness. It was observed that the surface roughness increased as the grain size increased.
8. Low radial force and low surface roughness values are obtained when processing with low axial depth and low radial cutting width. The greater the depth of the axial cutting depth and the radial cutting width, the more advantageous it is to improve the processing performance and surface quality.

As a result of the confirmation test, it is concluded that it is well estimated in the optimal parameter combinations determined by the estimation and is applicable in real operating conditions.

7.References

Altintas, Y., 1994. Direct adaptive control of end milling process. *Int. J Mach Tools Manuf.,* **34(4)**, 461–472. https://doi.org/10.1016/0890-6955(94)90078-7.

Arunramnath, R., Thyla, P.R., Mahendrakumar, N., Ramesh, M., Siddeshwaran, A., 2019. Multi-attribute optimization of end milling epoxy granite composites using TOPSIS. *Mater Manuf Process,* **34(5)**, 530–543. https://doi.org/10.1080/10426914.2019.1566960.

European Standards Institute (EN) 2003 Natural stone test methods determination of Knoop hardness, Standard No. EN 14205. 2003; English

European Standards Institute (EN) 2006 Natural stone test methods determination of real density and apparent density, and of total and open porosity. Standard No. EN 1936. English

European Standards Institute (EN) 2006 Natural stone test methods determination of uniaxial compressive strength. Standard No. EN 1926. English

European Standards Institute (EN) 2007. Characterization of waste and soil-determination of elemental composition by X-ray fluorescence. Standard No. EN 15309. English

European Standards Institute (EN) 2008 Natural stone test methods determination of water absorption at atmospheric pressure. Standard No. EN 13755. English

European Standards Institute (EN) 2008 Natural stone test methods determination of flexural strength under constant moment. Standard No. EN 13161. English

European Standards Institute (EN) 2017 Natural stone test methods determination of the abrasion resistance. Standard No. EN 14157

Gálos, M., Gyurika, I.G., 2014. Quality measuring numbers of milled edges of granite surfaces. *Period Polytech Civ Eng.,* **58(2)**, 121–129. https://doi.org/10.3311/PPci.2158.

Gyurika, I.G., 2018. Researching the effects of feedrate and diamond grain size on edge chipping of milled granites. *Tehnicki Vjesnik-Technical Gazette.,* **25(1)**, 49–55. https://doi.org/10.17559/tv-20160504130353.

Gyurika, I.G., Szalay, T., 2019. The examination of the effect of variable cutting speeds on the surface and edge qualities of milled granite materials. *Adv Mech Eng.,* **11(7)**, 1–12. https://doi.org/10.1177/1687814019836319.

Kenda, J., Kopač, J., 2009. Diamond tools for machining of granite and their wear. *Journal of Mechanical Engineering.,* **12(55)**, 775–780.

Liu, J., Cheng, K., Ding, H., Chen, S., 2020. An investigation of influence of cutting parameters on three-dimensional surface topography in micromilling SiCp/Al composites, *Proc IMechE Part B: J Engineering Manufacture.* https://doi.org/10.1177/0954405420971098.

Ma, W., Wang, R., Zhou, X., Xie, X., 2020. The finite element analysis–based simulation and artificial neural network–based prediction for milling processes of aluminum alloy 7050. *Proc IMechE Part B: J Engineering Manufacture.* https://doi.org/ 10.1177/0954405420932442.

Moayyedian, M., Mohajer, A., Kazemian, M.G., Mamedov, A., Derakhshandeh, J.F., 2020. Surface roughness analysis in milling machining using design of experiment. *SN Applied Sciences,* **2**, 1698. https://doi.org/10.1007/s42452-020-03485-5.

Nagode, M., Fajdıga, M., 1995. Experiment Design for Structures Loading State Determination. *Strojniški vestnik- Journal of Mechanical Engineering,* **41**, 257-262.

Othman, K., Ghani, J.A., Juri, A., Mohd, M.S.R., Kassim, S., Haron, C.H.C., 2020. Optimization of Tool Life and Surface Roughness for Hypereutectic Al – Si Alloys in Face Milling. *Journal of Mechanical Engineering,* **17(2)**, 27-44.

Öktem, K., Erzurumlu, T., Çöl, M., 2006. A study of the Taguchi optimization method for surface roughness in finish milling of mold surfaces. *The International Journal of Advanced Manufacturing Technology,* **28**, 694-700. https://doi.org/10.1007/s00170-004-2435-6.

Özkan, E., Sarıışık, G., Ceylan, S., 2015. Application and productivity analysis of new channel opening method in natural stone quarries with diamond wire cutting machine. *Arabian Journal of Geosciences*, **8(2)**, 1089–1098. https://doi.org/10.1007/s12517-013-1230-9.

Özkan, E., Öz, O., 2020. Determination of appropriate cutting parameters depending on surface roughness by Taguchi method in milling of marbles. *Arabian Journal of Geosciences,* **13**, 532. https://doi.org/10.1007/s12517-020-05380-0.

Özkan E., Öz O., 2021. The effect of characterization of carbide end milled limestones on optimal parameters. *Arabian Journal of Geosciences,* **14**, 1181, https://doi.org/10.1007/s12517-020-05380-0.

Pham, T.H., Nguyen, D.T., Banh, T.L., Tong, V.C., 2019. Experimental study on the chip morphology, tool–chip contact length, workpiece vibration, and surface roughness during high-speed face milling of A6061 aluminum alloy. *Proc IMechE Part B: J*

Engineering Manufacture, https://doi.org/10.1177/0954405419863221

Polini, W., Turchetta, S., 2004. Force and specific energy in stone cutting by diamond mill. *Int J Mach Tools Manuf.,* **44(11)**, 1189–1196. https://doi.org/10.1016/j.ijmachtools.2004.04.001.

Sarıışık, G., Özkan, E., 2016. Bilgisayar Kontrollü Makine (CNC) ile Mermerlerin İşlenebilirliğinde Kesme Kuvveti ve Spesifik Enerjinin Belirlenmesi. *Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi.* **16(2)**, 420–430. https://doi.org/10.5578/fmbd.27592.

Sarıışık, G., Özkan, E., 2017. Mermerlerin CNCMakinesi ile İşlenmesinde Kesme Kuvvetleri ve Spesifik Kesme Enerjisinin İstatistiksel Analizi. *Journal of Science and. Engineering,* **19(55)**, 178–193. https://doi.org/10.21205/deufmd.2017195514.

Sarıışık, G., Özkan, E., 2018. Effects of natural rock properties on cutting forces, specific energy and specific cutting energy by four-axis machine. *Arabian Journal of Geosciences*, **11(84)**. https://doi.org/10.1007/s12517-018-3424-7.

Taguchi, G., Phadke, M.S., 1984. Quality engineering through design optimization. *IEEE Global Telecommunications Conference* GLOBECOM '84, November 26-29, Atlanta, GA,; 77-96. https://doi.org/10.1007/978-1-4684-1472-1_5.

Taguchi, G., Tsai, S.C., 1995. Quality engineering (Taguchi methods) for the development of electronic circuit technology*. IEEE Transactıons On Reliability,* **44(2)**, 225–229. https://doi.org/10.1109/24.387375.

Taguchi, G., Chowdhury, S., Wu, Y., 2004. Taguchi's quality engineering handbook, JohnWiley and Sons, Inc., Hoboken New Jersey, USA,.

Teruo, M., 2011. Taguchi methods benefits, impacts, mathematics, statistics, and applications. ASME Press, New York, USA.

Tien, D.H., Nguyen, N.T., Do, D.T., Nguyen, V.C., Nguyen, V.Q., Nguyen, V.L., Nguyen, H.P., 2020. Optimization of cutting parameters and cutter helix angle for Minimum Surface Roughness in Flat –end Milling of Al6061. *TRKU (Technology Reports of Kansai University),* **62(4)**, 2647–2656.

Tuğral, N., 2019. CNC makinesinde gerçek mermerlerin kesme genişliğinin yüzey kalitesine etkisinin taguchi yöntemiyle incelenmesi, Yüksek Lisans Tezi, Afyon Kocatepe Üniversitesi Fen Bilimleri Enstitüsü, Afyonkarahisar, 81.

Turchetta, S., Polini, W., Buyuksagis, I.S., 2009. Investigation on stone machining performance using force and specific energy. *Adv Mech Eng.,* **1**, 175817, https://doi.org/10.1155/2009/175817.

Turchetta, S., 2012. Cutting force and diamond tool wear in stone machining. *Int J Adv Manuf Technol.,* **61(5-8)**, 441–448, https://doi.org/10.1007/s00170-011-3717-4.

Yuvaraj, T., Suresh, P., 2019. Analysis of EDM Process Parameters on Inconel 718 Using the Grey-Taguchi and Topsis Methods. *Strojniški Vestnik- Journal of Mechanical Engineering.* **65(10)**, 557-564. https://doi.org/10.5545/sv-jme.2019.6194.

Wang, F., Liu, S., Guo, Z., Cao, L., 2020. Analysis of cutting forces and chip formation in milling of marble. *Int J Adv Manuf Technol*., **108**, 2907–2916. https://doi.org/10.1007/s00170-020-05575-5.