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Research Article

An Investigation of Power Consumption in Milling AISI P20 Plastic Mold Steel by Finite Elements Method

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Abstract

Mold steels lead the production of products used in all areas of our lives. Performing the machinability tests of these materials with the finite element method (FEM) provides cost and time savings. In addition, it provides to get away from physical experiments that provide high power consumption. Because consumption must be eliminated in order to ensure a sustainable and clean production. In this study, AISI P20 mold steel was milled using the finite element method. Same directional milling and corner milling operations were performed. The effects of the cutting parameters used in the milling process on the power consumption were investigated. Four different feed rates (0.075-0.113-0.169 and 0.253 mm/tooth) four different cutting speeds (170-200-230-260 m/min), and two different cutting depths (0.075-1.5 mm) were used in the study. Power consumption values were obtained by taking the resultant values of the cutting forces (Fx, Fy and Fz) occurring during cutting. According to the results obtained, it was concluded that the power consumption increased with the increase in feed rate, cutting speed and cutting depth. The highest power consumption value was determined as 8041.91 W, and the lowest power consumption value was determined as 1748.10 W. As a result, it has been shown that the FEM and statistical evaluation yield consistent results.

Keywords: Mold steel, AISI P20, Milling, Finite elements, Power consumption.

AISI P20 Plastik Kalıp Çeliğinin Sonlu Elemanlar Yöntemi ile Frezelenmesinde Güç Tüketiminin İncelenmesi

Öz

Kalıp çelikleri hayatımızın her alanında kullanılan ürünlerin üretimine öncülük etmektedir. Bu malzemelerin işlenebilirlik deneylerinin sonlu elemanlar yöntemi (FEM) ile yapılması maliyet ve zaman tasarrufu sağlar. Ayrıca yüksek güç tüketimi sağlayan fiziksel deneylerden uzaklaşmayı sağlar. Çünkü sürdürülebilir ve temiz bir üretimin sağlanabilmesi için tüketimin ortadan kaldırılması gerekmektedir. Bu çalışmada, AISI P20 kalıp çeliği sonlu elemanlar yöntemi kullanılarak frezelenmiştir. Aynı yönlü frezeleme ve köşe frezeleme işlemleri yapılmıştır. Frezeleme işleminde kullanılan kesme parametrelerinin güç tüketimi üzerindeki etkileri araştırılmıştır. Çalışmada dört farklı ilerleme miktarı (0.075-0.113-0.169 ve 0.253 mm/diş) dört farklı kesme hızı (170-200-230-260 m/dak) ve iki farklı talaş derinliği (0.075-1.5 mm) kullanılmıştır. Kesme sırasında oluşan kesme kuvvetlerinin (Fx, Fy ve Fz) bileşke değerleri alınarak güç tüketim değerleri elde edilmiştir. Elde edilen sonuçlara göre ilerleme miktarı, kesme hızı ve talaş derinliği arttıkça güç tüketiminin arttığı sonucuna varılmıştır. En yüksek güç tüketim değeri 8041,91 W, en düşük güç tüketim değeri ise 1748,10 W olarak belirlenmiştir. Sonuç olarak FEM ve istatistiksel değerlendirmenin birbirleri ile uyumlu sonuçların elde edildiğini göstermiştir.

Anahtar Kelimeler: Kalıp çeliği, AISI P20, Frezeleme, Sonlu elemanlar, Güç tüketimi.

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1. Introduction

In mold production, material selection is important for the quantity and quality of the product to be produced. Not only the mechanical properties of the steel material to be selected, but also its chemical properties and the machinability criteria of machining in the manufacturing industry should be considered [1]. Machining methods in the manufacturing industry include milling, drilling, grinding and turning etc. High quality production of complex geometry materials with these methods is more efficient than other manufacturing methods (casting, forging, etc.). However, the selection of processing parameters is important in order to produce materials with the desired quality and desired efficiency with machining methods. As a result of choosing these parameters properly, the process outputs (Cutting force, surface roughness, cutting temperature and power consumption, etc.) will lead to a good result [2,3,4]. With the developing technology, the cost of experimental research with machining is also increasing. For this reason, alternative numerical models for research processes are increasing nowadays. The most widely used method in numerical modeling is the FEM. Mechanical properties of materials, machinability tests etc. with finite element method operations can be done easily. In experimental studies, the obtained cutting force, cutting temperature, moment, power consumed and the rate of stress between the material and the tool can also be done by the finite element method [3,5,6].

When the studies in the literature are examined, the machinability tests performed with the finite element method increase, although not as much as the experimental studies. To summarize the research and development studies carried out are as follows. Kuram et al. investigated the specific cutting energy (SCE) by measuring the cutting forces in the milling process [7]. Gök, studied, compared the cutting forces and temperature values that occur by turning AISI 1045 steel with both physical and finite element methods [8]. Yaşar et al., examined the cutting forces generated in the turning process of AISI P20 steel as experimental and numerical analysis [3]. Valiorgue et al. evaluated of AISI 304L steel in a hybrid method combining both experimental and numerical [9]. Özel and Zeren, using the Arbirary Lagrangian Eulerian method, processed AISI 1045 steel with the finite element method [10]. Korkmaz and Günay, on the other hand, investigated the cutting force and consumed energy by making the machinability of AISI 420 steel with finite elements [5]. Ezilarasan et al. performed the turning experiments of Nimonic C-263 superalloy using the finite element method [11].

The literature studies are evaluated, it is seen that turning experiments are generally carried out. Therefore, in this study, the amount of power consumed during milling of AISI P20 steel with the finite element method was investigated. Feed rate per tooth, cutting speed and cutting depth values were evaluated as machinability parameters. In addition, the values obtained as a result of the FE analysis were evaluated by the Taguchi method.

2. Material and Method

AISI P20 mold steel, which is widely used in the mold industry, was used in the study. Milling of this material was done using the FEM. The chemical and mechanical properties of AISI P20 die steel material are given in Table 1 and Table 2.

Table 1. Chemical composition (%) [12].

C	Si	Mn	P	S	Cr	Mo
0,40	0,8	1,00	0,03	0,03	2,00	0,55

Table 2. Mechanical properties [12].

Properties	Metric
Hardness, Rockwell C	30
Tensile ultimate strength (MPa)	965-1030
Tensile yield strength (MPa)	827-862
Elongation at break (in 50 mm)	20.00%
Poisson ratio	0.30
Elastic modulus (GPa)	190-210

Machining parameters were determined as a result of the suggestions of the cutting tool company and literature reviews, and two different cutting depths were selected with four different feed rates and cutting speeds. Processing parameters are given in Table 3.

Table 3. Cutting parameters and levels.

Machining parameter	Levels
Cutting speed (m/min)	170-200-230-260
Feed Rate (mm/tooth)	0.075-0.113-0.169-0.253
Depth of Cut (mm)	0.75-1.50

The Johnson-Cook (JC) model parameters required for the finite element method of AISI P20 material were obtained from the study by Shatla et al. [13]. JC model parameters are given in Table 4.

Table 4. JC parameters [13].

A (Mpa)	B (MPa)	n	c	m	Tm
145	565.5	0.154	0.03	1.8	1753

The equation of the JC model parameter used in the study is given below.

$$\sigma^0=(A+B(\varepsilon^p)^n(1+C\ln\left(\frac{\dot{\varepsilon}^p}{\dot{\varepsilon}_0}\right))(1-(\frac{T-T_r}{T_m-T_r})^m) \quad (1)$$

Milling operations were performed using the finite element program. In this context, AISI P20 material used in the milling process is defined as the length 50 mm, its width is 25 mm and its thickness is 25 mm. For the purpose of define the cutting tool to the program, the drawing data was made with the CATIA program (Figure 1). In the study, carbide cutting tool with the code AOMT123608PEER-M, which was coated with the PVD method produced by Mitsubishi company, was used. In the milling simulation process of AISI P20 steel, the surface relationship between the workpiece and cutting tool materials was chosen as the Coulomb friction law. The milling method was chosen in the down milling. The representation of the milling process in the simulation program is given in Figure 2.

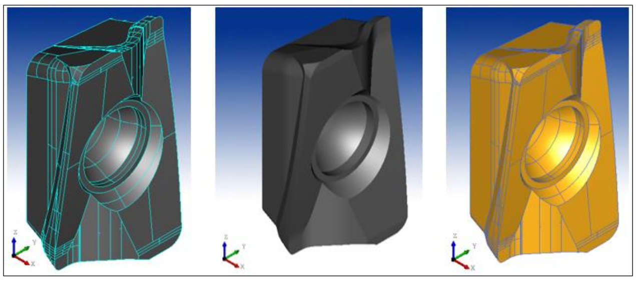

Fig. 1. Cutting tool.

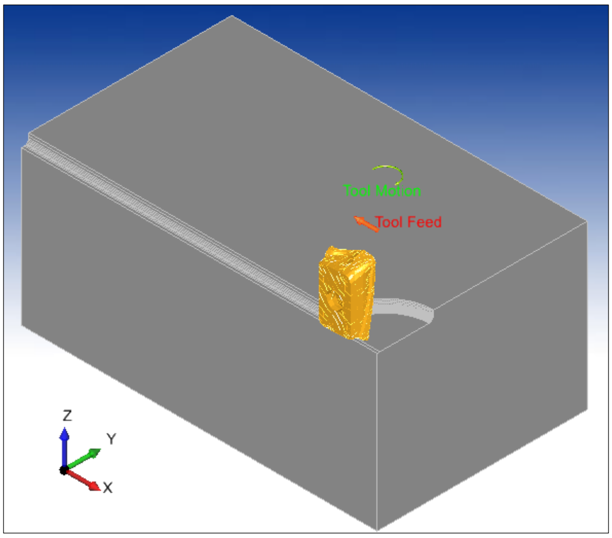

Fig. 2. Milling in finite elements method.

3. Results and Discussion

In the evaluation of the analysis results of the milling process with the FEM, the resultant values of the cutting forces, which are important in terms of power consumption in the milling process, were taken into account. Evaluation of power consumption was made with the formula in Equation 2 [5].

$$P = Fx\frac{V}{60} \quad (2)$$

The results obtained as a result of the studies are given in Table 5 and their graphical representations are given in Figure 3 and Figure 4.

Table 5. Power consumption values obtained depending on cutting parameters.

Cutting Speed (m/min)	Feed Rate (mm/tooth)	Depth of Cut (mm)	Power (W)
170	0,075	0,75	1748,10
170	0,113	0,75	2472,57
170	0,169	0,75	3465,26
170	0,253	0,75	2531,74
200	0,075	0,75	2251,42
200	0,113	0,75	2945,36
200	0,169	0,75	3505,73
200	0,253	0,75	3125,08
230	0,075	0,75	2807,45
230	0,113	0,75	3735,72
230	0,169	0,75	4299,41
230	0,253	0,75	3517,60
260	0,075	0,75	2732,75
260	0,113	0,75	3331,57
260	0,169	0,75	5250,29
260	0,253	0,75	3958,83
170	0,075	1,50	2574,90
170	0,113	1,50	3606,12
170	0,169	1,50	5214,51
170	0,253	1,50	4773,10
200	0,075	1,50	2927,66
200	0,113	1,50	5375,69
200	0,169	1,50	4731,19
200	0,253	1,50	6462,89
230	0,075	1,50	3308,59
230	0,113	1,50	6451,96
230	0,169	1,50	6872,32
230	0,253	1,50	6759,91
260	0,075	1,50	4002,06
260	0,113	1,50	6308,09
260	0,169	1,50	7741,63
260	0,253	1,50	8040,91

In general, there is an increase in the amount of power consumed depending on the increasing cutting speed and feed. This situation is similar to the literature [5]. However, when both amount of depths of cut are evaluated according to the, it is seen that there is a fluctuating change in some machining parameters. This can be attributed to the milling mechanics having different cutting mechanics.

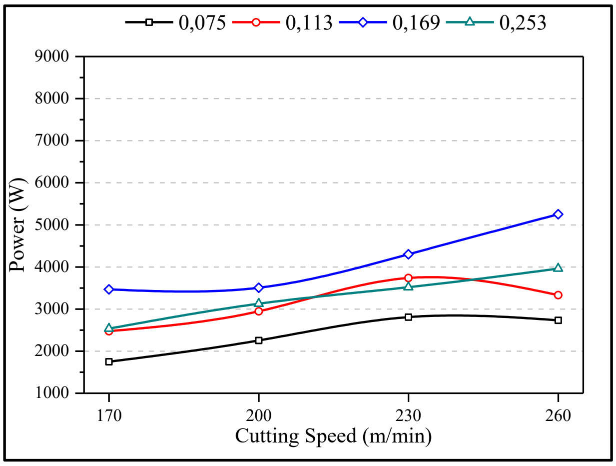

Fig. 2. Power consumption change graph according to cutting speed and feed rate at 0.075 mm depth of cut.

By examining the graph in Figure 2, the lowest power value (1741.10 W) at a cutting speed of 170 m/min and a tooth feed rate of 0.075 mm, and it is seen that the highest power value (5250.29 W) is at 260 m/min cutting speed and 0.169 mm/tooth feed. There was a 201.55% variation between the lowest and highest power amount. The highest change between successive parameters was observed with an increase of 57.59% from 0.113 mm/tooth feed to 0.169 mm/tooth feed at 260 m/min cutting speed. The lowest change between the successive parameters was observed in the increase from 0.169 mm/tooth feed rate to 0.253 mm/tooth feed rate at 200 m/min cutting speed with 10.85.

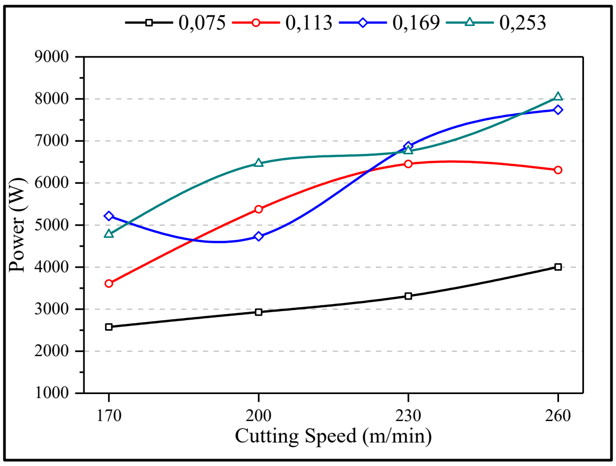

Fig. 4. Power consumption change graph according to cutting speed and feed rate at 1.5 mm depth of cut.

According to the graph in Figure 4, it is seen that there is an increase in the amount of power in general with increasing cutting speed. Although it is observed that there is a fluctuating change according to the feed rate, it can be said that there is an increase in the amount of power with the increase in the feed rate in general. The lowest power value (2574.90 W) occurred at a cutting speed of 170 m/min and a tooth feed rate of 0.075 mm, as in the cutting depth of 0.075 mm, and the highest power value (8040.91 W) at a cutting speed of 260 m/min and it is seen that it is 0.253 mm/tooth feed rate. There was a 212.28% change between the lowest and highest power amount. The highest change between successive parameters was observed in the increase of 95% to 230 m/min cutting speed from 0.075 mm/tooth feed to 0.113 mm/tooth feed. The lowest change of about 1.63% among consecutive parameters was observed at the cutting speed of 230 m/min and the increase from 0.169 mm/tooth feed to 0.253 mm/tooth feed.

According to the analysis results obtained in terms, it was observed that the optimum parameters were 170 m/min cutting speed and 0.075 mm/tooth feed at both cutting depths.

The reason why machinability studies are difficult both in physical experiments and in finite element analysis is the determination of combinations of machining parameters. Depending on the parameters, metal removal can be time consuming and complex. For the purpose of save time and cost, the number of experiments can be reduced by the taguchi method in determining the optimum processing conditions [14,15]. The criterion used for the measurement and evaluation of quality characteristics in the Taguchi experimental design method is the S/N ratio. S (Signal) indicates the actual value given by the system and wanted to be measured, and N (Noise) indicates the share of uncontrollable and undesirable factors in the measured value. There are 3 types of S/N ratios [16]. These are given below.

The nominal-the best: $S/N=10\log(\bar{y}/S_y^2)$ (3)

The larger-the better: $S/N=-10\log(1/n\sum_{i=1}^{n}\frac{1}{y_i^2})$ (4)

The smaller-the better: $S/N=-\log(1/n\sum_{i=1}^{n}y_i^2)$ (5)

In equations; "$\bar{y}$" is the mean of the observed data, "S_y^2" is the variance of y, "n" is the number of observation experiments, and "y" is the observed data [17].

For the purpose of determine the optimum combinations of processing parameters that should be used in order to keep the amount of power at a minimum, an orthogonal experimental design was implemented of for the purpose of distribute the effect levels of each parameter. In the study, S/N ratios were determined by considering "the smaller-the-better" quality characteristic objective function in order to find the optimum parameter values using the L32 orthogonal experimental design (Table 6) [18].

Table 6. Average S/N response for the power consumption.

Level	Cutting Speed (m/min)	Feed Rate (mm/tooth)	Depth of Cut (mm)
1	**-67.86**	**-68.70**	**-69.90**
2	-71.36	-72.14	-74.05
3	-72.99	-73.89	-
4	-73.68	-73.17	-
Delta	3.83	5.19	4.15
Rank	3	1	2

The parameter with the highest Delta values given for each level in Table 6 has the greatest effect on power consumption. Impact rankings are expressed as Rank in the table. Accordingly, in order to reach the optimum power value, it has been determined that the possible parameter combination is firs level of cutting depth, first level of feed rate and first level of cutting speed.

In Figure 5, graphs of S / N ratio responses for power are given. The maximum points of the slopes in the figure give information about the efficiency levels of the cutting parameters on the power consumption.

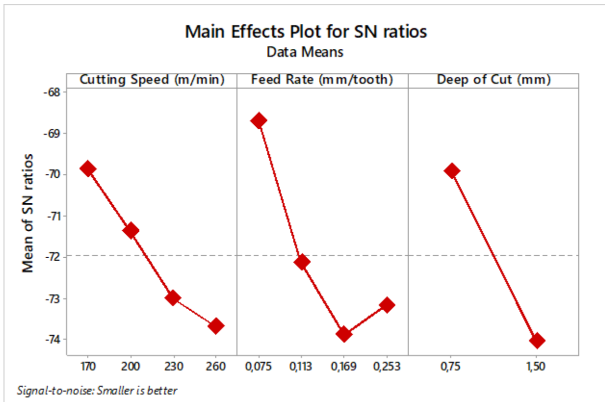

Figure 5. S/N chart for power consumption.

Anova method was used to determine numerically the interactions between control factors and processing parameters [17]. The analysis of variance results for power consumption values are in Table 7.

Table 7. ANOVA for the power consumption.

	Df	SS	MS	F	P	PCR (%)

Cutting Speed (m/min)	3	70.55	23.517	23.35	0.000	18.53
Feed Rate (mm/tooth)	3	126.84	42.278	41.98	0.000	29.52
Depth of Cut (mm)	1	137.90	137.898	136.93	0.000	38.93
Error	24	24.17	1.007			13.02
Total	31	359.45				
R^2=%93.28						

In Anova, it is decided whether each parameter has an effect on each other by looking at the p value. Considering the 95% confidence interval, it is concluded that the parameter has an effect on the response when P<0.05 (5% significance value). Whichever factor has the highest F value, it is the factor that most affects the result [19]. As a result of examining the data in Table 7, it was concluded that the most effective parameter for power values was the cutting depth with 38.93% and the feed rate with 29.52%. It was concluded that the least effective parameter was the cutting speed with 18.53 percent.

4. Conclusions and Recommendations

In this study, the analysis of AISI P20 die steel material with the finite element method was carried out. The optimum parameters of the obtained findings were obtained by using the statistical method. The simulation and statistical results are summarized below.

In general, it was determined that the amount of power increased with the increase of cutting speed, cutting depth and feed rate.

The lowest power value (1741.10 W) occurred at 170 m/min cutting speed, 0.075 mm/tooth feed and 0.075 mm cutting depth, and the highest power value (8040.91 W) at 0.253 mm/tooth feed, 260 m/min cutting speed and 1.5 mm cutting depth.

In order to reach the optimum power value, it has been determined that the possible parameter combination is first level of cutting depth, first level of feed rate and first level of cutting speed.

According to the Anova results, it was determined that the parameter with the least effect on the power consumption value was the cutting speed at a rate of 18.53%.

It was concluded that the FEM is useful for machinability experiments and the taguchi method is useful for parameter determination.

In order to obtain more comprehensive research and results, the number of experiments can be increased and comparisons can be made with physical experiments.

References

[1] M. Coşkun, İ. Çiftçi and H. Demir, "AISI P20S Kalıp Çeliğinin İşlenebilirliğinin İncelenmesi", *İmalat Teknolojileri ve Uygulamaları*, vol. 2, no. 2, pp. 1-9, 2021.

[2] E. P. DeGarmo, J. T. Black and R. A. Kohser, *Materials and Processes in Manufacturing*, New Jersey: Prentice-Hall Inc., 2013.

[3] N. Yaşar, M. Sekmen, M. E. Korkmaz and M. Günay, "AISI P20 Çeliğinin İşlenmesinde Kesme Kuvvetinin Deneysel ve Nümerik Analizi", *Gazi Üniversitesi Fen Bilimleri Dergisi Part:C, Tasarım ve Teknoloji*, vol. 4, no. 1, pp. 13-19, 2016.

[4] E. Salur, A. Aslan, M. Kuntoglu, A. Gunes and O. S. Sahin, "Experimental study and analysis of machinability characteristics of metal matrix composites during drilling", *Composites Part B: Engineering*, vol. 166, pp. 401-413, 2019.

[5] M. E. Korkmaz and M. Günay, "Finite Element Modelling of Cutting Forces and Power Consumption in Turning of AISI 420 Martensitic Stainless Steel", *Arabian Journal for Science and Engineering*, vol. 43, pp. 4863-4870, 2018.

[6] G. Kant and K. S. Sangwan, "Prediction and optimization of machining parameters for minimizing power consumption and surface roughness in machining", *Journal of Cleaner Production*, vol. 83, pp. 151-164, 2014.

[7] E. Kuram, B. Ozcelik, M. Bayramoglu, E. Demirbas and B. T. Simsek, "Optimization of cutting fluids and cutting parameters during end milling by using D-optimal design of experiments", *J. Clean. Prod.*, vol. 42, pp. 1389-1406, 2013.

[8] K. Gök, "Development of three-dimensional finite element model to calculate the turning processing parameters in turning operations", *Measurement*, vol. 75, pp. 57-68, 2015.

[9] F. Valiorgue, J. Rech, H. Hamdi, P. Gilles and J. M. Bergheau, "3D modeling of residual stresses induced in finish turning of an AISI304L stainless steel", *Int. J. Mach. Tool. Manuf.*, vol. 53, no. 1, pp. 77-90, 2012.

[10]T. Özel and E. Zeren, "Finite element method simulation of machining of AISI 1045 steel with a round edge cutting tool", *Proceedings of 8th CIRP International Workshop on Modeling of Machining Operations*, pp. 533-542, 2005.

[11]C. Ezilarasan, V. S. Senthil kumar and A. Velayudham, "Theoretical predictions and experimental validations on machining the Nimonic C-263 super alloy", *Simul. Model. Pract. Theory*, vol. 40, pp. 192-207, 2014.

[12](2022) ASTMSTEEL web site. [Online]. Available: https://www.astmsteel.com/product/p20-steel-plate-1-2311-3cr2mo-mold-tool-steel/.

[13]M. Shatla, C. Kerk and T. Altan, "Process modeling in machining. Part I: determination of flow stress data", *International Journal of Machine Tools and Manufacture*, vol. 41, no. 10, pp. 1511-1534, 2001.

[14]T. Kıvak, "Optimization of surface roughness and flank wear using the Taguchi method in milling of Hadfield steel with PVD and CVD coated inserts", *Measurement*, vol. 50, pp. 19-28, 2014.

[15]K. Palanikumar, "Experimental investigation and optimisation in drilling of GFRP composites", *Measurement*, vol. 44, no. 10, pp. 2138-2148, 2011.

[16]N. Masmiati and A. A. D. Sarhan, "Optimizing cutting parameters in inclined end milling for minimum surface residual stress – Taguchi approach", *Measurement*, vol. 60, pp. 267-275, 2015.

[17]N. Mandal, B. Doloi, B. Mondal and R. Das, "Optimization of flank wear using Zirconia Toughened Alumina (ZTA) cutting tool: Taguchi method and Regression analysis", *Measurement*, vol. 44, no. 10, pp. 2149-2155, 2011.

[18]S. Neşeli, "Tırlama titreşimleri üzerine süreç sönümleme etkisinin analitik olarak araştırılması ve tornalamada kararlı kesme derinliği ile süreç sönümleme değerlerine bağlı parametre optimizasyonu, Doktora Tezi", Selçuk Üniversitesi Fen Bilimleri Enstitüsü, Konya, Turkey 2013.

[19]E. Şirin, Ş. Şirin, Y. Turgut and İ. Korkut, "AISI D2 Soğuk İş Takım Çeliğinin Frezelenmesinde Yüzey Pürüzlülüğünün Taguchi Metodu İle Optimizasyonu", *Düzce Üniversitesi Bilim ve Teknoloji Dergisi*, vol. 3, no 1 pp. 132-144, 2015.