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OPTIMIZATION OF SURFACE ROUGHNESS OF ALUMINIUM 6013-T6 ALLOY IN THE TURNING PROCESS

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ABSTRACT: One of the most common methods of machining is turning. Cutting speed, depth of cut, and feed rate are the most effective cutting parameters on the surface roughness. In addition to cutting parameters, the use of cooling type, the cutting tool is also essential on the surface roughness of materials. In this study, the surface roughness properties of Al 6013-T6 material were investigated depending on feed rate and cutting speed in turning process. Experiments were planned according to L9 orthogonal array. Optimum conditions were found via Taguchi's Signal/Noise analysis. Variance analysis (ANOVA) was performed to determine the parameters that affect the turning process. As a result of experimental studies surface roughness values increased as feed rate increased and decreased as cutting speed increased. The analysis results showed that feed rate is a dominant parameter on surface roughness. It was also observed that the cutting parameters had a significant effect on the machining time. As the machining time decreases, the surface roughness increases.

Keywords: *Turning, Surface roughness, Optimization, Taguchi method*

Alüminyum 6013-T6 Alaşımlarının Tornalama İşlemlerinde Yüzey Pürüzlülüğünün Optimizasyonu

ÖZ: Tornalama işlemi, parçaların işlenmesinde en yaygın kullanılan yöntemlerden biridir. Devir hızı, kesme derinliği ve ilerleme hızı, yüzey pürüzlülüğü üzerinde en etkili kesme parametreleridir. Ayrıca kesme parametrelerinin yanında kesici takım özellikleri ve soğutma tipi de yüzey pürüzlülüğü üzerinde etkilidir. Al 6013-T6 malzemesinin tornalama işlemi sonucu yüzey pürüzlülüğü, ilerleme hızına ve devir hızına bağlı olarak incelenmiştir. Adım başına ilerleme arttıkça yüzey pürüzlülüğü artmış ve devir hızı azaldıkça azalmıştır. Çalışmada taguchi deney tasarımı ve varyans analizi (ANOVA) de yapılmıştır. Analiz sonuçlarına göre, yüzey pürüzlülüğü üzerinde ilerleme hızının en baskın parametre olduğu belirlenmiştir. Aynı zamanda kesme parametrelerinin işleme süresi üzerinde önemli bir etkiye sahip olduğu görülmüştür. Işleme süresi azalırken yüzey pürüzlülüğü artmıştır.

Anahtar Kelimeler: *Tornalama, Yüzey pürüzlülüğü, Optimizasyon, Taguchi metodu*

1. INTRODUCTION

In the machinery industry, the surface quality of the machined parts is a significant factor. Good surface quality is preferred because it reduces costs and improves quality in manufacturing. Each parameter used during the processing of the materials affects the surface sensitivity. The purpose of the chip removal is not just to shape the parts. It is also to manufacture according to a certain degree of accuracy shown in the part picture in terms of geometry, size, and surface (Hariharan *et al*., 2021, Abasa *et al*., 2020, Ajay and Vinoth., 2021, Panthangi *et al*., 2021)

Turning, an important branch of machining constitutes the process. Turning operation with rotary motion designed to the part by removing chips from a material cylindrical shape forming. The effect of the independent variables on the dependent variables in turning are the factors that directly affect the product quality. Investigation and determination of the parameters that cause changes in the dependent variables are important in terms of increasing the product quality. In turning, cutting speed, feed, depth of cut, speed, process length, type of cutting tool, material, cutting fluid etc. parameters represent independent variables. These independent variables are surface roughness, wear, force, etc. has a large effect on the dependent variables. These effects constitute the focus of attention of researchers (Özlü *et al*. 2019, Yağmur *et al*. 2021, Pul and Bican, 2021, Pul and Özerkan, 2022).

Many studies have examined the surface roughness properties of aluminium and steel materials in the turning process (Mia et al., 2018; Sarnobat and Raval, 2019; Davim and Figueira, 2007; Poulachon et al., 2004; Asiltürk and Akkuş, 2011; Kumar, 2019). Asilturk et al. studied on optimization of turning parameters on AISI 4140 steel to minimize surface roughness with Taguchi method. Results of this study indicate that the feed rate has the most significant effect on surface roughness values (Asiltürk and Akkuş, 2011). Kumar investigated effect of spindle speed, feed rate and depth of cut in micro turning operation. It was reported that depth of cut has significant influence on surface roughness.

Srithar et al. studied the surface roughness properties with the hard turning process on AISI D2 steel, and they found that the most critical factor among the cutting parameters was the feed rate (Srithar et al., 2014). Jeyaprakash et al. analyzed analytically and experimentally the surface roughness values with minimum cutting thickness in CNC micro turning of aluminium 19000 alloys. Analytical and experimental results were close to each other (Jeyaprakash et al., 2020). Some researchers have developed hybrid nano-cutting fluid with a different volumetric concentration based on alumina. Thermophysical properties of hybrid nanofluids, machining forces, and surface roughness of steel during turning were investigated (Sharma et al., 2020). Acayaba et al. developed estimation models using the experimental data. They proved that the neural network performed better with a more appropriate difference (1400%) than the linear model (Acayaba and Escalona, 2015). Patel et al. studied cutting conditions and tool geometry by developing a mathematical model. According to the developed model, the estimated surface roughness values were close to the experimental values (Patel and Gandhi, 2019). Lalwani et al. investigated the effect of cutting force and surface roughness on tool wear. The axial depth of the cut has the most significant impact on component forces (Lalwani *et al*., 2008). By Kim *et al*., the cutting speed is insufficient to explain the surface roughness variation. Also, unlike most studies, the depth of cut is an effective parameter (Kim and Kwon, 2015). Bilgic *et al*. investigated the prediction of surface roughness and tool temperature values for turning using the Artificial Neural Networks method and Multi Linear Regression Model. (Bilgic *et al*., 2019). Selveraj *et al*. investigated the effects of process parameters on tool wear in dry turning of duplex stainless steel material at different speeds and feed rates. They reported that the cutting speed was the most effective parameter in the turning process, optimized with the Taguchi method (Selvaraj *et al*., 2014). Bindhushree *et al*. studied on turning of Aluminum material by using Taguchi method. They investigated effects of parameters painstaking as a cutting speed, feed rate and depth of cut, output obtained are material removal rate, machining time through turning. They showed that the very important factors are speed and depth of cut. Surface roughness increases with increasing speed and depth of cut. Machining time is decreases with increasing speed and depth of cut values (Bindhushree *et al*., 2021).

One of the indispensable quality characteristics in machining is the surface quality. It is very important to obtain the intended surface depending on the place where the product works. For this reason, it is very important to determine the parameters that affect the achievement of the intended surface quality. In this study, the surface roughness properties of Al 6013-T6 material in the turning process were investigated experimentally and statistically. The turning process was carried out at three feed rates and cutting speed levels. Also, machining time of turning process is calculated. The optimization study was carried out by comparing the results with each other. The aim of this study to find optimum turning conditions of Al 6013-T6 in turning process.

2. EXPERIMENTAL METHODS

2.1. Materials and method

6013-T6 Aluminum alloy was used in the experimental study. Al 6013-T6 has high hardness and corrosion resistance. Its weldability is good. It can be used in the aircraft industry, seat, and door construction, anywhere requiring hardness and machinability. The chemical compositions of 6013-T6 Aluminum Alloy are shown in Table 1. Mechanical properties of workpiece materials are given in Table 2. Al 6013-T6 used in the experiments was 20 mm in diameter and 100 mm in length. The view of test specimen is shown in Figure 1.

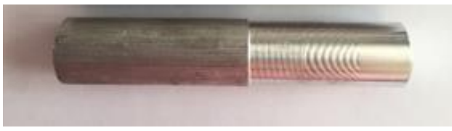

Figure 1. View of the test specimen

Table 1. Composition of 6013-T6 Aluminium (%)

Mg	Cu	Si	Mn	Fe	Cr	Zn	Ti	Al
0.90	0.94	0.73	0.36	0.26	0.03	0.06	0.02	balance

Table 2. Mechanical properties of workpiece materials

Materials	Hardness (Brinell)	Yield strength (MPa)	Tensile strength (MPa)
Al 6013-T6	130	385	405

Experimental samples were prepared at The Tezsan TN50 BR model turning machine in Sakarya University Mechanical Engineering Department Laboratory. The process was carried out at three different feed rate (0.1 mm / rev, 0.2 mm / rev, 0.3 mm / rev) and three levels of cutting speed (60 m/min, 80 m/min, 100 m/min). The experiments were carried out with VBGT160404L-Y PV7020 coded cermet turning insert, whose geometric features and dimensions are given in Figure 2. The turning process was performed as dry machining. The value of cut depth was taken as 0.5 mm and maintained constant throughout the experiment. Each test was repeated three times at dry machining conditions, and then surface roughness was measured and averaged. Teskon TR200 was used to measure the surface roughness of the workpieces processed on the lathe. Surface roughness measurements were made according to TS 2495 EN ISO 3274 standard. In order to measure the surface roughness values on the workpiece, the cutting length (Lc) was chosen as 0.8 mm and the sample length (Lt) as 4.8 mm.

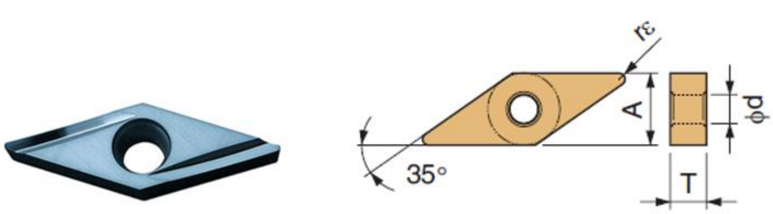

Figure 2. Technical properties of cutting tool

2.2. Taguchi method and experimental plan

The method, which was developed by combining the experimental design theory and the concept of quality loss function, is widely used with its low number of experiments and ease of use. The method is particularly successful in experimental systems where there are qualitative variables where the surface response method cannot be used. This experimental design process consists of 3 main phases: the planning phase, the implementation phase, and the analysis interpretation phase. The planning phase is the most important phase that should be given maximum attention. Data collected from all experiments are analyzed to determine the effects of various design parameters. This approach implements the fractional factorial approach and this is accomplished using orthogonal arrays. Orthogonal arrays are standardized by the Taguchi method and their degrees of freedom must be greater than or equal to the degrees of freedom of the experimental system. The degree of freedom of the experimental system is determined by the factor level and the number of interactions. Taguchi's experimental design method was used in the optimization study. This method has optimized control parameters and levels for minimum surface roughness. Selected parameters and levels are indicated in Table 3. In Taguchi method orthogonal array is used to decrease experiment numbers. The L9 (32) orthogonal array was chosen to determine the optimum conditions and analyze the parameters.

Table 3. Control parameters and their levels

Symbol	Parameters	Level 1	Level 2	Level 3
A	Feed rate (mm/rev)	0.1	0.2	0.3
B	Cutting speed (m/min)	60	80	100

3. RESULTS AND DISCUSSIONS

3.1. S/N ratio results

The average values of surface roughness (μm) measurements are shown in Table 4. Each measurement was repeated three times. As seen in Table 4, surface roughness significantly increased as the feed rate increased. The increase in cutting speed has reduced the surface roughness. It is determined that the effect of the cutting speed is much less than the effect of the feed rate. Similar results had been reported in the literature. Srithar and Sharma (Srithar *et al*. 2014, Sharma *et al*. 2020) have found similar results in the turning process. Surface roughness values decreased as spindle speed increased and surface roughness increased as feed rate increased. The feed rate significantly impacts Ra values [Mia *et al*., 2018, Sarbonat *et al*., 2019, Asiltürk and Akkuş, 2011). The optimization was performed using obtained results. This optimization process has three useful functions known as the signal-to-noise ratio (S/N) function. These are 'larger is better', 'nominal is the best', and 'smaller is better'. The characteristic of surface roughness is better suited to the 'smaller is better' situation. The following equation calculates the S/N ratio,

S/N Ratio= - 10 log10 1/n (sum of mean of square of surface roughness) (1)

Table 4. The experimental results and S/N ratio values

Specimen No	Feed rate (mm/rev)	Cutting Speed (m/min)	Surface roughness (Ra)	S/N ratio for Ra (dB)
1	0.1	60	0.766	2.3154
2	0.1	80	0.753	2.4641
3	0.1	100	0.712	2.9504
4	0.2	60	3.584	-11.0874
5	0.2	80	3.498	-10.8764
6	0.2	100	3.481	-10.8341
7	0.3	60	7.829	-17.8741
8	0.3	80	7.529	-17.5347
9	0.3	100	7.362	-17.3399

Machining time is one of the important parameters in the turning process. As the machining time decreases, the surface roughness increases. Therefore, minimizing surface roughness can result in high machining times. High machining time is also undesirably related to increased cost. The processing time can be calculated with the following equation;

$$t_h = \frac{Dx\pi xL}{Vx1000xf} \quad (2)$$

where, tm: Machining time (min), D: Original diameter (mm), L: Length of cut (mm), V : Cutting speed (m/min), f : feed rate (mm/rev).

The machining times calculated according to Equation 2 are given in Table 5.

Table 5. The machining times calculated according to Equation 2

Specimen No	Feed rate (mm/rev)	Cutting Speed (m/min)	Machining time (s)
1	0.1	60	12
2	0.1	80	10
3	0.1	100	8
4	0.2	60	6
5	0.2	80	5
6	0.2	100	4
7	0.3	60	4
8	0.3	80	3,33
9	0.3	100	2,67

As can be seen from Table 5, machining time is higher at low cutting speed. It was observed that while the feed rate increased at the same cutting speed, the machining time decreased.

Variation of surface roughness and machining time as a function of feed rate and cutting speed is given in Figure 3.

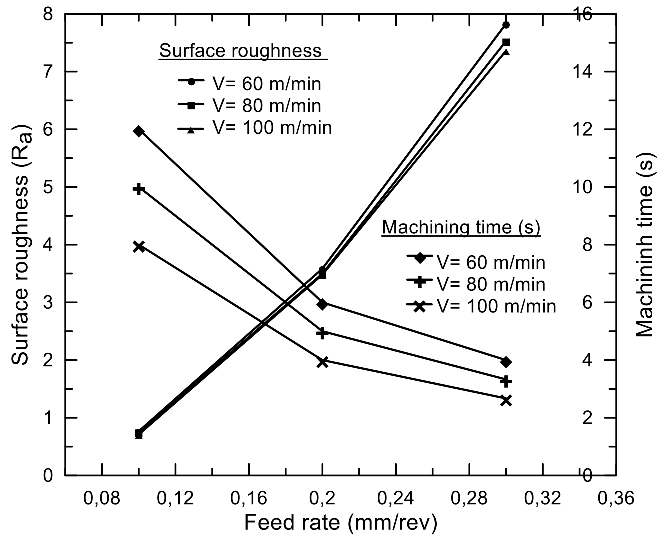

Figure 3. Change of surface roughness and machining time at different cutting speeds according to feed rate

As shown in Figure 3, as the feed rate increases, the surface roughness increases. The lowest surface roughness was obtained at 0.712 µm and 0.1 mm/rev feed rate 100 m/min cutting speed. The highest surface roughness was obtained at 7.829 µm and 0.3 mm/rev feed rate 60 m/min cutting speed. From this graph, we can see clearly that the effect of the feed rate is much more dominant than the cutting speed in the turning process.

Figure 3 clearly shows that surface roughness and machining time vary inversely (Qehaja *et al.*, 2015, Bindhushree *et al.*, 2021, Ragab *et al.* 2017). Machining time varies inversely with feed rate and cutting speed. The lowest machining time was obtained at a cutting speed of 100 m/min and a feed rate of 0.3 mm/rev.

"S/N response table" shows the effect of each parameter on the surface roughness in Table 6. Graphical forms of control factor levels for Ra given in Table 6 are shown in Figure 4. The best level of each factor was found by looking at the highest S/N ratio in control factor levels. The factors giving the best Ra value were for the A factor (Level 1, S/N=2.577) and for the B factor (Level 3, S/N=-8.408). This means that an optimum Ra value can be obtained from these factor levels.

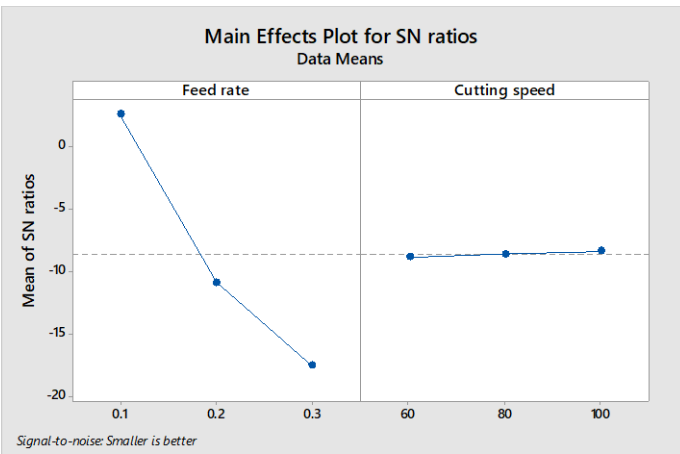

Figure 4. S/N graphs for surface roughness

Table 6. S/N response table for surface roughness

Level	A (Feed rate)	B (Cutting speed)
1	2.577	-8.882
2	-10.933	-8.649
3	-17.583	-8.408
Delta	20.160	0.474
Rank	1	2

3.2. Variance analysis and regression analysis

MINITAB 18 was used to perform variance and regression analysis. The regression equation below shows the relationship between the process parameters (cutting speed and federate) and surface roughness for turning with a correlation coefficient (R^2) of 0.99.

$$\mathrm{Ra} = -2.38 + 34.15\,\mathrm{f} - 0.0004\,\mathrm{v} \qquad (3)$$

Variance analysis (ANOVA) was performed to investigate the effects of turning parameters on surface roughness values of materials. ANOVA test results were given in Table 7. The effect of each parameter is given in the last column of the table. From Table 7, it is found that feed rate (99.84 %) is the most significant factor on surface roughness, and the second factor is cutting speed (0.094 %). The effect of cutting speed on surface roughness for chosen speed values is negligible.

Table 7. ANOVA test results

Variance Source	Degree of freedom	Adjusted Sum of squares	Adjusted Mean square	F ratio	Contribution rate %
Feed rate	2	70.7793	35.3897	2665.82	99.84
Cutting speed	2	0.0666	0.0333	2.51	0.094
Error	4	0.0531	0.0133		0.066
Total	8	70.8990			100

4. CONCLUSIONS

In this study, surface roughness properties of Al 6013-T6 material were investigated by the turning process. Results were evaluated with the Taguchi test design method. Taguchi method was successfully applied to Al materials. By using this method, both time and cost savings were achieved. The results obtained will be helpful for future academic research and industrial applications. Following results can be drawn based on the experiments and statistical study,

- Surface roughness values decreased with the increase of cutting speed.
- Surface roughness values increased with the increase of feed rate.
- The optimum levels of the control factors for minimizing the surface roughness using S/N rates
- were determined. The best average surface roughness value was 0.712 μm at 0.1 mm/rev feed rate, at 100 m/min.
- The highest surface roughness value was 7.829 μm at 60 m/min cutting speed and 0.3 mm/rev feed rate.
- According to the Anova test, the effect of the feed rate on the surface roughness of the materials is significant (99.84 %); the second important parameter is cutting speed (0.094 %).
- R^2 of the equations which were obtained by the linear regression model for R_a were found to be 99%.

- Machining time and the surface roughness are inversely proportional.
- The lowest machining time was obtained at a cutting speed of 100 m/min and a feed rate of 0.3 mm/rev, while the highest machining time was obtained at a cutting speed of 60 m/min and a feed of 0.1 mm/rev.

5. REFERENCES

Abasa, M., Sayda, L., Akhtara, R., Khalida, Q.S., Khanb, A.M., Pruncu, C.I., 2020, "Optimization of machining parameters of aluminum alloy 6026-T9 under MQL-assisted turning process", *Journal of Materials Research and Technology*, 9(5), 10916–10940.

Acayaba, G.M.A., Escalona, P.M., 2015, "Prediction of surface roughness in low speed turning of AISI316 austenitic stainless steel", *CIRP Journal of Manufacturing Science and Technology*, 11, 62-67.

Ajay, C.V., Vinoth V., 2021, "Optimization of process parameters in turning of aluminum alloy using response surface methodology", *Materials Today: Proceedings*, 46, 9462–9468.

Asilturk, I., Akkus, H., 2011, "Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method", *Measurement*, 44, 1697-1704.

Bilgic, H.H., Guvenc, M.A., Cakir, M., Mistikoglu, S., 2019, "A study on prediction of surface roughness and cutting tool temperature after turning for s235jr steel", *Konya Journal of Engineering Sciences*, 7, 966-974.

Bindhushree, B.S., Arunadevi, M., Prakash, C.P.S., 2021, "Experimental investigation of process parameters for turning aluminum using ANOVA", *Materials Today: Proceedings*, 46, 5060-5066.

Davim, J.P., Figueira, L., 2007, "Machinability evaluation in hard turning of cold work tool steel (D2) with ceramic tools using statistical techniques," *Materials and Design*, 28(4), 1186-1191.

Hariharan, M.K., Anderson, A., Kumar, K. R., Senthilkumar, A., 2021, "Optimization of machining parameters in turning of LM6 high silicon aluminium alloy using aluminium titanium nitride and diamond like carbon coated carbide tool," *Materials Today: Proceedings*, 45, 5853–5859.

Jeyaprakash, N., Yang, C.H., Kumar, D.R., 2020, "Minimum cutting thickness and surface roughness achieving during micromachining of aluminium 19000 using CNC machine," *Materials Today: Proceedings*, 21, 755-761.

Kim, Y.S., Kwon, W.T., 2015, "The effect of cutting parameters for the finest surface roughness during the turning of AISI 1045 with a WC insert", *Journal of Materials Processing Technology*, 29(8), 3437-3445.

Kumar, S.P.L., 2019, "Measurement and uncertainty analysis of surface roughness and material removal rate in micro turning operation and process parameters optimization" *Measurement*, 140, 538-547.

Lalwani, D.I., Mehta, N.K., Jain, P.K., 2008, "Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel", *Journal of Materials Processing Technology*, 206(1), 167-179.

Mia, M., Morshed, M.S., Kharshiduzzaman, M.D., Razi, M.H., Mostafa, M.R., Rahman Ahmad, S.M.S., Hafiz, M.T., Kamal, A.M., 2018, "Prediction and optimization of surface roughness in minimum quantity coolant lubrication applied turning of high hardness steel", *Measurement*, 118, 43-51.

Özlü, B., Akgün, M., Demir, H., 2019, "AA6061 Alaşımının Tornalanmasında Kesme Parametrelerinin Yüzey Pürüzlülüğü Üzerine Etkisinin Analizi ve Optimizasyonu," *Gazi Mühendislik Bilimleri Dergisi*, 5(2), 151-158.

Panthangi, R.K., Rao K.S., Babu B.S., 2021, "Optimization of surface roughness in turning of LM9 aluminum casting alloy", *Materials Today: Proceedings*, 41, 1164–1168.

Patel, V.D., Gandhi, A.H., 2019, "Analysis and modeling of surface roughness based on cutting parameters and tool nose radius in turning of AISI D2 steel using CBN tool", *Measurement*,138, 34-38.

Poulachon, G., Bandyopadhyay, B.P., Jawahir, I.S., Pheulpin, S., Seguin, E., 2004, "Wear behavior of CBN tools while turning various hardened steels", *Wear*, 256(3–4), 302-310.

Pul, M., Bican, O., 2021, "Comparison of the Effect of Alloy Type on Some Machining Properties in Turning Different Aluminum Alloys", *Mühendislik Bilimleri ve Araştırmaları Dergisi*, 3 (1), 9-17.

Pul, M., Özerkan, H.B., 2022, "The effect of cutting depth and cutting tool geometry on surface roughness and tool wear behavior in the machining of Al 6061 alloy", *Journal of the Faculty of Engineering and Architecture of Gazi University*, 37(4), 2013-2024.

Qehaja, N., Jakupi, K., Bunjaku, A., Bruçi, M., Osmani, H., 2015, "Effect of Machining Parameters and Machining Time on Surface Roughness in Dry Turning Process", *Procedia Engineering*, 100, 135-40.

Ragab, A.E., Taha, M.A., Abbas, A.T., Al Bahkali, E.A., El-Danaf, E.A., Aly, M.F, 2017, "Effect of extrusion temperature on the surface roughness of solid state recycled aluminum alloy 6061 chips during turning operation", *Advances in Mechanical Engineering*, 9(10), 1–11.

Sarnobat, S.S., Raval, H.K., 2019, "Experimental investigation and analysis of the influence of tool edge geometry and work piece hardness on surface residual stresses, surface roughness and work-hardening in hard turning of AISI D2 steel", *Measurement*, 131, 235-260.

Selvaraj, D.P., Chandramohan, P., Mohanraj, M., 2014, "Optimization of surface roughness, cutting force and tool wear of nitrogen alloyed duplex stainless steel in a dry turning process using Taguchi Method", *Measurement*, 49, 205-215.

Sharma, A.K., Tiwari, A.K., Dixit, A.R., Singh, R.K., 2020, "Measurement of machining forces and surface roughness in turning of AISI 304 steel using alumina-MWCNT hybrid nanoparticles enriched cutting fluid", *Measurement*, 150, 1-13.

Srithar, A., Palanikumar, K., Durgaprasad, B., 2014, "Experimental Investigation and Surface roughness Analysis onHard turning of AISI D2 Steel using Coated Carbide Insert", *Procedia Engineering*, 97, 72-77.

Yağmur, S., Kaya, M.K., Şeker, U., 2021, "AA-6082 T4 Alaşımının Tornalamasında Çok Kristalli Elmas (ÇKE) Takımlara Uygulanan Talaş Kırıcı Formlarının Kesme Kuvvetleri Üzerindeki Etkilerinin Araştırılması", *Gazi Mühendislik Bilimleri Dergisi*, 7(1), 51-57.