Celal Bayar University Journal of Science

Experimental and response surface methodology investigation of cast material obtained by melting and recycling of chips

Harun AKKUŞ[1]*, Harun YAKA[2]

[1] Nigde Vocational School of Technical Sciences, Nigde Omer Halisdemir University, Niğde, Turkey
[2] Engineering Faculty, Amasya University, Amasya, Turkey
* harunakkus@windowslive.com
*Orcid: 0000-0002-9033-309X

Received: 17 March 2021
Accepted: 1 June 2021
DOI: 10.18466/cbayarfbe.898972

Abstract

In this study, it is aimed to draw attention to the new materials and recycling produced by the melt-casting process of chips in industry. For this purpose, the aluminum 5000 material with 90 HB hardness was turned. The chips obtained by turning were melted in melting furnace and molded as a cylinder mold. The hardness value of the material Recycled Al 5000 obtained by casting method was measured as 95 HB. Materials were examined by surface microscopy. Experimental design, analysis of surface roughness values of Al 5000 and Recycled Al 5000 material, regression equations, coefficients of determination, optimum point, cutting parameters interaction graphs were carried out with response surface methodology (RSM). It was concluded that the surface roughness values decreased in the Recycled Al 5000 material. In order to determine this reduction, the surfaces of the chips and materials were examined. Optimum parameter levels for Ra were found as cutting speed 222 m/min, feed rate 0,14 mm/rev, depth of cut 1,77 mm. Feed rate was the most effective parameter for surface roughness in both materials. In prediction experiments, it was observed that the RSM model yielded 90% reliability.

Keywords: turning, chips, recycling, casting, RSM.

1. Introduction

Nowadays, the consumption of available resources increases rapidly due to the increasing population. With the rapid depletion of the resources used, the important institutions in the world about how to use the resources efficiently need to do various studies. While meeting our current needs, we should not endanger the potential of future generations to meet their needs [1]. The main subject of our study is to provide recycling of waste aluminum chips. We support the conservation of both our natural resources and our resources.

Waste shavings or materials resulting from machining can be collected and recycled through scrap work. Metal materials take a long time to disappear in nature. Aluminum is lost in nature in about one hundred years. Energy and material savings are ensured by recycling.

The casting processes of different materials, which are important in industrial production, constitute the basis of many studies. Metalworking and shaping with the discovery of metals in human history has been practiced almost simultaneously. In this sense, the foundry and casting technique has continued its development throughout the ages, and it continues to be popular in today's information age [2, 3].

Aluminum is one of the most common metals used in many sectors (automotive, construction, aerospace, electric-electronics, etc.) due to its advantages (such as lightness, process ability, oxidation resistance and electrical conductivity). Recycling of scrap or waste materials for aluminum production saves approximately 90% energy from ore to aluminum production. This shows how important recycling of aluminum is. Aluminum is produced from primary aluminum and scrap as secondary aluminum [4-6].

Nowadays, it is aimed to obtain high quality products with low manpower in a short time [7]. For this purpose, the use of CNC machine has become widespread in order to be able to produce flexible and mass production. A wide variety of metal removal methods are available in the manufacturing industry. Turning is an important chip removal method because it is faster

Celal Bayar University Journal of Science
Volume 17, Issue 3, 2021, p 267-273
Doi: 10.18466/cbayarfbe.898972

than other operations and gives better results in surface quality [8]. There are several factors that influence the surface roughness in turning. The most important of these are the cutting speed, feed and chips depth known as cutting parameters [9-11]. Generally, the desired cutting parameters are determined according to the experience or according to the catalogs determined by the cutting tool manufacturers [12]. However, in order to obtain a better result in surface roughness, optimization of cutting parameters and surface roughness should be modeled [13]. Developing technology and increasing product diversity force manufacturers to produce more quality and faster. Therefore, cutting tool technology is constantly evolving. Recently, the improvement of cutting tools has not only increased the removed chip ratio but also reduced processing costs and processing time as well as increasing the quality of the desired surface [14]. In order to obtain a smooth surface, many experimental and statistical studies were performed on the optimization of the cutting parameters. In order to find the optimum value by decreasing the number of experiments, Taguchi method was used in studies and unnecessary experiments were avoided [15]. Bensouilah et al. Used surface roughness and shear force analysis in the hard turning process with and without coating using Taguchi method. In the experiments, the surface roughness was better at the coated ceramic ends and the cutting force was lower at the uncoated ceramic ends [16]. In his work, Noordin and his colleagues subjected AISI 1040 steel material to a lathe operation with a coated insert and investigated the effect of cutting parameters on surface roughness. At the end of their studies, they found that the most important parameter affecting the surface roughness was the progress [17]. In addition, in the literature, optimization with the response surface methodology (RSM) is widely used to determine optimum cutting parameters [18-20].

The main purpose of this study is to investigate the machinability of the new material obtained by the melt-casting method of the chip pieces produced by the machining in the enterprises or workshops. The surface roughness of the material obtained as a result of the process and the internal structure of the material were investigated. In this way, it was aimed to create awareness in the department students and to cooperate with the industry in accordance with the data we obtained.

2. Materials and Methods

In this study, aluminum 5000 work piece used in heating and cooling equipment, roof coverings, writing signs, panels, traffic lights, architectural applications, chemical industry, parts requiring coating.

First, aluminum 5000 cylindrical material is machined on the lathe. The chips formed during turning are deposited and pressed into the box placed on the lathe to keep them away from any contaminants such as oil and dirt. The pressed chips are melted in the crucible in our own melting furnace and poured into a cylindrical hollow material. Charcoal was used to heat the melting furnace. Slag formed during melting were removed. During melting, the average temperature reached 730 °C. After casting, the material was cooled to room temperature. Before the material was used, it was processed on the lathe to smooth the surface and the residues were removed. In Figure 1, flow chart is given. The parameters and definitions related to the experiment are given in Table 1. In the experiments, a cylindrical piece with dimensions of Ø50x175 mm was used. Process length was selected as 60 mm.

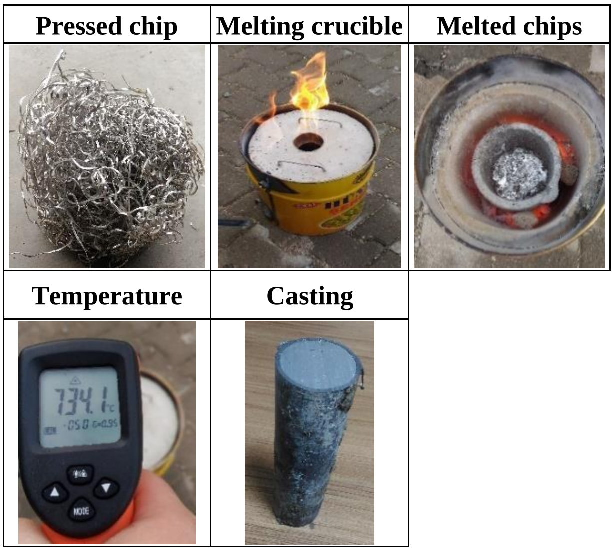


Figure 1. Flow chart.

Table 1. Experimental parameters.

Processing Conditions	Definitions
Workpiece	Aluminum 5000
Workpiece hardness (Al 5000)	90 HB
Workpiece hardness (Al 5000, Recycled from chips)	95 HB
Workpiece dimensions	Ø50x175 mm
Process length	60 mm
Lathe	ACE Micromatic Designers LT-20C

Cutting speed (m/min)	222-308-394
Feed rate (mm/rev)	0,14-0,21-0,28
Depth of cut (mm)	0,33-1,77-3,21
Cutting media	Dry
Cutter tips	Lamina Technologies VBMT 160404 NN LT10&LT100
Tools holder	TIMAXIP SVHBR 2525 M16
Measured value	Average surface roughness (Ra)
Roughness measuring instrument	Mitutoyo Surftest SJ-210
Temperature measuring instrument	Infrared Thermometer DT 8016H
Hardness measuring instrument	BMS Digirock RSR
Metallographic grinding and polishing machine	Metkon FORCIPOL 2V Grinder-Polisher
Microscope	Leica DMC 2900
Used programs	Design Expert, Microsoft Excell

Experimental design Design Experiment 11 program with a Box Behnken approach was created with 15 experimental lists. Experimental design and obtained test results are given in Table 2.

3. Experimental Results

Table 2 shows the experimental results and the graph of the test results in Figure 2. When the results of the experiment are examined, it is seen that the surface roughness values of the Recycled Al 5000 material decreased. It is determined that this decrease is caused by material hardness, internal structure of material and chip form.

Table 2. Experimental design and experimental results.

No	V (m/min)	f (mm/rev)	a (mm)	Al 5000 Ra (µm)	Recycled Al 5000 Ra (µm)
1	308	0,21	1,77	3,535	1,741
2	308	0,28	3,21	5,444	3,991
3	308	0,28	0,33	5,899	4,486
4	394	0,28	1,77	5,742	5,382
5	222	0,14	1,77	2,159	1,479
6	222	0,21	0,33	3,077	1,989
7	222	0,28	1,77	5,288	4,250
8	222	0,21	3,21	3,365	3,096
9	308	0,14	0,33	2,342	2,010
10	394	0,14	1,77	2,220	1,946
11	308	0,21	1,77	3,718	3,205
12	308	0,21	1,77	3,341	3,054
13	394	0,21	0,33	3,516	3,269
14	308	0,14	3,21	2,329	1,983
15	394	0,21	3,21	4,599	3,419

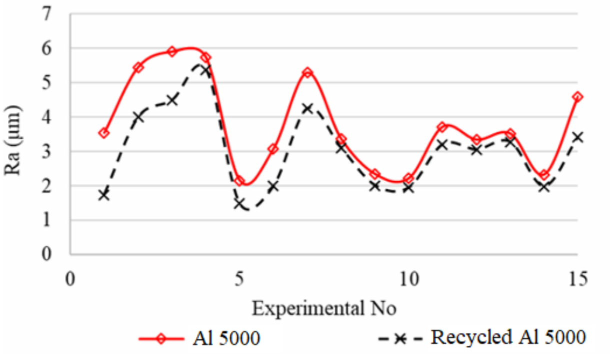


Figure 2. The roughness comparison of Al 5000 and Recycled Al 5000 material.

Figure 3 shows the chips of Al 5000 materials and the Recycled Al 5000. When the chips are examined, the chips in the Recycled Al 5000 material are not coiled in any way because of the short structure. As the Al 5000 material is being processed, the chips are not fragile, so the roughness values are increased. In other words, during the turning process of the Al 5000 material, the chips entrained in the part caused scratches on the surface. This situation increased the surface roughness of scratches.

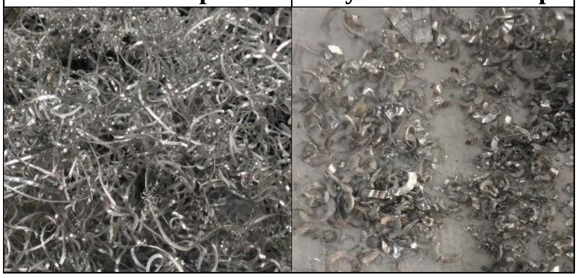
Al 5000 chips	Recycled Al 5000 chips
	

Figure 3. The chips structures formed during the processing of Al 5000 material and Recycled Al 5000 material.

Celal Bayar University Journal of Science
Volume 17, Issue 3, 2021, p 267-273
Doi: 10.18466/cbayarfbe.898972

In order to examine the differences in the chips structure as a result of the processing of Al 5000 material and Recycled Al 5000 material, the sections were taken from the samples and examined by Leica DMC 2900 microscope. The surfaces of the samples were prepared with Metkon FORCIPOL 2V Grinder-Polisher before the examination. The samples were ground in liquid medium with 180, 800 and 1200 sandpaper. Grinding surfaces are polished by using special liquid with felt. Figure 4 shows microscope images for 20x magnification. When the shape is examined, the surface of Al 5000 material is seen as a whole, but cracks and gaps are seen on the surface of the Recycled Al 5000 material. These images also explain the difference in the chips structures in Figure 3.

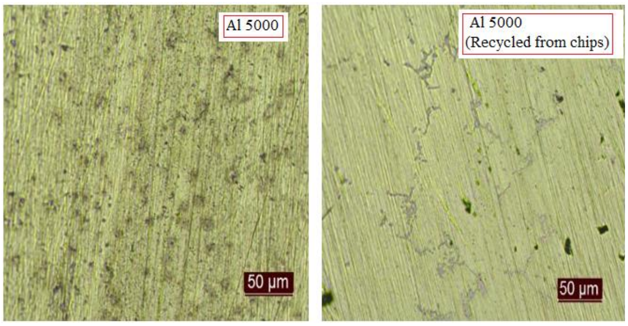


Figure 4. Microscope images.

4. Respond Surface Methodology (RSM)

The statistical analyzes of the experimental results were performed by Design Expert program. For optimum surface roughness of linear, quadratic, qubic equations have been tried. The most appropriate model was created by the quadratic equation. According to coefficients calculated in Design Expert program, quadratic model equations are obtained.

$$Ra\_\ Al\ 5000 = 3{,}531+0{,}273*V+1{,}665*f+0{,}112875*a+0{,}098*V*f+0{,}198*V*a-0{,}1105*f*a-0{,}0216*V^2+0{,}342*f^2+0{,}129*a^2$$

$$Ra\_\ Recycled\ Al\ 5000 = 2{,}666+0{,}401*V+1{,}336*f+0{,}091*a+0{,}166*V*f-0{,}239*V*a-0{,}117*f*a+0{,}211*V^2+0{,}385*f^2+0{,}064*a^2$$

R^2 was obtained as 89% for Al 5000 material. R^2 of the Recycled Al 5000 material was 97%. Table 3 and Table 4 show the results of ANOVA. When Table 3 and Table 4 show the equation coefficients, it is seen that the effective and important parameter on the roughness is progress. Table 3 and Table 4 also show that the model created for the Al 5000 material is not important and the model created for the Recycled Al 5000 material is important.

Table 3. ANOVA results for Al 5000 material.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	16,71	9	1,86	4,5	0,0562
A-v	1,28	1	1,28	3,11	0,1383
B-f	14,29	1	14,29	34,62	0,002
C-a	0,0675	1	0,0675	0,1636	0,7026
AB	0,1106	1	0,1106	0,2679	0,6268
AC	0,229	1	0,229	0,5548	0,4899
BC	0,0548	1	0,0548	0,1327	0,7306
A^2	0,1654	1	0,1654	0,4009	0,5545
B^2	0,5499	1	0,5499	1,33	0,3005
C^2	0,0156	1	0,0156	0,0377	0,8537
Residual	2,06	5	0,4127		

Table 4. ANOVA results for Recycled Al 5000 material.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	23,62	9	2,62	19,84	0,0021
A-v	0,5984	1	0,5984	4,52	0,0868
B-f	22,19	1	22,19	167,71	0.0001
C-a	0,1019	1	0,1019	0,7704	0,4203
AB	0,0386	1	0,0386	0,2919	0,6122
AC	0,158	1	0,158	1,19	0,3243
BC	0,0488	1	0,0488	0,3692	0,57
A^2	0,0017	1	0,0017	0,0131	0,9133
B^2	0,4333	1	0,4333	3,28	0,1301
C^2	0,062	1	0,062	0,4686	0,5241
Residual	0,6615	5	0,1323		

Figure 5 shows the graphs V-f, V-a and f-a. When Figure 5 is examined, it is seen that the parameter having the most effect on the surface roughness from the cutting parameters for Al 5000 and Recycled Al 5000 material is progress. It confirms our study in the literature [17, 21, 22].

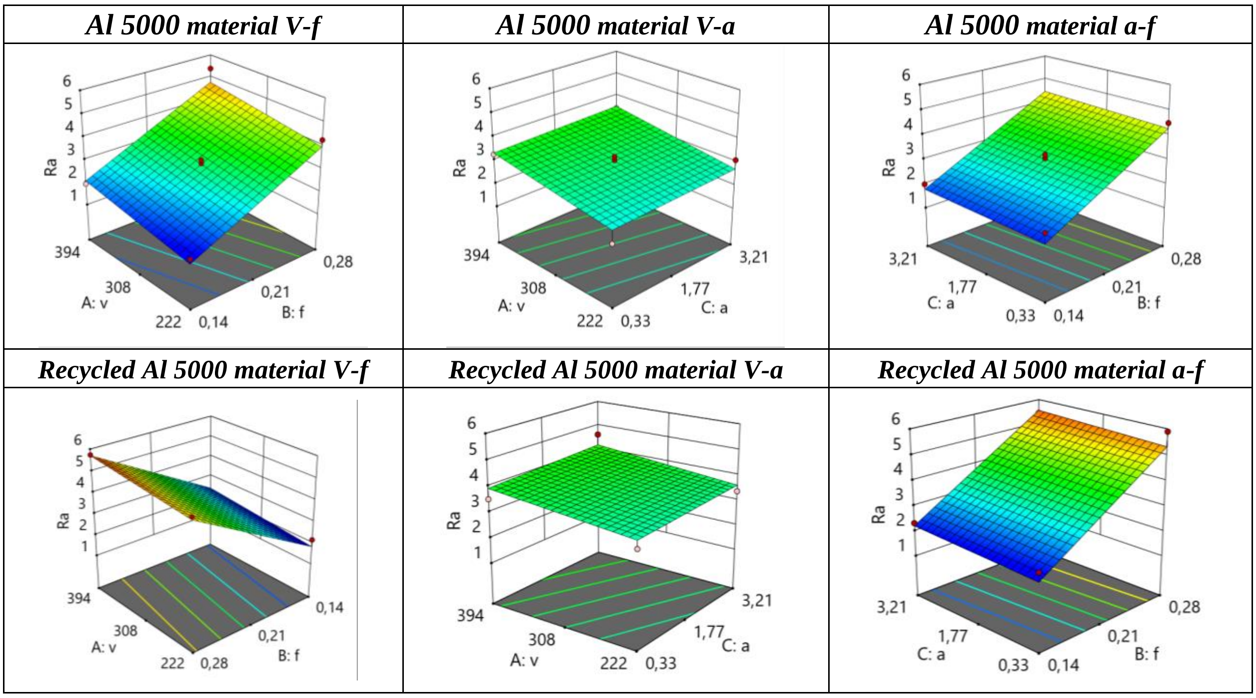


Figure 5. Al 5000 material and Recycled Al 5000 material for V-f, V-a, f-a graphics.

The optimum points for RSM models are determined in the Design Expert program. The determined optimum points and roughness values are given in Figure 6. Figure 6 shows that the cutting parameters (V = 222 m/min - f = 0,14 mm/rev - a = 1,77 mm) are the same for Al 5000 and Recycled Al 5000 material. For the same cutting parameters, Ra = 2,01 µm for Al 5000 material and Ra = 1,28 µm for Recycled Al 5000 material. The Ra value is low for the Recycled Al 5000 material.

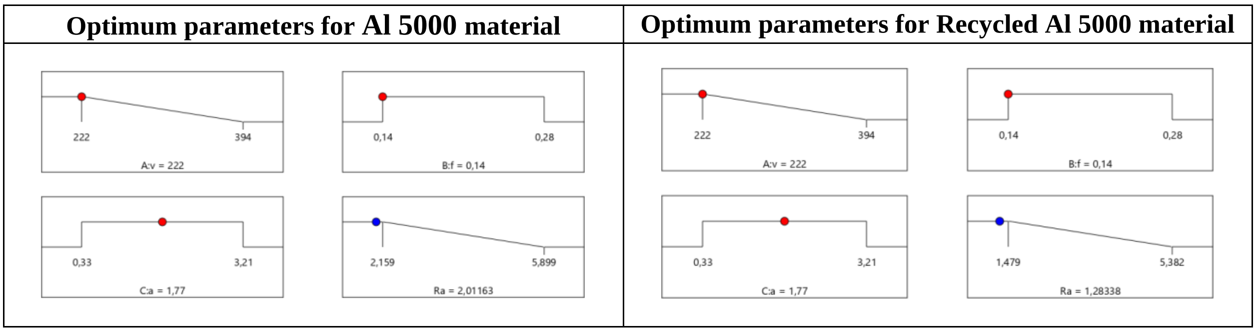


Figure 6. Optimum parameters for Al 5000 and Recycled Al 5000 material.

The result estimation and the experiments were performed for the cutting parameters determined in the Design Expert program for the RSM models. When Table 5 and Table 6 are examined, the estimation models for Al 5000 material and Recycled Al 5000 material approached approximately 90% of the experimental results. This has demonstrated the reliability of estimation models.

Table 5. Estimation experiments for Al 5000 material.

Test no	V (m/min)	f (mm/rev)	a (mm)	Actual	Predict	Absolute difference	Absolute error (%)
1	222	0,14	1,77	2,219	2,011	0,21	9,37
2	250	0,2	1,03	3,435	3,152	0,28	8,24
3	380	0,27	3,2	6,342	5,805	0,54	8,47

Celal Bayar University Journal of Science
Volume 17, Issue 3, 2021, p 267-273
Doi: 10.18466/cbayarfbe.898972

Table 6. Estimation experiments for Recycled Al 5000 material.

Test no	V (m/min)	f (mm/rev)	a (mm)	Actual	Predict	Absolute difference	Absolute error (%)
1	222	0,14	1,77	1,381	1,283	0,10	7,10
2	250	0,2	1,03	2,785	2,511	0,27	9,84
3	380	0,27	3,2	5,012	4,591	0,42	8,40

5. Conclusion

In this study, aluminum 5000 material is turned. The chips formed during the turning process were collected and melted in our own design melting pot and a new cylindrical material was produced. Recycling of chips is provided.

The hardness of the Al 5000 material was 90 HB and the hardness of the Recycled Al 5000 material was 95 HB. The obtained surface roughness values were reduced in the Recycled Al 5000 material for the same cutting parameters. The reason for this decrease is due to the increased hardness of the material due to the fact that the chips are more fragile and do not wrap the surface and create scratches on the surface.

Sections were examined by microscope. While the surface of Al 5000 material is seen as a whole, cracks and gaps in the surface of the Recycled Al 5000 material is noteworthy. This explains why the chips structures are broken in the Recycled Al 5000 material.

Optimum parameter levels for Ra were found as cutting speed 222 m/min, feed rate 0,14 mm/rev, depth of cut 1,77 mm. Feed rate was the most effective parameter for surface roughness in both materials.

RSM models for Ra values were obtained by Design Expert statistical program. Quadratic regression models were created for Ra values. ANOVA tables are given in the RSM results. In the RSM model, the graphs V-f, V-a and f-a are given. In the equations and graphs obtained, it is concluded that the most effective parameter is Ra.

Three experimental parameters were determined to determine the reliability of the predicted part of the RSM model. In this experiment and model comparison, approximately 90% of the results were obtained.

Different materials and different methods can be used in future manuscripts. We made the process of recycling with the charcoal smelting due to impossibility. Electric or natural gas melting furnaces can be used to reduce environmental damage.

Acknowledgement

This study was supported by Amasya University Scientific Research Projects Coordination Unit with the projects of FMB-BAP 18-0316 and FMB-BAP 20-0447.

Author's Contributions

Harun AKKUŞ: Conceptualization, Methodology, Software, Validation, Verification, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition.
Harun YAKA: Conceptualization, Methodology, Validation, Verification, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing, Visualization.

Ethics

There are no ethical issues after the publication of this manuscript.

References

1. Akbulut H., Içaga Y., Gürer C. 2003. The Possibility of Recycle of Waste Agregates in the Asphalt Pavement and CEN Standards. *III National Kırmataş Symposium*, 3-4.

2. Akar M. 2018. Casting errors and design methods for prevention, *Pamukkale University Graduate School of Natural and Applied Sciences*.

3. Cooper D. R., Song J., Gerard R. 2018. Metal recovery during melting of extruded machining chips. *Journal of Cleaner Production*; 200: 282-292.

4. Jirang C. U. I., Roven H. J. 2010. Recycling of automotive aluminum. *Transactions of Nonferrous Metals Society of China*; 20: 11: 2057-2063.

5. Martínez V.P., Torres J.T., Valdes A.F. 2017. Recycling of aluminum beverage cans for metallic foams manufacturing. *Journal of Porous Materials*; 24: 3: 707-712.

6. Gürbüz M. 2018. Effect of the cold working on mechanical properties of aluminum produced from waste beverage cans. *Journal of Science and Engineering*; 20: 58: 28-35.

7. Özel T., Karpat Y. 2005. Predictive modeling of surface roughness and tool wear in hard turning using regression and neural networks. *International Journal of Machine Tools and Manufacture*; 45: 467-479.

8. Gupta M.K., Sood P.K. 2016. Optimizing multi characterstics in machining of AISI 4340 steel using Taguchi's approach and utility concept. *Journal of The Institution of Engineers (India): Series C*; 97: 63-69.

9. Kopac J., Bahor M., Soković M. 2002. Optimal machining parameters for achieving the desired surface roughness in fine turning of cold pre-formed steel workpieces. *International Journal of Machine Tools and Manufacture*; 42: 707-716.

10. Özlü B. 2021. Investigation of the effect of cutting parameters on cutting force, surface roughness and chip shape in turning of Sleipner cold work tool steel. *Journal of the Faculty of Engineering and Architecture of Gazi University*, 36(3), 1241-1251.

11. Özlü B., Akgün M., Demir H. 2019. Analysis and optimization of effects on surface roughness of cutting parameters on turning of AA6061 alloy. *Gazi Müh Bilim Derg*, 5, 151-158.

12. Sahoo P. 2011. Optimization of turning parameters for surface roughness using RSM and GA. *Advances in Production Engineering and Managemen*t; 6: 197-208.

13. Tzeng C.J., Lin Y.H., Yang Y.K., Jeng M.C. 2009. Optimization of turning operations with multiple performance characteristics using the Taguchi method and grey relational analysis. *Journal of Materials Processing Technology*; 209: 2753-2759.

14. Bhattacharya A., Das S., Majumder P., Batish A. 2009. Estimating the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA. *Production Engineering*; 3: 31-40.

15. Kurt M., Bagci E., Kaynak Y. 2009. Application of Taguchi methods in the optimization of cutting parameters for surface finish and hole diameter accuracy in dry drilling processes. *The International Journal of Advanced Manufacturing Technology*; 40: 458-469.

16. Bensouilah H., Aouici H., Meddour I., Yallese M.A., Mabrouki T., Girardin F. 2016. Performance of coated and uncoated mixed ceramic tools in hard turning process. *Measurement*; 82: 1-18.

17. Noordin M.Y., Venkatesh V.C., Sharif S., Elting S., Abdullah A. 2004. Application of response surface methodology in describing the performance of coated carbide tools when turning AISI 1045 steel. *Journal of Materials Processing Technology*; 145: 46-58.

18. Aslan A. 2020. Optimization and analysis of process parameters for flank wear, cutting forces and vibration in turning of AISI 5140: A comprehensive study. *Measurement*, 163, 107959.

19. Kuntoğlu M., Aslan A., Pimenov D. Y., Giasin K., Mikolajczyk T., Sharma S. 2020. Modeling of cutting parameters and tool geometry for multi-criteria optimization of surface roughness and vibration via response surface methodology in turning of AISI 5140 steel. *Materials*, 13(19), 4242.

20. Kuntoğlu M., Aslan A., Pimenov D. Y., Giasin K., Mikolajczyk T., Sharma S. 2020. Modeling of cutting parameters and tool geometry for multi-criteria optimization of surface roughness and vibration via response surface methodology in turning of AISI 5140 steel. *Materials,* 13(19), 4242.

21. Akkus H. 2018. Optimising the effect of cutting parameters on the average surface roughness in a turning process with the Taguchi method. *Materiali in Tehnologije*; 52: 6: 781-785.

22. Akkuş H. 2021. Multiple optimization analysis of MRR, surface roughness, sound intensity, energy consumption, and vibration values in machinability of TC4 titanium alloy. *Surface Review and Letters*, 2150072.