Avrupa Bilim ve Teknoloji Dergisi
Özel Sayı 45, S. 151-158, Aralık 2022

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
Special Issue 45, pp. 151-158, December 2022

Research Article

Fuzzy Logic Modelling Of the Effect of Tool Tip Radius on Surface Roughness in Machining Co28Cr6Mo Wrought Steels in CNC Turning

Ilhan Asiltürk *, Mehmet Alper Ince[2]

[1]University of Necmettin Erbakan , Faculty of Engineering, 42075, Konya, Turkey, (ORCID: 0000-0002-8302-6577), iasiltürk@yahoo.com
[2]University of Necmettin Erbakan , Faculty of Engineering, 42075, Konya, Turkey, (ORCID: 0000-0003-4457-9520), mehmet4219@hotmail.com

(1st International Conference on Engineering, Natural and Social Sciences ICENSOS 2022, December 20 - 23, 2022)

(**DOI:** 10.31590/ejosat.1223563)

ATIF/REFERENCE: Asiltürk, I. & Ince, M.A. (2022). Fuzzy Logic Modelling Of The Effect Of Tool Tip Radius On Surface Roughness In Machining Co28Cr6Mo Wrought Steels In CNC Turning. *European Journal of Science and Technology*, (45), 151-158.

Abstract

This study includes fuzzy logic modeling of surface roughness experimental values obtained as a result of machining Co28Cr6Mo medical alloy in CNC turning (rotational speed (*n*), feed rate (*f*), depth of cut (*a*) and tool tip radius (*r*)) depending on cutting parameters. According to the hardness of the material to be cut and the type of cutting tool used, fuzzy logic solution models that can determine the most suitable tool tip radius for the surface roughness (*Ra*) were created. In the model created using fuzzy logic, experimental studies on the rule base created by using the membership functions of the input parameters and the output parameters, the membership function foot widths and the relations between the membership functions were used. Triangle (trimf) membership function was chosen with Mamdani approach on the rule base. The results obtained using the established model are interpreted with 2 and 3 dimensional graphics for tool tip radius. We can say that a good surface quality (minimum surface roughness) is obtained on the material with the most suitable (optimal) tool tip radius determined by models established with fuzzy logic.

Keywords: Fuzzy Logic, Co28Cr6Mo, Surface Roughness, CNC Turning, Cutting Parameters.

Co28Cr6Mo Çeliklerin CNC Tornalanmasında Takım Uç Yarıçapının Yüzey Pürüzlüğüne Etkisinin Bulanık Mantıkla Modellenmesi

Öz

Bu çalışma, Co28Cr6Mo medikal alaşımının CNC tornalamada (devir sayısı, ilerleme hızı, kesme derinliği ve takım uç yarıçapı) kesme parametrelerine bağlı olarak işlenmesi sonucu elde edilen yüzey pürüzlülüğü deneysel değerlerinin bulanık mantıkta modellenmesini içermektedir. Kesilecek malzemenin sertliği ve kullanılan kesici takımın cinsine göre yüzey pürüzlülüğü için en uygun kesme hızı, ilerleme hızı, kesme derinlikleri ve kesici uç yarıçapını belirleyebilen bulanık mantık çözüm modelleri oluşturulmuştur. Bulanık mantık kullanılarak oluşturulan modelde giriş parametreleri ve çıkış parametrelerinin üyelik fonksiyonları, üyelik fonksiyon ayak genişlikleri ve üyelik fonksiyonlarının aralarındaki ilişkiler kullanılarak oluşturulan kural tabanında yapılan deneysel çalışmalardan faydalanılmıştır. Kural tabanında Mamdani yaklaşımıyla üçgen (trimf) üyelik fonksiyonu seçilmiştir. Kurulan model kullanılarak elde edilen sonuçlar, her bir kesme parametresinde 2 ve 3 boyutlu grafiklerle yorumlanmıştır. Bulanık mantıkla kurulan modellerle belirlenen en uygun (optimum) kesme parametreleriyle, malzeme üzerinde iyi bir yüzey kalitesi (minimum yüzey pürüzlülüğü) elde edildiğini söyleyebiliriz.

Anahtar Kelimeler: Bulanık Mantık, Co28Cr6Mo, Yüzey Pürüzlülüğü, CNC Tornalama, Kesme Parametreleri.

* Corresponding Author: iasiltürk@yahoo.com

1. Introduction

With the developing technology, shaping with machining methods (turning, milling, drilling, etc.) still maintains its importance. The development of steel materials used in the manufacturing industry is increasing day by day. The usage areas of steel in many fields from food to health and from automotive to aerospace industry are becoming more and more widespread. Therefore, the machinability of steel materials has an important place among the subjects that still need to be investigated in order to improve the production efficiency and cost [1].

In order to produce the same quality (standard) product in the production process, the production must be controlled simultaneously. The fact that the parameters that are effective in turning operations do not deteriorate the expected standard in production depends on their good control. In an effective production, it is necessary to consider quality, efficiency and economy together. While determining the production strategies, the target functions covering all of these should be determined. Surface roughness, which plays a key role in quality and economical production, is affected by the workpiece-tool material relationship and cutting parameters. Machining parameters such as cutting speed, feed rate, depth of cut, which play an important role in the selection of cutting tools and the efficient use of the tools used, also have great effects on the total production cost [2,3]. Because the cutting parameters that are not determined appropriately will wear the tool and the roughness will increase, and the quality will deteriorate as the roughness increases. The cost of energy withdrawn from the system will increase and the unit cost of tool change due to quality defect will increase. In recent years, artificial intelligence methods such as Artificial Neural Networks, Fuzzy Logic and Genetic Algorithm have been used in the optimization studies of cutting parameters in machining. Among these methods, fuzzy logic is the most used for optimizing cutting parameters. Fuzzy logic is a very successful method in the control of processes when it is non-linear, complex, difficult to model and the characteristics of the information are uncertain or uncertain. Zadeh put forward the first serious step regarding the concept of fuzzy logic in an article published in 1965 under the name of fuzzy logic or fuzzy set theory. Some of the general features of fuzzy logic was expressed by Zadeh as follows;

- Fuzzy logic uses approximate thinking instead of thinking based on exact values.
- In fuzzy logic, information is in the form of linguistic expressions (large, small, a lot, a little, etc.).
- In fuzzy logic, everything is represented with a certain degree in the range [0,1].
- Fuzzy logic is very suitable for systems where mathematical model is very difficult to obtain.

Mamdani made the first application of fuzzy logic control in 1974 with the control of the steam engine. Mamdani has shown that Zadeh's linguistic rule approach is provided in a form that is easily processed by the computer. Thanks to the approaches of Japanese researchers on new technologies, fuzzy logic has developed very quickly. Today, fuzzy logic has found application in many areas such as electronic control systems, automotive industry brake systems, process planning and home electronics. With the application of fuzzy logic to the household appliances we use every day, significant energy and time savings have been achieved. For example, if classical and fuzzy set theory is applied to an age problem selected as an example, classical set membership functions can be seen in Figure 1 and fuzzy set membershipfunctions can be seen in Figure 2 [4].

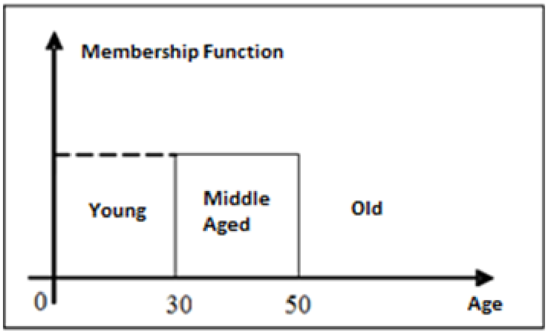


Fig. 1 Classical Set Theory [4]

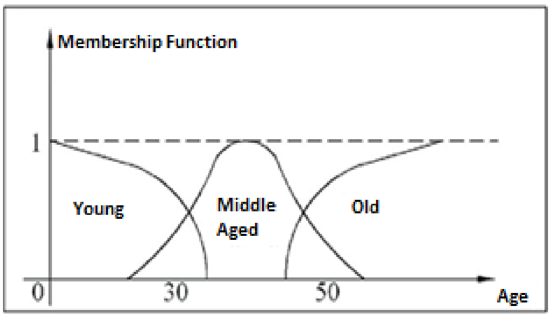


Fig. 2 Fuzzy Set Theory [4]

Basic elements of Fuzzy Logic system; The fuzzyfication, fuzzy output set, rule base and defuzzification unit are shown in Figure 3 [5,6].

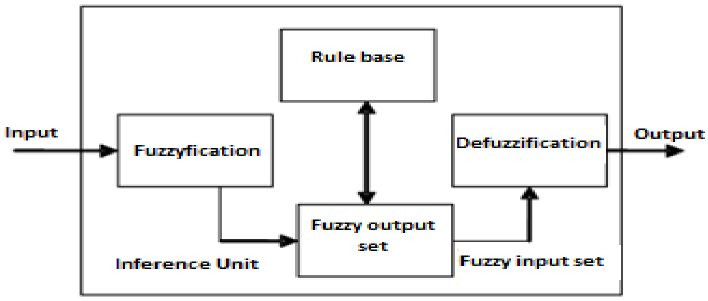


Fig. 3 Basic structure of Fuzzy Logic system [5,6]

To date, many studies have been carried out on Fuzzy Logic in the optimization of cutting parameters in machining. Some of those;

In the study by Wong et al. [7], a general fuzzy model was established for the selection of machining cutting parameters. Several fuzzy models were created for different cutting tools and compared. The results showed that the accepted model was formed with a mean error of 6%. Chungchoo and Saini [8] estimated tool wear in CNC turning process using fuzzy-Neural network model. For this, the tool wear classification is made with fuzzy logic, the inputs are normalized, the mesh is formed according to the least square error, and the lateral and crater wear is estimated with high accuracy. Du et al. [9] monitored tool breakage, wear and tip formation in the turning process using fuzzy logic. At the end of the experiments using a multi-sensor system including a power sensor, a force sensor and a vibration sensor, the method applied showed 90% accuracy. Rajasekaran et al. [10] investigated the effect of combinations of machining parameters on obtaining a good surface finish using a CBN cutting tool in turning CFRP (Carbon Fiber Reinforced Plastics) composite material and predicting surface roughness values using fuzzy modeling. Suhail et al. [11] designed a method for determining cutting parameters using MANFIS (Multi Adaptive Network Based Fuzzy Inference System). By examining the surface roughness, which is a single output, values for cutting parameters (cutting speed, feed rate and depth of cut) were determined. These parameters are variable and have been modified in another set of ANFIS (Adaptive Network Based Fuzzy Inference System) models. Then, they created a MANFIS model by adding a second output (workpiece surface temperature) to this ANFIS model. As a result, they observed that the MANFIS model is suitable for machinability in data selection. Ko and Cho [12] investigated the lateral wear length of the cutting edge of the cutting tool, which affects the geometric accuracy and surface roughness during the final machining in the milling process. They estimated the lateral wear length in milling with an error of 12% by writing rules with the fuzzy logic method and applying tests under various cutting conditions. Sharma et al. [13] predicted and analyzed the cutting force so induced during hard turning operation. They analyzed rotational speed, feed rate and depth of cut were as the controllable variables and their effect on cutting force. They used L9 orthogonal array. In this study, they benefited the ANOVA analysis for revealed the contribution of each machining parameter on cutting force. Furthermore, they developed cutting force models for the prediction purpose using regression and fuzzy logic method. Bhasker et. al [14] studied the bearing performance characteristics having different operating conditions. They reported results that oil film pressure and temperature distribution profile obtained experimentally are in good agreement with the theoretical results. Fuzzy-based Taguchi optimisation has been used in this experimental analysis to predict the optimal input parameters. Rajeswari et al. [15] determined the optimum level of geometrical parameters such as helix angle, tool tip radius, rake angle and machining parameters such as cutting speed, feed rate and depth of cut to arrive minimum surface roughness and tool wear during end milling of Al 356/SiC metal matrix composites (MMCs) using high speed steel end mill cutter. For this, they used L27 Taguchi orthogonal design with six factors and three levels is employed for conducting experiments and Analysis of variance (ANOVA) is carried out using Minitab16 software to find the influence of each input parameter on output performance measure. Prabhu et. al [16] investigated the surface characteristics of AISI D2 Tool Steel with graphite as a tool electrode during EDM process. They mixed the multiwall carbon nanotube with dielectric fluids to analyze the surface roughness and micro-cracks using atomic force microscope measurements. They developed response surface model (RSM) to predict the surface roughness for EDM parameters. Analysis of variance and F test have been used to check the validity of response surface model and determine the significant process parameter affecting the surface roughness. They used a fuzzy logic model to investigate relationships between the machining parameters and determine the efficiency of each parameter with and without using CNT-based EDM process. Kacalak et. al [17] presented the assumptions and results of the optimization of the grinding process using fuzzy logic to the defnition of objectives and constraints imposed on the example of the sequential grinding of small ceramic elements. They defined an objective function that allows determining the impact of the degree of fulfillment of individual objectives and processing constraints on the result of the fuzzy decision. They carried out experimental study to determine the relationships allowing the transfer of objectives and constraints of the grinding process from the output variable space into the grinding parameters space. They optimized process parameters assuring maximization of fuzzy decision using a genetic algorithm. Determining the optimum cutting parameters and cutting conditions for the processing of hot-tempered Co28Cr6Mo steel, which has low machinability, high mechanical properties, resistance to corrosion and temperature, and is generally used for prosthetics in the medical field, is considered as a major problem to be solved by production environments. In this study, it was aimed to determine the optimum tool tip radius to obtain minimum surface roughness in dry cutting conditions in the machining of Co28Cr6Mo steels in CNC turning. Surface roughness values obtained as a result of longitudinal turning of Co28Cr6Mo steel on CNC machine were measured. In order to determine the effects of the parameters used in the experiments, rule bases in fuzzy logic were created.

2. Material and Method

2.1. Cutting Conditions And Roughness Measurements

In the experimental study, Co28Cr6Mo ASTM F1537 quality hot-tempered steel with a hardness of 40 HRC was used. The workpiece is prepared in Ø50x500 mm dimensions. The turning process was carried out on a Sogotec TC25-L type CNC lathe and the surface roughness values were measured with the SJ-201 mitutoyo device (cut-off distance 2.5 mm). The experiments were carried out by longitudinal turning of the workpieces using a new tool tip for each test in dry cutting conditions. MTJNR-L 2525 M16 was used as tool holder, Taegutec production and PVD method, TNMG 160404 MT, TNMG 160408 MT and TNMG 160412 MT form and TT 8020 quality were used as tool tips. Cutting parameters given in Table 1 were determined in line with the manufacturer's recommendations and experiments were carried out using the combinations given in Table 2.

Table 1. Cutting parameters and levels.

Symbol	Parameter	Unit	Level 1	Level 2	Level 3
n	Rotational speed	rpm	318	477	636
f	Feed rate	mm/rev	0.1	0.15	0.25
a	Depth of cut	mm	0.5	0.7	0.9
r	Tool tip radius	mm	0.4	0.8	1.2

Table 2. Experimental parameters and measured average roughness values

Number of tests	Parameter				Roughness
	n (rpm)	***f*** (mm/rev)	***a*** (mm)	***r*** (mm)	***Ra*** (µm)
1	318	0.1	0.5	0.4	1.660
2	318	0.1	0.7	0.8	0.810
3	318	0.1	0.9	1.2	1.070
4	318	0.15	0.5	0.8	1.593
5	318	0.15	0.7	1.2	1.137
6	318	0.15	0.9	0.4	2.920
7	318	0.25	0.5	1.2	2.750
8	318	0.25	0.7	0.4	7.110
9	318	0.25	0.9	0.8	4.923
10	477	0.1	0.5	0.8	1.590
11	477	0.1	0.9	1.2	0.987
12	477	0.1	0.9	0.4	1.690
13	477	0.15	0.5	1.2	0.857
14	477	0.15	0.7	0.4	4.410
15	477	0.15	0.9	0.8	2.647
16	477	0.25	0.5	0.4	8.207
17	477	0.25	0.7	0.8	3.037
18	477	0.25	0.9	1.2	1.950
19	636	0.1	0.5	1.2	1.690
20	636	0.1	0.7	0.4	4.017
21	636	0.1	0.9	0.8	1.720
22	636	0.15	0.5	0.4	3.567
23	636	0.15	0.7	0.8	1.417
24	636	0.15	0.9	1.2	2.547
25	636	0.25	0.5	0.8	3.243
26	636	0.25	0.7	1.2	2.193
27	636	0.25	0.9	0.4	4.787

The average of the roughness values measured in the direction parallel to the workpiece axis from three different parts of the cylindrical surface formed after each cutting process was used. Mitutoyo SJ-201 series surface roughness device (cut-off distance 2.5 mm) was used to measure the roughness values. A total of 27 physical experiments were carried out for four parameters and three levels used in this study, adhering to the $L_{27}(3^4)$ Taguchi standard orthogonal experimental design. Cutting parameters are modeled as 4 inputs (*n*,*f*,*a*,*r*) and single output (*Ra*) with fuzzy logic. And finally, it was determined the optimum tool tip radius to obtain minimum surface roughness.

2.2. Modeling Of Cutting Parameters With Fuzzy Logic

In modeling the problem to be solved with the fuzzy logic method, the parameters affecting the problem and the target function must be determined exactly. The factors affecting the problem to be modeled are called input parameters, and the parameters that make up the target function are called output parameters. Membership function numbers, names, lower and upper limit leg widths of all parameters are determined according to the effectiveness of the input and output parameters on the problem to be modeled. For example; For rpm, which is one of the input parameters, the lower limit value is 318 rpm, the upper limit value is 636 rpm, membership functions are defined as slow, normal, fast. While creating the solution model of the surface roughness parameter with fuzzy logic, the lower and upper limits of the parameters were determined in accordance with the previous experimental studies, expert opinion and the purpose of the problem. Rpm, feed rate, depth of cut and tool tip radius input parameters are determined and membership functions, lower and upper limit values of each parameter are given in Figure 4. The mean surface roughness value that will occur as a result of turning operations, the lower and upper limit values of the output parameter membership functions are given in Figure 5. The lower limit value of the mean surface roughness, which is the target function, is determined as 0.810, the upper limit value is 8.207, and the membership functions are determined as very good, good, medium, bad, terrible. Mamdani's approach was used in fuzzy logic modeling..

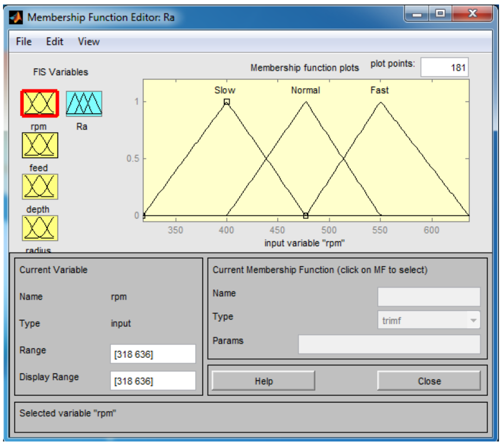
rpm	Degree of Speed
318-477	Slow
318-636	Normal
477-636	Fast

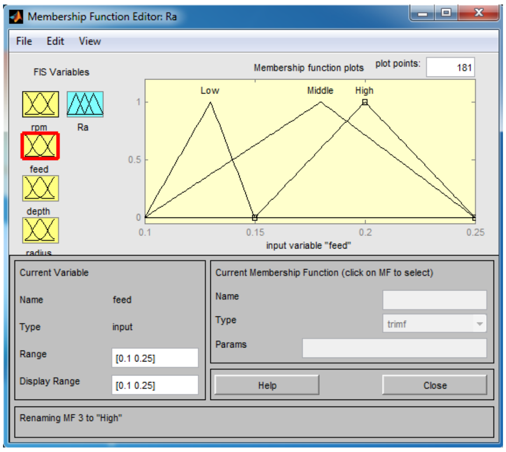
Depth of cut (mm)	Degree of depth
0.5-0.7	Little
0.5-0.9	Middle
0.7-0.9	Much

Feed rate (mm/rev)	Degree of feed
0.1-0.15	Low
0.1-0.25	Middle
0.15-0.25	High

Tool tip radius(mm)	Degree of radius
0.4-0.8	Small
0.4-1.2	Regular
0.8-1.2	Large

Average surface roughness , *Ra*, (μm)	Degree of Roughness
0.81-2.3	Very Good
0.81-3.8	Good
2.3-5.3	Medium
3.8-6.75	Bad
5.3-8.207	Terrible





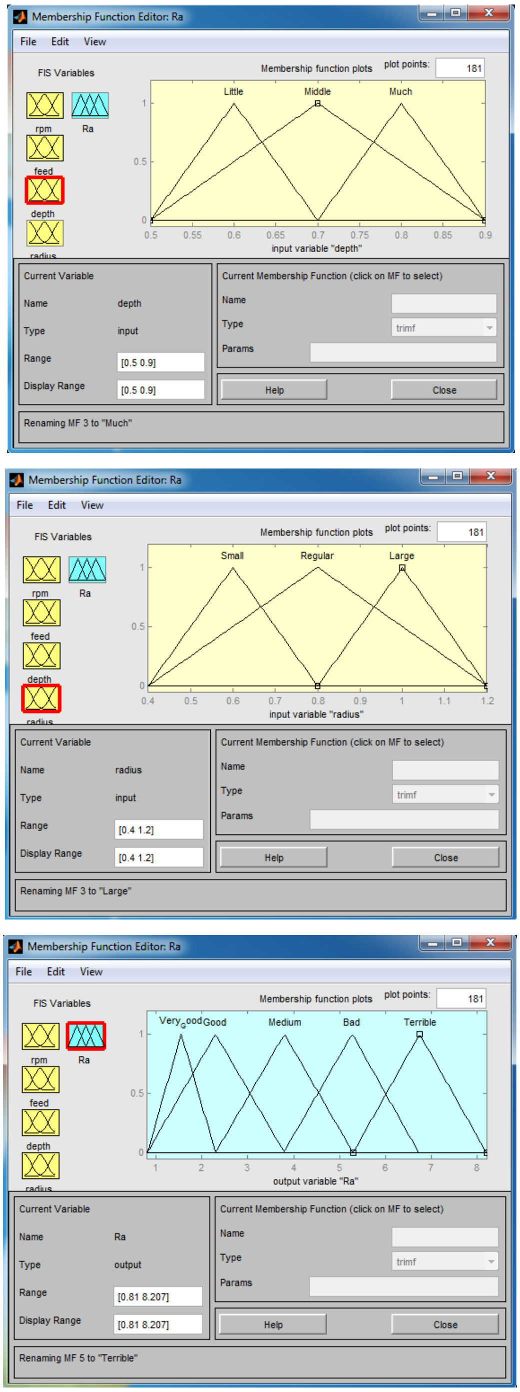


Fig. 5 Membership functions and foot widths of the surface roughness parameter

In this study, which aims to model the cutting parameters in the CNC turning process with fuzzy logic, 52 rule bases were created in order to apply them to the cutting parameters in order to provide the best surface quality. The created rule bases and rule viewer sample are shown in Figure 6.

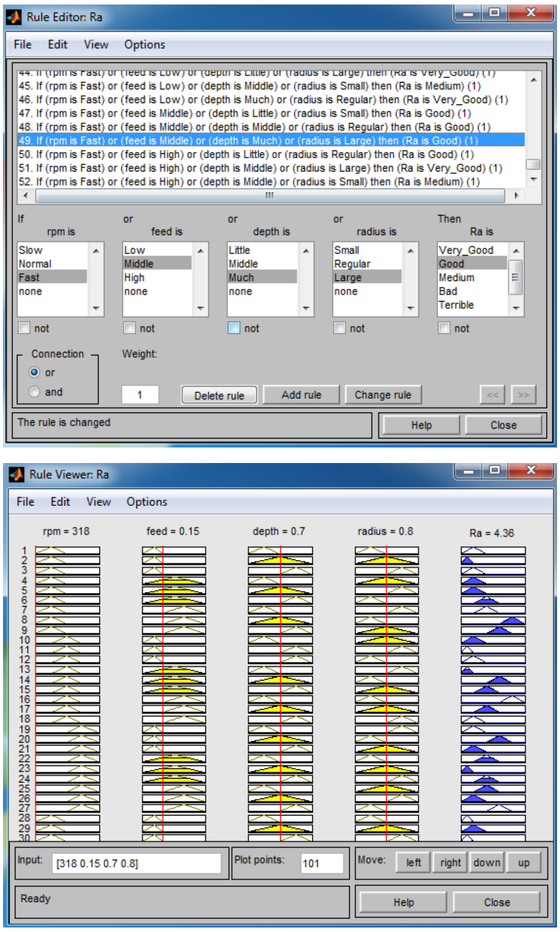


Fig. 6 Created rule bases and rule viewer sample

3. Results and Discussion

In this study, fuzzy logic modeling of surface roughness values obtained as a result of machining of Co28Cr6Mo medical alloy depending on cutting parameters in CNC turning (rpm, feed rate, depth of cut and tool tip radius) was made. According to the hardness of the material to be cut and the type of cutting tool used, fuzzy logic solution models were created that can determine the most appropriate tool tip radius for the surface roughness. And it is aimed to obtain minimum surface roughness with the created rule bases. Various 2D graphics was obtained from these solution models and these graphics were interpreted. And finally, the most suitable tool tip radius for the processing of this material were determined. Obtained 2D graphics are shown in Figure 7-8.

a= 0.5 , 0.9 mm

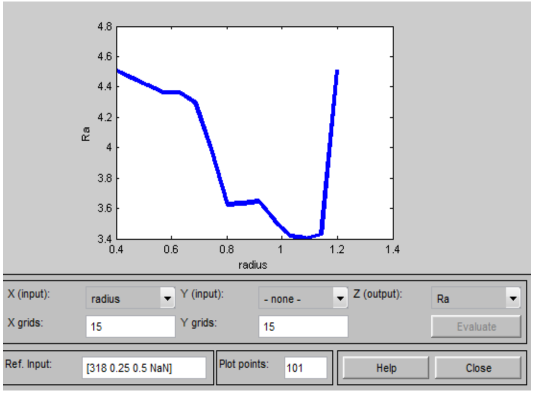
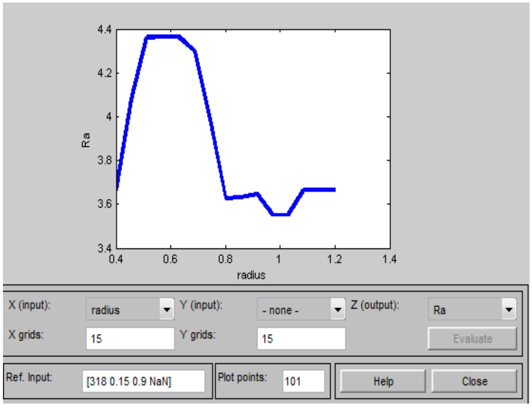


Fig. 7 Effect of tool tip radius on surface roughness while *n*= 318, 636 rpm, *f*= 0.1, 0.25 mm/rpm, *a*= 0.5,0.9 mm

a= 0.5 , 0.9 mm



a= 0.7 mm and *n*=477 rpm

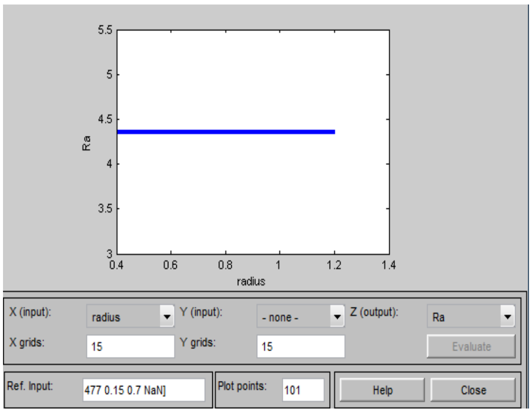


Fig. 8 Effect of tool tip radius on surface roughness while *n*= 318, 636 rpm, *f*= 0.15 mm/rpm, *a*= 0.5-0.9 mm

In Figure 7-8, minimum surface roughness was obtained in the value ranges *n*= 318-636 rpm , *f*= 0.1-0.25 mm/rpm, *a*= 0.5-0.9 mm value ranges *r*= 1-1.2 mm. From these figures, we can say that as the radius of the tool tip increases, the surface roughness generally decreases. No change was observed in the surface roughness even when *n*= 477 rpm and *a* = 0.7 mm. That is, *n*= 477 rpm and *a*= 0.7 mm do not affect the roughness.

4. Conclusions

It is possible to reach the following conclusions from all these figures: For minimum surface roughness; 0.8-1.2 mm (degree of [1,2] radius large) of tool tip radius were obtained. And it was observed that the minimum surface roughness was *Ra*= 3.41 µm. In other words, it is possible to say that the degree of roughness is reduced to both the good and the medium by Mamdani's approach. Here, it is possible to make the following inferences as the reasons for the increase in surface roughness in a certain range of values: The radius chosen too large will increase the cutting force, resulting in friction at the cutting edge and poor surface quality; In case the radius is chosen small, too much depth of cut cannot be given, and poor surface quality is obtained due to the wear of the tool only by scraping, Due to the difficult processing of the material at certain intervals at the specified rpm and feed rate, high vibration can be shown as the reason. In other cases, we can say that a good surface quality (minimum surface roughness) is obtained on the material with the most suitable (optimal) tool tip radius determined by models established with fuzzy logic by Mamdani's approach.

This study will contribute to both the manufacturing sector and academic studies in achieving the best results in difficult-to-machine materials such as Co28Cr6Mo on the basis of surface roughness. And the same time, It is an important study on modeling and relation of machining with fuzzy logic.

References

1. Y. Kayır, A. Aytürk, ''AISI 316 Ti Paslanmaz Çeliğin İşlenebilirlik Karakteristiklerinin İncelenmesi,'' *Pamukkale University Journal of Engineering Sciences*, Ankara, 18:61-71, 2012.
2. K. Hashmi, M.A. El Baradie, M. Ryan ''Fuzzy-Logic Based Intelligent Selection of Machining Parameters'', *Journal of Materials Processing Technology*, Vol. 94, 1999, p. 94-111.
3. C.Y.H. Lim, P.P.T. Lau, S.C. Lim, ''The Effects of Work Material on Tool Wear'', *Wear*, Vol. 250, 2001, s. 344-348.
4. Özek, M. Sinecen, ''Modeling Air Conditioning System Control with Fuzzy Logic'', *Pamukkale University Engineering Faculty Journal of Engineering Sciences*, 10(3), 353- 358, 2004.
5. P. Dadone, ''Design Optimization of Fuzzy Logic Systems", Doctor of Philosophy in Electrical Engineering, Virginia Polytechnic Institute and State University, 2001.
6. J. M. Mendel, "Fuzzy Logic Systems for Engineering: A Tutorial", *Proceedings of the IEEE*, 83(3), 1995.
7. S.V. Wong, A.M.S. Hamouda, M.A. El Baredie, ''Generalized Fuzzy Model For Metal Cutting Data Selection'', *Journal of Materials Processing Technology*, Vol. 89-90, 1999, s. 310-317.
8. C. Chungchoo, D. Saini, ''On-Line Tool Wear Estimation in CNC Turning Operations Using Fuzzy Neural Network Model'', *International Journal of Machine Tools & Manufacture*, Vol. 42, 2002, s. 29-40.
9. R.X. Du, M.A. Elbestawi, S. Li, ''Tool Condition Monitoring in Turning Using Fuzzy Set Theory, *International Journal of Machine Tools & Manufacture*, Vol. 32/6, 1992, s.781.

10. T. Rajasekaran, K. Palanikumar, B.K. Vinayagam, ‘’Application of fuzzy logic modeling surface roughness of turning CFRP composites using CBN tool’’, *Springer, Prod. Eng. Res. Devel.,* (2011) 5: 191-199.
11. A.H. Suhail, N. Ismail, S.V. Wong, Abdul, J.N.A. Abdul, ‘’Cutting parameters identification using multi adaptive network based Fuzzy inference system’’, *An artificial intelligence approach. Sci. Res. Essay,* 6(1): 187-195.
12. T.J. Ko, D.W. Cho, "Estimation of Tool Wear Length in Finish Milling Using a Fuzzy Inference Algorithm, *Wear*, Vol. 169, 1993, s. 97.
13. V. Sharma, P. Kumar, J. Misra, ‘’Cutting force predictive modelling of hard turning operation using fuzzy logic’’, *Materials Today: Proceedings*, (2020), 740-744, 26.
14. B. Bhasker, N. Seetharamaiah, P. Ramesh Babu, S.K. Gugulothu, ‘’Hydrodynamic Bearing Performance Trade-off Study and Fuzzy Based Multi-objective Optimisation on a Offset Surface Textured Journal Bearing, *Journal of Bio- and Tribo-Corrosion*, (2020), 7:17.
15. S. Rajeswari, P.S. Sivasakthivel, ‘’Optimisation of milling parameters with multi-performance characteristic on Al/SiC metal matrix composite using grey-fuzzy logic algorithm’’, *Multidiscipline Modeling in Materials and Structures*, (2018), s. 284-305, 14(2).
16. S. Prabhu, Uma M. Uma, B.K. Vinayagam, ‘’Electrical discharge machining parameters optimization using response surface methodology and fuzzy logic modeling’’, *J Braz Soc Mech Sci Eng.,* 36:637–652, (2014).
17. D. Lipinski, W. Kacalak, B. Balasz, ‘’Optimization of sequential grinding process in a fuzzy environment using genetic algorithms’’, *J Braz Soc Mech Sci Eng.,* 41:96, 6, (2019).