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Experimental and Statistical Investigation of Ra in Turning of AISI 4140

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Abstract

In this study, 48 HRC hardness AISI 4140 is turned on in different cutting parameters and cooling environment. The Taguchi L_9 test design was developed based on the three-level cutting speed (*V*), feed rate (*f*), depth of cut (*a*) and cooling environment parameters. According to the L_9 experimental design, the mean surface roughness (Ra) values were measured. Chip form occurring during turning is photographed. The S/N (Signal/Noise) ratios of the Taguchi experiment design in the Minitab program have been determined. According to the experimental results, the most significant effect on the Ra from the four factors was found in the hand made by the depth of cut. In ANOVA, it was respectively determined that depth of cut, cutting speed, feed rate and cooling environment affected 95% confidence in Ra value. It has been found that the repeat experiments for the optimum parameters yielded about 90% accuracy compared to the Taguchi estimate.

Keywords: AISI 4140, turning, surface roughness, chip formation, optimization

1. INTRODUCTION

Recently, improvements in the resulting cutting insert and machine tools has enabled the material to be processed to form hardened. The production of the material in the hardened state provides the following advantages; reduction in processing time, reduction in the number of machine tools required, reduction in processing costs, better surface quality, reduction in finish operations, removal of degradation caused by heat treatment, production of complex parts, etc. [1,2]

The goal in machining is to bring a workpiece to the desired geometry and to provide the desired surface qualities in the workpiece [3]. To create this geometry, the production engineer must determine factors such as the appropriate material, tool, cooling environment, cutting parameters, and looms. An important part of machining is turning. The turning operation is a cylindrical shaping operation designed to take up a piece of material through a rotating material. Today, there are different studies about turning [4,5]. Surface roughness, tool wear, vibration, acoustic emission, force values resulting from turning are the main issues of today's articles [6-9]. These values are studied experimentally, simulated and statistically [10,11].

Taguchi optimization method, presently the most commonly preferred method optimization. Taguchi method; with a low-cost development cycle, aims to improve product performance in system and process design. This method is an experimental and analytical approach that determines the most efficient parameters on total performance. The Taguchi method provides a design that covers the whole process with a few experiments [12-15]. This saves time and money.

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One of the important parameters in machining is surface quality [16]. Surface roughness is considerably influential on piston-cylinder mechanisms, bearings, gears et al. [17]. Surface texture is used as an effective factor in machining. Surface roughness or texture is the most commonly used quality indicator [18]. Experimental, statistical, artificial intelligence methods and surface topography of surface roughness have been studied in many studies [19,20]. The factors affecting the surface roughness are cutting speed, feed rate, depth of cut, cooling medium, material hardness, material type, tool tip, ambient temperature, humidity etc. [21]. The common aim of these studies is to obtain the optimum surface roughness and determine the best parameters for the factors affecting surface roughness. The two most important parameters affecting the roughness of the surface are the feed rate and insert geometry [22-24].

In this study, the Ra values of the AISI 4140 steel were measured and the chip formation were photographed. Taguchi L_9 orthogonal array is used as experimental design. Obtained surface roughness values were determined by Taguchi analysis. Estimated by the constructed Taguchi model and experimentally investigated for accuracy.

2. EXPERIMENTAL DESIGN

In this study AISI 4140 workpiece material was used. AISI4140 is steel which used to crankshaft, crank arms, axle shaft and sleeve, automobile and aircraft construction, gear and wheel making, on construction and agricultural machinery, on machine tools, such as bolts, nuts and studs, high strength steel suitable for surface hardening. The residue on the surface of the test material was cleaned before the heat treatment was applied. The material was heated at 700 °C for one hour and then cooled to air and normalization was applied. It was then heated to 830 °C and cooled in oil for one hour. BMS Digirock RSR hardness tester was measured at an average of 48 HRc.

For the experiments, the steel material was cut at Ø80x180 mm. Dimension differences and surface layer on the surface of the material after heat treatment have been removed on the lath.

Experiments were carried out on the ACE Micromatic Designers LT-20C lathe counter at the Amasya University Machine Laboratory. In the experiments Sandvik DDJNR 2525M 15 tool holder, Sandvik DNMG 15 06 08-PM 4325 insert was used. The processing distance is 100 mm. Figure 1 shows the lathe, tool holder and insert used in the experiments.

Figure 1. Test sample in the lathe, inserts and tool holder

Three different cutting parameters (*V*-*f*-*a*) and cooling environment were determined. The cutting parameters was determined according to the manufacturers catalog. The cooling environment is also defined as three parameters: dry, liquid and air. These cut-off parameters and the cooling environment are given in Table 1. In the 32 °C temperature of the dry cutting environment, the liquid environment was cooled by the counter's own coolant pump with 50 lpm of spray amount and with boron oil mixed water and for the air environment compressed air is used at a pressure of 15 bar with a 200 liter capacity air compressor.

Table 1. Cutting parameters

Parameters	Units	Level 1	Level 2	Level 3
V	m/min.	300	345	390
f	mm/rev.	0,15	0,30	0,45
a	mm	1	3	5
Cooling enviroment	-	Dry	Air	Liquid

Taguchi L_9 orthogonal array was created by Minitab statistical program. Taguchi is profitable in terms of cost and time. Ra values were measured with Mitutoyo SJ-210 surface roughness tester.

The experiments were performed as seven replicates. Ra values were averaged. Since the blade used in this study has four corners, the cutting edge is used differently in each process. Table 2 shows the experimental list generated by the L_9 test design and the average Ra values obtained.

3. RESULTS

3.1. Evaluating Results with Taguchi

Optimum cutting conditions for Ra were determined by choosing the smaller-the-better S/N ratio in the Taguchi optimization method. S / N ratios, level values calculated. The obtained S / N ratios are given in Table 2.

Table 2. Ra values and S/N ratios.

Case no	*V* (m/min)	*f* (mm/rev)	*a* (mm)	Cooling enviroment	Ra (µm)	S/N
1	300	0,15	1	Dry	0,74	2,6154
2	300	0,30	3	Air	3,25	-10,2377
3	300	0,45	5	Liquid	5,74	-15,1782
4	345	0,15	3	Liquid	4,92	-13,8393
5	345	0,30	5	Dry	4,38	-12,8295
6	345	0,45	1	Air	4,49	-13,0449
7	390	0,15	5	Air	5,67	-15,0717
8	390	0,30	1	Liquid	3,53	-10,9555
9	390	0,45	3	Dry	7,27	-17,2307

The most important criterion used in the Taguchi method is the S / N ratio. The optimum cutting conditions were determined according to the point where the S / N ratio was the maximum. According to this method, in Table 2, in the orthogonal array L_9, the optimum cutting parameters were obtained as Ra of 2,6154 S/N for Ra.

The optimum surface roughness value will be reached in first level for *V*, first level for *f*, first level for *a* and first level for cutting environment. The level values given in Table 3 of Figure 2 are given graphically. After this, the optimum cutting conditions of the experiments to be carried out under the same conditions can be determined and interpreted according to the level values of the cutting speed, feed rate, depth of cut and cooling enviroment factors specified in Table 3 and Figure 2.

In this case, the first level of the *V* factor, the first level of the *f* factor, the first level of the *a* factor and the first level of the cooling environment are shown in Figure 2 and Table 3. Therefore, the optimum cutting conditions determined under the same conditions for the experiments to be performed will be 300 m/min for *V*, 0,15 mm/rev for *f*, 1 mm of *a* and dry cooling environment. In Table 3, the order of effect of the cutting parameters on the surface roughness is obtained as *a*, *V*, *f* and cooling environment.

Table 3. The order of importance of the parameters for Ra

Level	*V*	*f*	*a*	Cooling enviroment
1	-7,6	-8,765	-7,128	-9,148
2	-13,238	-11,341	-13,769	-12,785
3	-14,419	-15,151	-14,36	-13,324
Delta	6,819	6,386	7,231	4,176
Rank	2	3	1	4

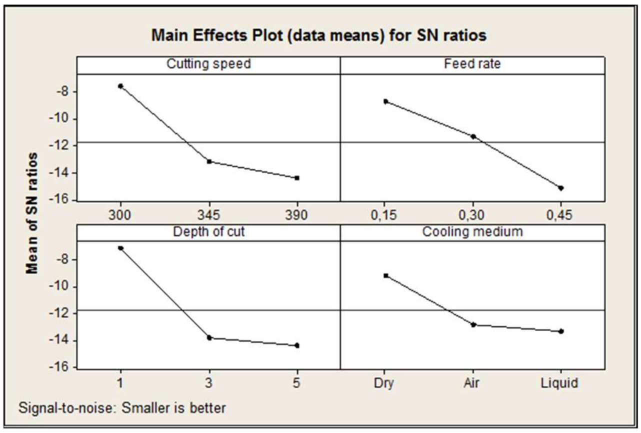

Figure 2. Data means for S/N ratios

While the optimum cutting conditions were determined from the S/N ratio obtained by Taguchi method, the relationship between the cutting parameters and the variance analysis was determined. The relationship between S/N-*V*, *f*, *a* and cooling environment is evaluated. The S/N ANOVA analysis results are shown in Table 4-8. According to the results of ANOVA, p

<0.01 or p <0,05 should be at significance level. According to these results, the most meaningful value is depth of cut. *a*, *V* and *f* were effective at 95% confidence level.

Table 4. The interaction S/N – V for Ra

Source	DF	SS	MS	F	P
V	2	7,68	3,84	1,17	0,0318
Error	6	19,71	3,28		
Total	8	27,38			

Table 5. The interaction S/N – f for Ra

Source	DF	SS	MS	F	P
f	2	8,7	4,35	1,4	0,0373
Error	6	18,68	3,11		
Total	8	27,38			

Table 6. The interaction S/N – a for Ra

Source	DF	SS	MS	F	P
a	2	10,46	5,23	1,86	0,0236
Error	6	16,92	2,82		
Total	8	27,38			

Table 7. The interaction S/N – cooling medium for Ra

Source	DF	SS	MS	F	P
Cooling enviroment	2	0,54	0,27	0,06	0,0942
Error	6	26,84	4,47		
Total	8	27,38			

Taguchi aims to reduce the number of experimental design experiments and to arrive at the correct result in a short time. The prediction experiments conducted in this study were conducted to prove the closeness of the Taguchi estimate, which was not considered time and cost. At the end of the Taguchi analysis, estimates for the levels given in Table 8 were performed. In Table 8 show that Taguchi's estimate, test result and the absolute error between these results is given as a percentage. In the light of these results, Taguchi realized the prediction with about 90% accuracy of the experimental results.

Table 8. Estimate and experimental test results so absolute error

V	*f*	*a*	Cooling enviroment	Experiment Ra	Taguchi Ra	Absolute difference	Absolute error %
300	0,15	5	Dry	2,814	3,083	0,269	9,559
345	0,3	3	Air	4,198	4,603	0,405	9,647
390	0,45	1	Liquid	6,195	5,643	0,552	8,910

3.2. Turning Result Occurring Chip Structures

In Fig. 3, sawdust structures are shown in the experiments. According to the test design, the chip forms obtained in the processes are evaluated according to ISO 3685. Table 10 gives the names of the chip structures that have been formed. According to the results obtained by Debnath et al. (2016), tool wear and chip structure are directly related to each other. They found that cutting speed (43,1%), depth of cut (35,8%), cooling medium (13,7%) and advance (7,2%) effect on tool wear were obtained. As the depth of cut increases, Arc chips-loose chips form. In the processes performed in liquid air and air-cooled environment, fracture occurs in the chip formation due to pressure effect.

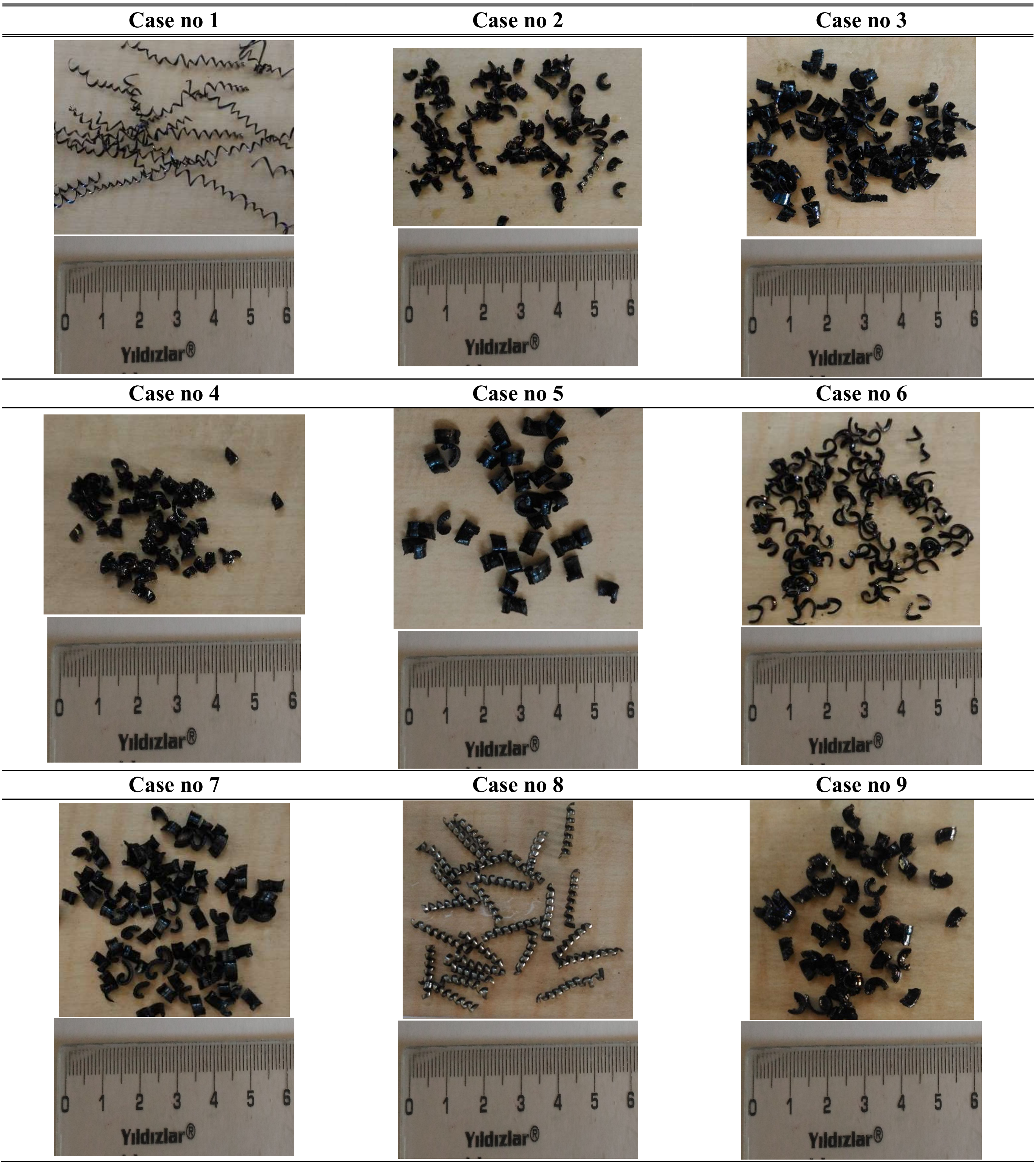

Figure 3. Photographs of chip formation from experiments

Table 9. Chip formation according to ISO 3685

Case number	*V* (m/min.)	*f* (mm/rev.)	*a* (mm)	Cooling enviroment	ISO 3685 chip formation
1	300	0,15	1	Dry	Tubular chips-Long
2	300	0,30	3	Air	Arc chips-Loose
3	300	0,45	5	Liquid	Arc chips-Loose
4	345	0,15	3	Liquid	Arc chips-Loose
5	345	0,30	5	Dry	Arc chips-Loose
6	345	0,45	1	Air	Arc chips-Connected
7	390	0,15	5	Air	Tubular chips-Short
8	390	0,30	1	Liquid	Arc chips-Loose
9	390	0,45	3	Dry	Arc chips-Loose

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, the turning operation was performed using the Taguchi experiment design to determine the optimum cutting parameters for Ra values.

L_9 orthogonal array was obtained by using Taguchi method in MINITAB statistical packet program for three levels of *V*, *f*, *a* and cooling medium as independent variables. In this case, 9 experiments were performed instead of 81 experiments with full factorial design. Experiments performed on the orthogonal array L_9 yielded the S/N of the final Ra. Using the smaller-the-better equation, the maximum value of S/N was searched. Optimum cutting parameters are obtained with maximum S/N ratio. The lowest surface roughness value in the turning operation was obtained at a *V* of 300 m / min., *f* of 0,15 mm/rev., *a* 1 mm and a dry cutting environment corresponding to the 2,6154 S/N.

By applying ANOVA to the S/N ratios, the relationship levels of the cutting parameters over the Ra were obtained. According to the ANOVA analysis, it was concluded that the determined factors (*V*-*f*-*a*-cooling medium) had a 95% confidence level. The most effective parameter from the cutting conditions was the depth of the cut.

Taguchi estimation and the experimental result shows that the design with Taguchi is about 90% accurate.

In future studies, different materials, different tips, different processing methods, different cooling liquids, different hardness values can be used in experiments. Wear, force, vibration, acoustic emission can be measured. Different statistical methods and models can be used.

5. REFERENCES

[1] Z. Hessainia, A. Belbah, M.A. Yallese, T. Mabrouki, J. F. Rigal, “On the prediction of surface roughness in the hard turning based on cutting parameters and tool vibrations”, *Measurement*, 46(5), 1671-1681, 2013

[2] M. Mia, N.R. Dhar, “Prediction of surface roughness in hard turning under high pressure coolant using artificial neural network”, *Measurement,* 92, 464-474, 2016

[3] Y. Yamane, T. Ryutaro, S. Tadanori, I.M. Ramirez, Y. Keiji, “A new quantitative evaluation for characteristic of surface roughness in turning”, *Precision Engineering,* 50, 20-26, 2017

[4] G.S. Ahmed, S.S. H. Quadri, M. S. Mohiuddin, “Optimization of feed and radial force in turning process by using Taguchi design approach”, *Materials Today: Proceedings,* 2(4-5), 3277-328, 2015

[5] D. Deepak, B. Rajendra, “Optimization of Machining Parameters for Turning of Al6061 using Robust Design Principle to minimize the surface roughness”, *Procedia Technology*, 24, 372-378, 2016

[6] D.M. D’Addona, S.J. Raykar, “Analysis of surface roughness in hard turning using wiper insert geometry”, *Procedia CIRP,* 41, 841-846, 2016

[7] E.G. Plaza, P.N. López, “Application of the wavelet packet transform to vibration signals for surface roughness monitoring in CNC turning operations”, *Mechanical Systems and Signal Processing,* 98, 902-919, 2018

[8] X. Yue, M. Xu, W. Du, C. Chu, “Effect of cutting edge radius on surface roughness in

diamond tool turning of transparent $MgAl_2O_4$ spinel ceramic", *Optical Materials,* 71, 129-135, 2017

[9] S. Debnath, M.M. Reddy, Q.S. Yi, "Influence of cutting fluid conditions and cutting parameters on surface roughness and tool wear in turning process using Taguchi method", *Measurement,* 78, 111-119, 2016

[10] S. Ramesh, L. Karunamoorthy, K. Palanikumar, "Measurement and analysis of surface roughness in turning of aerospace titanium alloy (gr5)", *Measurement,* 45(5), 1266-1276, 2012

[11] P. Zhang, Z. Liu, "Modeling and prediction for 3D surface topography in finish turning with conventional and wiper inserts", *Measurement,* 94, 37-45, 2016

[12] İ. Asiltürk, H. Akkuş, "Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method", *Measurement*, 44(9), 1697-1704, 2011

[13] Agrawal, S. Goel, W.B. Rashid, M. Price, "Prediction of surface roughness during hard turning of AISI 4340 steel (69 HRc), *Applied Soft Computing*, 30, 279-286, 2015

[14] M. Nalbant, H. Gökkaya, G. Sur, "Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning", *Materials & Design*, 28 (4), 1379-1385, 2007

[15] İ. Tekaüt, M. Günay, U. Şeker, "Optimization of cutting parameters and chip breaker form by Taguchi method in turning operations", *6th International Advanced Technologies Symposium,* 127-131, 2011

[16] Torres, I. Puertas, C.J. Luis, "Surface roughness analysis on the dry turning of an Al-Cu alloy", *Procedia engineering,* 132, 537-544, 2015

[17] T. Asakura, "Surface roughness measurement", *Speckle metrology,* 11-49, 1978

[18] M. Tomov, M. Kuzinovski, P. Cichosz, "Modeling and prediction of surface roughness profile in longitudinal turning", *Journal of Manufacturing Processes,* 24, 231-255, 2016

[19] J. Chen, Q. Zhao, "A model for predicting surface roughness in single-point diamond turning", *Measurement*, 69, 20-30, 2015

[20] T. Mikołajczyk, K. Nowicki, A. Bustillo, D.Y. Pimenov, "Predicting tool life in turning operations using neural networks and image processing", *Mechanical Systems and Signal Processing,* 104, 503-513, 2018

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

[22] J.C. Pereira, R.G. Ruiz, "Influencia de los parámetros de corte y geometría de la herramienta en la rugosidad superficial obtenida en operaciones de torneado del bronce SAE 40", *Revista Ingeniería,* 14(3), 77-85, 2007

[23] S. Chandraker, "Taguchi analysis on cutting force and surface roughness in turning MDN350 steel", *Materials Today: Proceedings*, 2(4-5), 3388-3393, 2015

[24] C.L. He, W.J. Zong, Z.M. Cao, T. Sun, "Theoretical and empirical coupled modeling on the surface roughness in diamond turning" *Materials & Design*, 82, 216-222, 2015