International Journal of Analytical, Experimental and Finite Element Analysis (IJAEFEA), Issue. 3, Vol. 5, Oct 2018
e-ISSN: 2394-5141, p-ISSN: 2394-5133, pp 44 - 49
DOI: 10.26706/IJAEFEA.3.5.20180901

Optimization of Cutting Parameters in Finishing Milling of Hardox 400 Steel

Fuat KARA
fuatkara@duzce.edu.tr

Düzce University, Technology Faculty, Department of Mechanical and Manufacturing Engineering, 81620, Düzce, Turkey

***Abstract*—In this study, it was performed to optimization of cutting parameters in finishing milling of Hardox 400 steel with PVD TiAlN+TiN coated carbide inserts. Milling experiments were made according to Taguchi L_{16} orthogonal array. The evaluation of the experimental results was based on the signal/noise (S/N) ratio. Control factors that given optimum surface roughness values were determined by using the Taguchi method. Two different cutting speeds (60 and 120 m/min) and cooling method (dry and wet) as control factors was selected. In addition, depth of cut and feed rate were taken as 0.3 mm and 0.1 mm/rev, respectively. The effect levels on the surface roughness of the control factors with analysis of variance (ANOVA) performed using the experimental results were determined. The Taguchi analysis found the optimum results for surface roughness to be with the cutting speed of 120 m/min and cooling method of wet.**

***Index Terms*—**Finishing milling, Hardox 400, Taguchi method, surface roughness

I. Introduction

The variety of products is increasing day by day because people are always looking for better. In addition to this, it derives new intermediate products with evolving technology in all areas. This is an example of Hardox steel group. These steels are basically named with numbers that indicate hardness grades in the market for hardening to the foreground. Hardox steel has 7 different types such as HITUF, 400, 450, 500, 500TUF, 550 and 600 [1]. Hardox 400 is resistant to abrasion with 400 brinell hardness and at the same time has high cold formability. The weldability is also high thanks to the low carbon equivalent. In our daily life, we very often see vehicles made using Hardox 400 such as garbage trucks and dump trucks. Besides, it is used in parts where the wear is excessive such as crushers, industrial trucks, excavator - loaders, trucks, presses, etc. The hard-to-wear and non-heavy Hardox 400 is used as a protective front on the inside surfaces of the truck dumpers, which seriously increases the life of the truck dumpers. Because it is not too heavy, the truck dumper can be easily primed when it can be formed.

The outer surfaces and bottoms of the transport containers that pack and protect long journeys and too many items are also covered with Hardox 400, which is protected against trailing impacts. This significantly reduces the cost of international shipping. It is also the Hardox 400 steel that provides protection against the impact of underground mining equipment on road construction vehicles, stone mines. As a result, the Hardox 400 steel is used in every area of life to make life easier, more protective and durable. As a result, the Hardox 400 steel is used in everyday life to make life easier, protect and durable [1, 2].

In the present study, the effects of the factors of cutting speed and cooling method on surface roughness were statistically evaluated in the finishing milling of Hardox 400 steel. For this purpose, the experiments were designed according to the Taguchi L_{16} orthogonal array, and optimal milling parameter values giving the lowest surface roughness were determined. The effects of the control factors on surface roughness (Ra) were determined by ANOVA.

II. MATERIAL AND METHODS

A. Test Specimen and Experimental Setup

This study aimed to determine the optimum milling conditions by investigating the effects of the cutting parameters on the surface roughness in finishing milling of Hardox 400 (40 HRc) steel. The steel used in the tests was manufactured in workpiece dimensions of 180×150×15 mm, and its chemical composition is given in Table 1.

TABLE I

CHEMICAL COMPOSITION OF HARDOX 400 STEEL (MAX %)

C	Si	Mn	P	S	Cr	Ni	Mo	B
0.32	0.70	1.60	0.025	0.010	1.40	1.50	0.60	0.004

The CNC milling machine used in the experiments is DELTA SEIKI CNC 1050 A model with a 15 KW drive motor. In milling experiments, carbide inserts with PVD-TiAlN+TiN coated with TT9080 coded obtained from TaeguTec were used. Measuring and evaluating surface roughness is very important in machinability studies. For the surface roughness measurements of the machined surfaces, the Taylor Hobson Surtronic 25 surface roughness tester was used. The surface roughness (Ra) value was calculated as the average of three measurements taken from the machined surfaces.

B. Taguchi Experimental Design

In experimental studies, it is necessary to design the experiment correctly in order to reach the right result. Consequently, the Taguchi method was used for experimental design and analysis. In this approach developed by Genichi Taguchi, a statistical performance measure known as the signal/noise (S/N) ratio is used to analyze the results. The results obtained from the experiments are evaluated by converting the S/N ratio, in which S is the signal factor (the actual value from the system) and N is the noise factor (a factor not included in the experimental design, but which influences the experimental result). Noise sources are all variables that cause the desired performance characteristics to deviate from the target value. In the calculation of S/N ratios, the "nominal is best" (depending on the characteristic type), the "largest is best" and the "smallest is best" methods are used [3,4]. For the determination of the S/N values in this study, the formula corresponding to the "smallest is best" principle given in Equation 1 was used since the lowest Ra value is desirable in terms of machining efficiency.

$$\frac{S}{N} = -10log\left(\frac{1}{n}\sum_{i=1}^{n} {y_i}^2\right) \quad (1)$$

Here, y_i are the measured surface roughness values, and n is the number of tests performed. The machining parameters chosen were cutting speed (V) and cooling method (Cm). The control factors and levels used in the finishing milling of Hardox 400 steel are given in Table 2. The L_{16} orthogonal array shown in Table 3 was used for conducting the experiments. By applying ANOVA at a 95% CI on the experimental results, the effect levels of the variables on Ra were determined. The experimental design and statistical analysis according to the Taguchi method were performed using Minitab 16 software.

TABLE II

CONTROL FACTORS AND LEVELS

Symbol	Control factors	Level 1	Level 2
A	Cutting speed - V (m/min)	60	120
B	Cooling method - Cm	1 (Dry)	2 (Wet)

TABLE III

TAGUCHI L_{16} DESIGN WITH ORTHOGONAL ARRAY

Experiment number	Factor A	Factor B	Experiment number	Factor A	Factor B
1	1	1	9	2	1
2	1	1	10	2	1
3	1	1	11	2	1
4	1	1	12	2	1
5	1	2	13	2	2
6	1	2	14	2	2
7	1	2	15	2	2
8	1	2	16	2	2

III. Discussion And Results

A. Experimental Results

The variation in surface roughness depended on the milling parameters were given in Figure 1. The measured Ra values range from 0.29 to 0.72 microns. These values correspond to finishing milling. When the changes in Ra due to cutting speed were examined, the tendency of the Ra values to decrease with increasing cutting speed was observed in all parameters. Increases in cutting speed reduce the tool-to-chip contact area, thereby reducing friction, which allows better surface quality to be achieved. The Figure reveals that the surface roughness decreases when the coolant is used. This is attributed to the lubrication and cooling properties of the cutting fluid. Most of the cutting tool wears result from high temperatures that occur in the cutting zone. Since these temperatures are minimized by the cutting fluid, surface roughness is improved by reducing tool wear [5, 6].

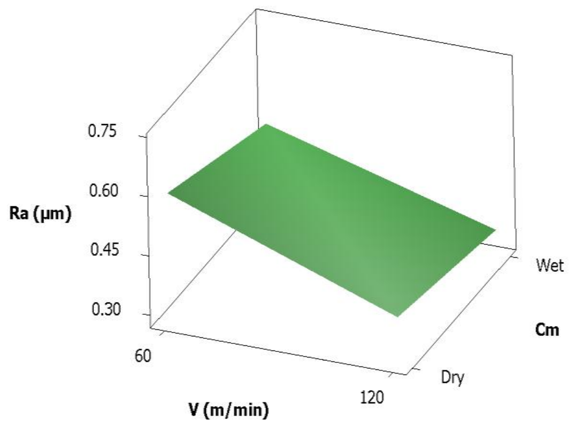

Figure 1.Effects of cutting parameters on the surface roughness.

B. Optimization of Surface Roughness

The S/N ratios calculated on the basis of the Ra values obtained as a result of the finishing milling tests performed on the Hardox 400 steel according to the Taguchi L_{16} test design are given in Table 4.

TABLE IV
EXPERIMENTAL DESIGN, RA AND S/N RATIOS

Exp. no	(A) Cutting speed (m/min)	(B) Cooling method	Surface roughness Ra (µm)	Ra - S/N ratio (dB)	Exp. no	(A) Cutting speed (m/min)	(B) Cooling method	Surface roughness Ra (µm)	Ra - S/N ratio (dB)
1	60	Dry	0.5067	4.346	9	120	Dry	0.3667	8.1708
2	60	Dry	0.5000		10	120	Dry	0.3933	
3	60	Dry	0.6600		11	120	Dry	0.3867	
4	60	Dry	0.7267		12	120	Dry	0.4133	
5	60	Wet	0.4867	6.1507	13	120	Wet	0.3200	9.6512
6	60	Wet	0.4600		14	120	Wet	0.3467	
7	60	Wet	0.5400		15	120	Wet	0.3533	
8	60	Wet	0.4800		16	120	Wet	0.2933	

The S/N responses generated by the Taguchi method were used to determine the most effective of the control factors on the optimum levels and surface roughness. The highest S/N values in this table show the optimum level of each control factor. The S/N responses showing the effect of each control factor on surface roughness are given in Table 5.

TABLE V
S/N RESPONSE TABLES

Levels	Control factors	
	A Cutting speed (m/min)	B Cooling method (Dry-Wet)
Level 1	5.248	6.258
Level 2	**8.911**	**7.901**
Delta	3.663	1.643
Range	1	2

When Table 5 is examined, it can be seen that the most effective factors on the surface roughness were the cutting speed and cooling method, respectively. These results were confirmed by ANOVA. Moreover, the optimum surface roughness for the milling of the Hardox 400 steel was obtained at the second level (A2) of the cutting speed and at the second level (B2) of the cooling method.

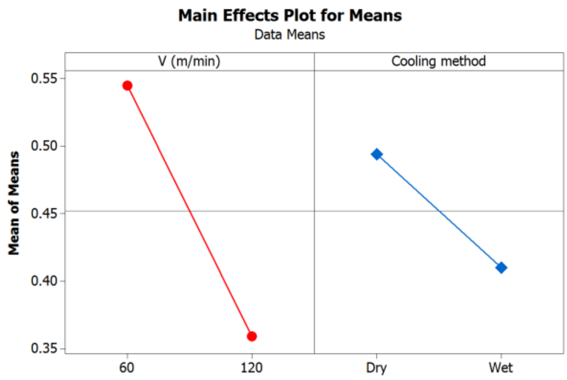

Figure 2.Main effects plot for means.

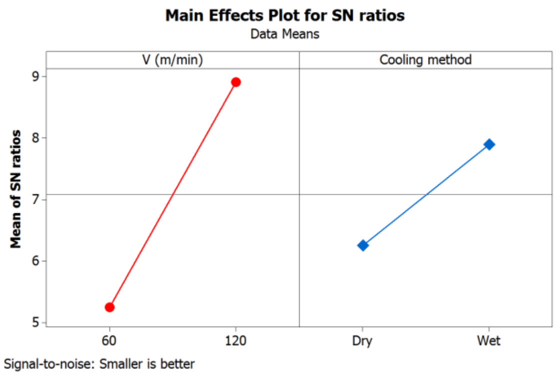

Figure 3. Main effects plot for S/N ratios.

The main effect graphs showing the optimum values of the control factors, i.e., the machining parameters, are given in Figure 2 and Figure 3. The lowest values in Figure 2 show the parameters giving the optimum surface roughness. As in the S/N response table, the highest S/N values in the main effect graph for S/N ratios show the optimum level for that parameter. Thus, the optimum values for the surface roughness determined for the cutting speed and cooling method were 120 m/min and wet milling, respectively.

C. Analysis of Variance

A variance analysis was performed to determine how all the control factors used in the experimental design influenced each other, what effect this had on the performance characteristics, and what kind of changes occurred in the performance characteristics at the different levels of the parameters [7-9]. The ANOVA results for the effect levels of the control factors on surface roughness are given in Table 6. Here, the F values and the percentage contribution ratio (PCR) showing the significance level of each variable can be seen. This analysis was performed at a 95% CI and 5% significance level. The effect of the control factors was determined by comparing the F values. The F factor is the biggest factor and has the most influence on the result.

TABLE VI.
ANOVA TABLE

Source	Degree of freedom (DF)	Sum of squares (SS)	Mean square (MS)	F	P	PCR (%)
Cutting speed (m/min)	1	0.138161	0.138161	38.02	0.000	64.64
Cooling method	1	0.028342	0.028342	7.80	0.015	13.26
Error	13	0.047237	0.003634			22.10
Total	15	0.213739				100

According to the ANOVA results, the most important parameter affecting the surface roughness was found to be the cutting speed (64.64%). The cooling method was effective on Ra at low levels (13.26%). The results of the S/N responses in Table 5 and the results of the main effect graphs in Figures 1 and Figure 2 were verified by ANOVA.

D. Confirmation Tests

Using the Taguchi optimization method, the optimal results of the surface roughness values were obtained in the experimental study and ANOVA analyses were performed to determine the percentage distributions of the parameters effective on the result. The final step of the optimization process was to perform confirmation experiments to test the validity of the optimization process. Equation 2 and 3 were used to calculate surface roughness values at the optimum milling conditions determined by the Taguchi method [10-12]. As a result of the calculations using these equations, under optimum conditions, surface roughness value was found to be 0.326 µm.

$$\eta_G = \bar{\eta}_G + (\bar{A}_2 - \bar{\eta}_G) + (\bar{B}_2 - \bar{\eta}_G) \quad (2)$$

$$Ra_{cal} = 10^{-\eta_G / 20} \quad (3)$$

Where η_G, is the S/N ratio calculated for the optimum levels, $\bar{\eta}_G$ is the average of the S/N ratios of all variables, $\bar{A}_{2,}$ is the optimal level of S/N ratio of the A factor, $\bar{B}_2$ is the optimum level of the S/N ratio of the B factor and Ra_{cal} is the calculated surface roughness for the optimum levels.

For Equation 4, $F_{\alpha,1,fe}$ is the F ratio at 95% CI, a is the level of significance, f_e is the degrees of freedom of error, V_e is error variance, n_{eff} is the effective number of replications, and R is the number of replications for the confirmation experiments. For Equation 5, N is the total number of experiments, and T_{dof} is the total main factor degrees of freedom.

$$CI_{Ra} = \sqrt{F_{\alpha,1,f_e}.V_e\left[\frac{1}{n_{eff}}+\frac{1}{R}\right]} \quad (4)$$

$$n_{eff} = \frac{N}{1+T_{dof}} \quad (5)$$

$F_{0.05,1,13}$ = 4.6672 (from F test table), V_e = 0.003634 (Table 6), R = 3 (Eq. (4)).
N = 3, T_{dof} = 2 and n_{eff} = 3 (Eq. (5)).

By using Equations (4) and (5) the CI was calculated as CI_{Ra} = ± 0.103. The average optimal Ra (CI 95%) was:

$(Ra_{opt} - CI_{Ra}) < Ra_{exp} < (Ra_{opt} + CI_{Ra})$ = (0.326 – 0.103) < 0.328< (0.326 + 0.103)

= 0.223< 0.328< 0.429

The experimental values of Ra_{exp} fell within acceptable CI limits. Consequently, the system for Ra was successfully optimized via the Taguchi method (p = 0.05). The results obtained from the confirmation experiments reflect the success of the optimization performed. Confirmation tests for the control factors were made via the Taguchi method at optimum and random levels. Table 7 shows the comparison of test results with the predicted values obtained using the Taguchi method. The predicted values and the experimental values were very close to each other. When the roughness values in Table 7 are compared, it is noticeable that the difference between the confirmation test results and the results obtained from the Taguchi approach is at an insignificant level. Therefore, the results obtained from the confirmation tests reflect successful optimization.

TABLE VII.
PREDICTED AND CONFIRMATION TEST RESULTS

Levels	Ra (µm)		
	Exp.	Pred.	Error (%)
A_2B_2 (Opt.)	0.328	0.326	0.61
A_1B_1 (Random)	0.598	0.600	0.33

IV. CONCLUSIONS

In this study, a series of milling experiments were performed to finishing milling Hardox 400 steel of 400 HRc hardness with PVD coated carbide cutting inserts at different cutting parameters. Experiments were designed according to the orthogonal array of Taguchi L_{16}. The effects of the milling parameters on the surface roughness were determined by analysis of variance. The validity of the optimization has been tested with the confirmation experiments. The results obtained are listed as follows.

- The obtained Ra values indicated that the machining was finishing milling.
- The optimal conditions were obtained by taking the highest values of the average S/N ratios, thus determining the best result for surface roughness to be the second level of cutting speed (120 m/min) and the second level of cooling method (wet).
- According to the statistical analyses results, the most effective parameter on the Ra was the cutting speed (64.64%) and then the cooling method (13.26%).
- The results of the confirmation test showed the measured Ra values to fall within the confidence interval (CI) of 95%.
- After calculation and the confirmation experiments, Ra values under optimum milling conditions were found to be 0.326 µm and 0.328 µm respectively.

The optimization results proved that the Taguchi experimental design process had been featly applied to specify the optimum surface roughness of the Hardox 400 steel in the finishing milling.

REFERENCES

[1] J. Majerik and J. Jambor,“Hard milling and hard drilling experiment of abrasion resistant steel Hardox 500 at dependence of T = f (vc, fz),”*Univ Rev.*,vol. 8(3-4), pp. 2-8, 2014.

[2] J.Majerik and I. Barenyi, ‘Experimental investigation into tool wear of cemented carbide cutting inserts when machining wear resistant steel Hardox 500,”*Eng Rev.*,vol. 36(2),pp. 167-174, 2016.

[3] G. Taguchi, S. Chowdhury and Y. Wu, ‘Taguchi's Quality Engineering Handbook’John Wiley & Sons Inc.: New Jersey, USA, ISBN: 978-0-471-41334-9, 2005.

[4] M. Karabatak and F. Kara, “Experimental optimization of surface roughness in hard turning of AISI D2 cold work tool steel,”*J Polytech.*,vol. 19(3), pp. 349-355, 2016.

[5] N. AltanÖzbek,“The Investigation of the Effects of Cryogenic Treatment Applied to Cutting Tools on Tool Life in Machining AISI 316 Austenitic Stainless Steel,” Ph.D. Thesis, Gazi University Institute of Sciences, 2013.

[6] F. Kara, “Optimization of surface roughness in finish milling of AISI P20+ S plastic-mold steel,” *Mater Technol.*, vol. 52(2), pp. 195–200, 2018.

[7] F. Kara, “Taguchi optimization of surface roughness and flank wear during the turning of DIN 1.2344 tool steel,”*Mater Test.*,vol. 59(10), pp. 903-908, 2017.

[8] E. Nas and B. Öztürk, “Optimization of surface roughness via the Taguchi method and investigation of energy consumption when milling spheroidal graphite cast iron materials,”*Mater Test.*,vol60(5), pp. 519-525. 2018.

[9] F. Kara and B. Öztürk, “Comparison and optimization of PVD and CVD method on surface roughness and flank wear in hard-machining of DIN 1.2738 mold steel,”*Sensor Rev.*,https://doi.org/10.1108/SR-12-2017-0266, in press, 2019.

[10] E. Yücel and M. Günay, “Modelling and optimization of the cutting conditions in hard turning of high-alloy white cast iron (Ni-Hard),”*Proc Inst MechEng Part C: J MechEng Sci.*,vol. 227(10), pp. 2280-2290, 2013.

[11] O.Özbek and N. AltanÖzbek, “Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning of hardened AISI 4140 steel,”*J AdvTechnol Sci.*,vol. 5(3), pp. 41-48, 2016.

[12] E. Yücel and H. Saruhan,“Design optimization of rotor-bearing system considering critical speed using Taguchi method,”*Proceedings of the Institution of Mechanical Engineers, Part E: J Process Mech Eng.*, vol. 231(2), pp. 138-146, 2017.