Journal of Trends in the Development of Machinery and Associated Technology
Vol. 21, No. 1, 2018, ISSN 2303-4009 (online), p.p. 5-8

TAGUCHI BASED SCREENING APPROACH IN THE MQL TURNING PROCESS OF X5CrNi 18-10 STAINLESS STEEL

Sabahudin Ekinović, Edin Begović
University of Zenica
Faculty of Mechanical Engineering
Fakultetska 1., 72000 Zenica
Bosnia and Herzegovina

Muhamed Mehmedović, Adnan Mustafić
University of Tuzla
Faculty of Mechanical Engineering
Univerzitetska 4., 75000 Tuzla
Bosnia and Herzegovina

ABSTRACT
This paper presents an investigation into the MQL turning process of X5CrNi18-10 stainless steel with the objective of screening and selecting the most important MQL parameters on machinability of austenitic stainless steel. Effects of selected MQL parameters such as flow rate of vegetable-based oil (10 and 50 ml/h) and tap water (300 and 1700 ml/h), nozzle direction relative to cutting tool (rake and flank face), spray distance (30 and 50 mm), number of applied nozzles (1 and 2) and cutting oil type in means of its physical properties (39 and 95 mm^2/s) were studied. In order to analyze the effect of MQL parameters on the quality characteristics of surface roughness and cutting forces, the cutting parameters including cutting speed, feed rate and depth of cut were kept constant for all experiments. A standard two level Taguchi orthogonal array L_{16} (2^6) was employed to select the most influential parameters. Results indicated that the most important parameters for simultaneous reducing of surface roughness and cutting forces were oil and water flow rate followed by the spray distance.
Keywords: MQL parameters, Screening design, Surface roughness and cutting forces.

1. INTRODUCTION
The process of near dry or minimum quantity lubrication (MQL) machining, due to increased demand for environmentally friendly manufacturing processes has seen a growing interest in the machining community [1,2]. A large number of formulation and processing variables influence the overall performance of MQL assisted machining. Thus, it becomes extremely difficult to study the effect of each parameter and interaction among them through the conventional approach. Therefore, one of the most important tasks in the MQL assisted machining process is to evaluate the most dominant parameters in order to obtain maximum efficiency in the manufacturing process. Since the nature of influence of such variables in the turning process is not widely known from prior literature reports, a Taguchi based screening design has been used to identify the potential parameters for further systematic DOE optimization studies.
Since the original Taguchi design is applied to optimize only single quality characteristic, several modifications are suggested to the original Taguchi technique for multi-performance characteristics optimization [3]. This paper illustrates the application of Taguchi technique and the utility concept for multiple characteristics [4], which uses weighting factors to each of the S/N ratio to obtain a multi-response S/N ratio for each trial of a selected orthogonal array.

2. EXPERIMENTAL SETUP
In this preliminary research study, a quenched and tempered X5CrNi18-10 austenitic stainless steel was used as the workpiece material. External turning tests were carried out on a bar of 70 mm diameter with separated 15 mm long segments for each cutting test. Before machining, the bar was pre-machined with a 0,5 mm depth of cut to remove any possible surface irregularities and ensure similar surface properties for all specimens. All turning tests were carried out at the Laboratory for Metal Cutting and Machine Tools (LORAM) at the Faculty of Mechanical Engineering in Zenica by

using a conventional lathe machine. The PCLNR 2020K-12 tool holder was chosen and used with IC 807 quality coated carbide insert (ISO code CNMG 120408-WG) produced by Iscar.

In order to minimize the influence of cutting tool wear on the investigated terms, each set of turning experiments was conducted using a new insert edge. Every machining test was carried out by the use of an advanced MQL system (JOOM J-T2X), which generates oil-on-water droplet aerosol with a constant pressure supply of 2 bars. Two types of vegetable-based cutting oils with different physical properties were atomized with tap water and transferred via standard MQL nozzles to the cutting zone. The cutting forces were measured using a Kistler 5070 dynamometer connected to an amplifier and a computer equipped with manufacturer's DynoWare software. Measurements of the surface roughness parameter Ra (arithmetic average deviation of the profile) were performed on a Mitutoyo Surftest SJ-301 profilometer at three different locations to minimize the deviation. The average values of Ra were considered for the analysis. Figure 1. shows the experimental setup for the turning experiments.

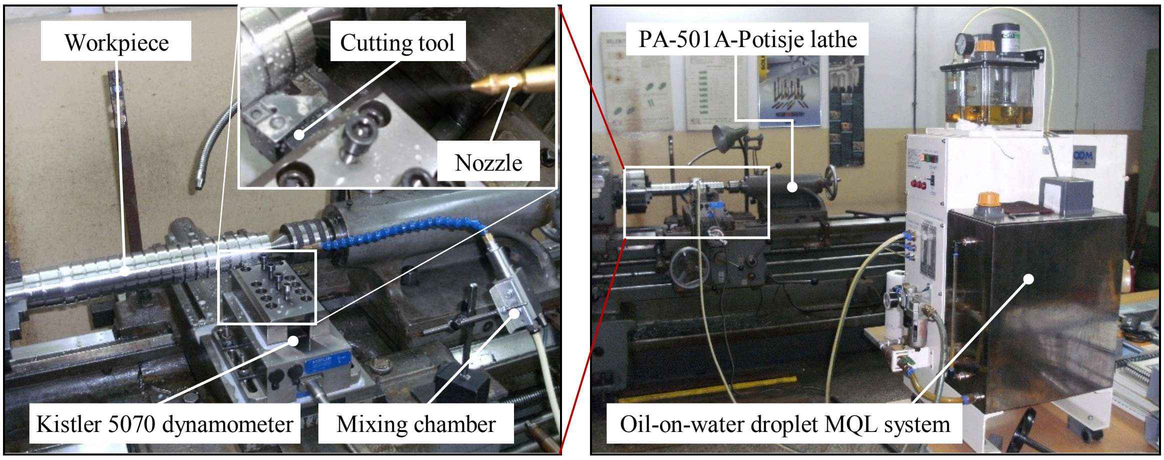

Figure 1. Experimental setup for turning tests

2.1. Design of Screening Experiment

In current study, screening of various MQL parameters, potentially influencing the machinability in means of cutting forces and surface roughness was performed employing the Taguchi method to achieve reliable results without increasing experimental costs. Flow rate of cutting oil and tap water, nozzle direction relative to cutting tool, spray distance, number of applied nozzles and cutting oil type were selected as control factors, and their levels are given in Table 1.

Table 1. Control parameters and their levels

Symbol	Parameters	Notation	Units	Level values	
				1	2
A	Oil flow rate	OFR	ml/h	10	50
B	Water flow rate	WFR	ml/h	300	1700
C	Spray distance	SD	mm	30	50
D	Oil viscosity	OV	mm^2/s	39	95
E	Nozzle number	NN	/	1	2
F	Nozzle direction	ND	/	Flank face **(F)**	Rake face **(R)**

The cutting speed 113 m/min, feed rate 0,195 mm/rev and depth of cut 1 mm were selected based on the recommendations of the cutting tool manufacturer for medium cutting conditions. These parameters were kept constant in all experiments in order to investigate only the effect of MQL parameters on the machinability of X5CrNi 18-10 stainless steel.

According to that, a standard two level Taguchi orthogonal array L_{16} (2^6) was employed to screen out the most dominant parameters. In the Taguchi method, the orthogonal array can provide an efficient means to perform the experiments with least number of trials [5]. Taguchi used the signal-to-noise (S/N) ratio as the quality characteristics of choice. There are three S/N ratio characteristic values: "smaller-is-better", "larger-is-better" and "nominal-is-better"

Since the aim of this study was to reduce the cutting force and surface roughness, the "smaller-is-better" characteristics were selected and calculated as follows:

$$S/N = -10 \cdot \log\left(\frac{1}{n} \cdot \sum_{i=1}^{n} Y_i^2\right) \tag{1}$$

where $\boldsymbol{Y_i}$ is the performance characteristics value, and $\boldsymbol{n}$ is the number of $\boldsymbol{Y_i}$ values. In the utility concept, the multi-response S/N ratio for each experimental trial in an orthogonal array according to [4] can be estimated as follows:

$$\eta = \omega_1 \cdot \eta_1 + \omega_2 \cdot \eta_2 \tag{2}$$

where ω_1 and ω_2 are the weighting factors associated with S/N ratio of each of the measured response variables. For the simultaneous minimization of resultant cutting force and surface roughness, weighting factor of 0,5 is considered, which gives equal priorities to both response variables.

3. RESULTS AND DISCUSSIONS

Experimental measured results of surface roughness and cutting forces, as well as the transformations into S/N ratios are given in Table 2.

Table 2. Taguchi orthogonal array L_{16} (2^6) with experimental results and calculated S/N ratios

Exp. No.	Levels of control factors						Experimental results					Calculated S/N ratios		
	A	B	C	D	E	F	Fx (N)	Fy (N)	Fz (N)	Fres (N)	Ra (µm)	S/N for Fres	S/N for Ra	S/N for MPC
1	1	1	1	1	1	1	317,3	252,0	584,5	711,21	1,77	-57,040	-4,992	-31,016
2	1	1	1	2	1	2	292,1	242,2	556,1	673,22	1,31	-56,563	-2,367	-29,465
3	1	1	2	1	2	1	300,2	246,3	560,1	681,53	1,49	-56,669	-3,483	-30,076
4	1	1	2	2	2	2	321,8	253,3	586,3	715,16	1,60	-57,088	-4,082	-30,585
5	1	2	1	1	2	2	312,0	242,6	587,2	707,81	1,29	-56,998	-2,256	-29,627
6	1	2	1	2	2	1	320,4	251,9	586,0	713,79	1,55	-57,071	-3,806	-30,438
7	1	2	2	1	1	2	333,8	256,3	599,5	732,47	1,63	-57,295	-4,243	-30,769
8	1	2	2	2	1	1	318,4	249,9	587,2	713,18	1,29	-57,064	-2,234	-29,649
9	2	1	1	1	2	2	321,4	255,3	594,4	722,34	5,50	-57,174	-14,812	-35,993
10	2	1	1	2	2	1	290,0	271,1	553,2	680,90	5,90	-56,661	-15,421	-36,041
11	2	1	2	1	1	2	314,8	253,7	575,1	702,99	5,21	-56,939	-14,342	-35,640
12	2	1	2	2	1	1	326,0	264,1	590,5	724,37	3,38	-57,199	-10,578	-33,888
13	2	2	1	1	1	1	306,0	255,2	567,1	693,08	6,21	-56,815	-15,866	-36,340
14	2	2	1	2	1	2	317,6	250,0	579,7	706,69	1,91	-56,984	-5,620	-31,302
15	2	2	2	1	2	1	294,7	244,4	563,9	681,58	1,32	-56,670	-2,455	-29,562
16	2	2	2	2	2	2	287,1	248,3	549,0	667,44	6,42	-56,488	-16,150	-36,319

According to the Taguchi methodology, the S/N response table was used for the analysis of the effects of control parameters on the total cutting force and surface roughness. The S/N response table is given in Table 3.

Table 3. S/N response table for resultant cutting force and surface roughness

Levels	Resultant cutting force (Fres)						Surface roughness (Ra)					
	A	B	C	D	E	F	A	B	C	D	E	F
Level 1	-56,97	-56,92	-56,91	-56,95	-56,99	-56,90	-3,433	-8,760	-8,143	-7,807	-7,531	-7,355
Level 2	-56,87	-59,92	-56,93	-56,89	-56,85	-56,94	-11,906	-6,579	-7,196	-7,533	-7,809	-7,985
Delta	0,11	0,01	0,01	0,06	0,13	0,04	8,473	2,181	0,947	0,274	0,278	0,630
Rank	**2**	6	5	**3**	**1**	4	**1**	**2**	**3**	6	5	4

In Table 3., the effects of investigated parameters are estimated based on the average S/N ratios of resultant cutting force and surface roughness. The delta value is calculated as the difference between maximum and minimum mean of S/N ratio, indicating that the number of used nozzles and oil flow rate, followed by the oil viscosity have the most dominant influence on the resultant cutting force. Contrarily, the water flow rate, spray distance and nozzle direction have the smallest delta values and thus have almost no influence on the measured response. On the other hand, the ranking of the tested MQL parameters according to the delta values and the degree of influence on the measured values of surface roughness can be written as: oil flow rate, water flow rate, spray distance, number of applied nozzles, nozzle direction and oil viscosity. Graphical interpretation of the measured results on the example of surface roughness given in Table 2. can be presented in means of main effects plot for all investigated MQL parameters according to Figure 2.

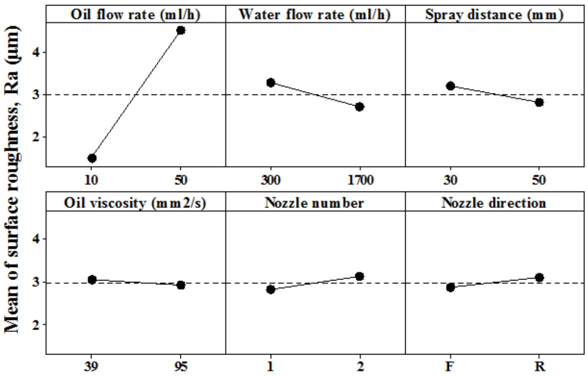

Figure 2. Main effects plot for Ra

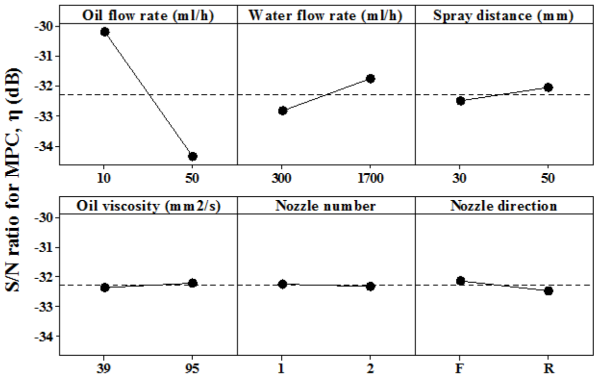

Figure 3. Main effects plot for MPC

The calculated values of the multi-response S/N ratio for each trial in the orthogonal array are presented in Table 2., as a single multiple performance characteristic (MPC). So, this calculated performance characteristic can be graphically presented as shown in Figure 3. This plot is very helpful in visualizing the magnitudes of simultaneous effects of the investigated parameters on the response variable. According to that, it reveals that oil and water flow rate followed by spray distance are the most dominant parameters for simultaneous reducing of surfaces roughness and cutting forces in the MQL system assisted turning of X5CrNi 18-10 stainless steel. Obviously, all other MQL parameters with a near zero slope have almost no impact on the simultaneous response variation.

4. CONCLUSIONS

In this study a Taguchi based screening design was used to screen out the most dominant MQL parameters in the turning process of austenitic stainless steel. The results can be drawn as follows:

- The number of used nozzles and oil flow rate, followed by the oil viscosity have the most dominant influence on the resultant cutting force.
- According to the delta values and the degree of influence on the measured values of surface roughness the ranking of the tested MQL parameters can be written as: oil flow rate, water flow rate, spray distance, the number of applied nozzles, nozzle direction and oil viscosity.
- For the simultaneous minimization of the response variables oil and water flow rate and the spray distance are identified as the most dominant, while nozzle parameters and oil viscosity are less important and thus can be removed from further experimental investigations.

5. REFERENCES

[1] Kaynak, J., Lu, T., Jawahir, I.S.: Cryogenic machining-induced surface integrity: A review and comparison with dry, MQL and flood-cooled machining, Machining Science and Technology: An International Journal, 18:2, pp.149-198, 2014.

[2] Ekinovic, S., Prcanovic, H., Begovic, E.: Investigation of influence of MQL machining parameters on cutting forces during MQL turning of carbon steel St.52-3., Procedia Engineering Vol.132, pp.608-614, 2015.

[3] Jeyapaul, R., Shahabudeen, P., Krishnaiah, K.: Quality management research by considering multi-response problems in the Taguchi method-a review, International Journal of Advanced Manufacturing Technologies, Vol.26, pp.1331-1337, 2005.

[4] Kumar, P., Barua, P.B., Gaindhar, J.L.: Quality optimization through Taguchi's technique and utility concept, Quality and Reliability Engineering International, Vol.16, pp.475-485, 2000.

[5] Yildirim, C.K., Kivak, T., Sarikaya M., Erzincali, F.: Determination of MQL parameters contributing to sustainable machining in the milling of nickel-base superalloy Waspaloy, Arabian Journal for Science and Engineering, Vol.42, Issue 11, pp.4667-4681, 2017.