Effects of Minimum Quantity Lubrication on Surface Roughness in Machining C45 Steel

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Abstract

In the machining process, the cooling lubricant plays an important role in improving the accuracy and quality of the machined surface. Minimum quantity lubrication is a new technology developed in recent decades and gradually proving its effectiveness in reducing production costs, friendly to the environment and the health of operators. This paper focuses on the effects of minimum quantity lubrication technology parameters on surface roughness via ANOVA analysis and find out the optimal MQL parameters by Taguchi method. The experimental work was carried out by turning cylindrical structural steel C45 bars, the cutting parameters namely feed rate, depth of cut and cutting speed were fixed during experiments base on recommendation of insert manufacturer. The main conclusion can be drawn from this study is that the air pressure in MQL is the most effectively factor on surface roughness.

Keywords: *MQL, least lubrication, turning operation, surface roughness.*

1. Introduction

Machining plays a significant role in the manufacturing industry nowadays. It is perhaps the most versatile manufacturing process in which the desired shape, size and surface finish are achieved through the removal of excess materials in the form of small chips. The challenge of modern machining industries is mainly focusing on the achievement of high quality, in terms of workpart dimensional accuracy and surface finish, high production rate and cost saving, with a reduced environmental impacts. Such goals are strongly affected by several elements; among them, the cutting fluids play a very important role.

Cutting fluids are used in machining processes to reduce friction at the tool-chip and tool-workpiece interfaces, to cool both the chip and the tool, and to remove chip. They have a strong effect on shearing mechanisms and, consequently, on machined surface quality and tool wear [1]. For companies, the costs related to cutting fluids represent a large amount of total machining costs. Research has found that the costs related to cutting fluids are frequently higher than those related to cutting tools. Moreover, cutting fluids have been found to cause health and social problems for workers, related to lubricant use and correct disposal [2]. It is important to consider environmental factors (minimization of waste and human toxicity, and saving of cutting fluid) and economic factors (saving energy and improvement of production efficiency) at the same time. Therefore, several other technologies have been developed in recent years to solve these problems. Sharma et al. [3] reviewed various cooling techniques, such as, flood cooling, cryogenic cooling, MQL/NDM, high pressure coolants, solid lubricants, compressed air/gas coolants, etc., in terms of controlling the temperature in the cutting zone. Dry machining and minimum quantity lubricant (MQL) machining have become the focus of attention of researchers and technicians in the field of machining as an alternative to traditional fluids. Lawal et al. [4] also assessed the various lubrication techniques in machining processes and makes a case for MQL technique using vegetable oil-based lubricant. They have concluded that MQL technique using vegetable oil-based lubricant in any machining processes offers the best alternative in combating the environmental problems. Goindi et al. [5] identified the areas of dry machining and they found that dry machining has not been successful in terms of providing process reliability, productivity, tool-life and component quality as MQL technique.

In researching the effects of MQL on product quality, surface roughness is one of the factors that many researchers are most concerned about. Surface finish and dimensional accuracy improved mainly due to reduction of wear and damage at the tool tip by the application of MQL as comparing of completely dry lubrication for the turning of AISI-1040 steel have been carried out by Dhar et al. [6]. Kamata and Obikawa [7] experimentally investigated high speed turning of Inconel-718 with different coated tools using the MQL technique and made a comparison between dry, wet and MQL techniques and the surface finish and tool life attained using MQL was found to be better than that in the wet and the dry machining for differently coated cutting tools.

In their investigation, Khan et al. [8] performed turning on AISI 9310 alloy steel using vegetable oil-based cutting fluid and found that MQL produced the best surface finish over a wide range of machining time as compared to the wet and dry turning. Among all the three types of coolant technique (wet, dry and MQL) on turning AISI 4140 alloy steel, Hadad and Sadeghi [9] found that MQL reducing the cutting forces which improves the chip–tool interaction, maintains sharpness of the cutting edges, lower machining temperatures and produced the best surface quality for the entire range of depth of cut due to reduction of wear and damage at the tool tip. Elmunafi et al. [10] evaluated the performance of MQL using castor oil as cutting fluid on turning hardened stainless steel 48 HRC and found that using small amount of lubricant of 50 ml/h during the particular turning process produces better results compared to dry cutting, in terms of longer tool life.

Recently during their experimental investigation of machining conditions and tool geometry on the surface roughness when turning Inconel 718, Kumar et al. [11] found that MQL assisted turning leads to significant improvement in surface quality as compared to wet and dry machining.

As described above, many researchers investigated the economic and environmental efficiency of MQL machining by comparison experiments within different cooling-lubrication techniques. However, not many studies have been done on the effects of MQL's parameters on the machinability (cutting force, surface roughness, tool life, etc.). This paper investigates the effect of MQL's parameters (pressure, flow rate, ratio of lubricant) on turning C45 steel in terms of surface roughness.

2. Experiment Details

The turning experiments were carried out on the lathe Mascut MA1880 (7.5 Hp and spindle speed 39÷2800 rpm using cemented carbide cutting tools for the machining of structural steel C45, which is 50 mm in diameter and 250 mm in length. The bars were pre-machined with a 1 mm cut to remove any possible surface irregularities and ensure similar surface properties for all the specimens. The chemical composition and mechanical properties of the workpiece material are listed in Table 1.

Fig 1. MQL system

Table 1: Chemical and mechanical properties of structural steel C45.

Chemical composition	C	Si	Mn	P max	S max	Cr max	Mo max	Ni max
Weight (%)	0.42 ÷ 0.5	0.17÷ 0.37	0.5 ÷ 0.8	0.04	0.04	0.25	0.1	0.25
Mechanical properties	Density (g/cm^3)	Tensile strength (MPa)		Yield strength (MPa)		Thermal conductivity (W/m.K)		Hardnes s (HRC)
	7.85	360		610		49.8		23 ÷ 25

MQL system was built with external aerosol supply, the oil and the compressed air are supplied to the ejector nozzle and the aerosol is formed just after the nozzle as Fig. 1 and the cutting parameter use in experiments given in Table 2.

The parameters of MQL use in experiments are air pressure, ratio of emulsion and spraying angle of nozzle. In order to compromise experimental runs and experimentation cost and also to search for the optimal process condition through a limited number of experimental runs, Taguchi's L9 orthogonal array consisting of 9 sets of data was selected. Experiments were conducted with the process parameters, given in Table 3

Table 2: Experimental conditions

Cutting parameters	Cutting speed 170 m/min; cutting feed rate 0.12 mm/rev; depth of cut 1mm
Tool geometry	CNMG 120408 Rake angle 10o, Nose radius 0.8mm
MQL	Lubricant: Blasocut 2000 Universal Flow rate: 120ml/h

Table 3: MQL parameters

MQL parameters	Notations	units	Levels of factors		
			Level 1	Level 2	Level 3
Air pressure	p	kgf/cm2	3	5	7
Spraying angle	a	degree	20	25	30
Ratio of emulsion	r	percent	6	8	10

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Mesurements of surface roughness parameter Ra (arithmetic average deviation of the profile) were performed on surface roughness tester Mitutoyo SJ-210 shown in Fig. 2. All measurements were repeated three times, and the average value was taken as the response value.

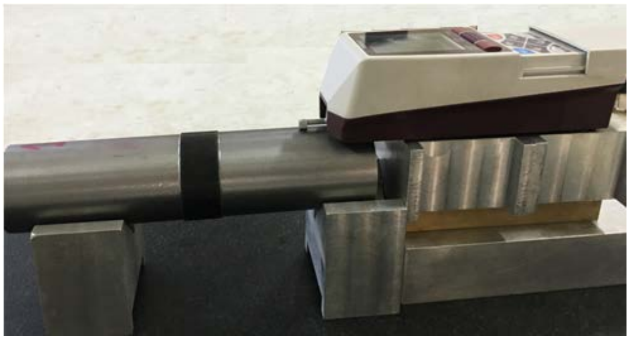

Fig 2. Measurement of surface roughness

3. Results

Based on Taguchi L9 orthogonal array consisting 9 sets of coded conditions and the experimental results for the responses Ra are shown in Table 4.

Table 4: Orthogonal Array L9 of Experimental Runs, Results

Exp .No	Parameter level			Experiment results Ra (μm)
	1	2	3	
1	1	1	1	1.655
2	1	2	2	1.215
3	1	3	3	1.655
4	2	1	2	1.166
5	2	2	3	1.172
6	2	3	1	1.258
7	3	1	3	2.155
8	3	2	1	1.545
9	3	3	2	1.471

Taguchi uses the S/N ratio to mesure the quality characteristic deviating from the desire value. The S/N ratio η is define as

$$\eta = -10\log(M.S.D) \qquad (1)$$

There are three categories of quality charateristics, i.e. the-smaller-the-better, the-higher-the-better and the-nominal-the-better. The mean-square deviation (M.S.D) for surface roughness was calculated base on the-smaller-the-better as described in below equation

$$M.S.D = \frac{1}{n}\sum_{i=1}^{n} y_i^2 \qquad (2)$$

Where, n is the number of experiments, and y is the measured value. The mean S/N ratio for each level of the MQL parameters is summarized and called the S/N response table for surface roughness (Table 5). In addition, the total mean S/N ratio for the nine experiments is also calculated and listed in table 5

Table 5: S/N response table for surface roughness

Symbol	MQL parameters	Mean S/N ratio (dB)			Max – Min
		Level 1	Level 2	Level 3	
p	Air pressure	-3.479	-1.569	-4.600	3.031
a	Spraying angle	-4.126	-2.282	-3.240	1.843
r	Ratio of emulsion	-3.380	-2.127	-4.141	2.014
Total mean S/N ratio = -3.22 dB					

Regardness of the-smaller-the-better qualyti characteristic, the greater S/N ratio corresponds to the smaller variance of the output characteristic around the desired value. Fig. 3 shows the S/N response graph for surface roughness.

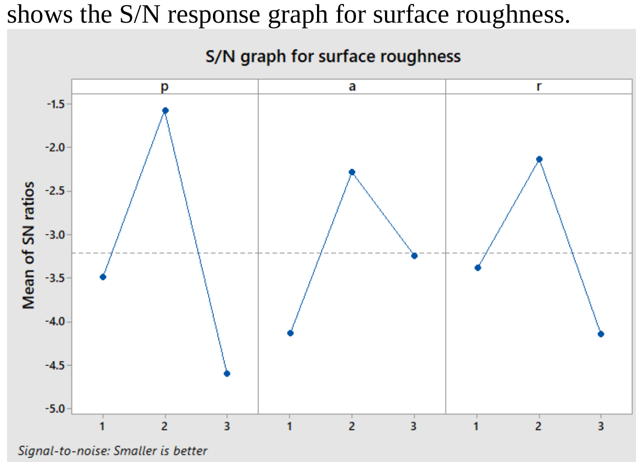

Fig 3. S/N graph for surface roughness

From Fig. 3, we clearly observed that p2a2r2 are the optimal levels of the design parameters for improved surface finish which implies at medium level of air pressure, spraying angle and ratio of emulsion.

Analysis of variance (ANOVA) is used to find out which design parameter affects the quality individualities significantly. ANOVA results for surface roughness which is used to find out the percentage contribution of each and every parameter on surface roughness and MRR was given in table 6.

Table 6: Results of **ANOVA** for surface roughness

	Degree of freedom	Sum of squares	Mean squares	Percentage
p	2	14.10	7.05	55.5
a	2	5.099	2.550	20.07
r	2	6.208	3.104	24.43
Error	0	0	0	
Total	6	25.407	12.704	

From the results, it was seen from the ANOVA that air pressure and ratio of emulsion were the most significant MQL parameters that affect surface roughness. The percentage contribution of MQL parameters for surface roughness such as air pressure, spraying angle and ratio of emulsion were calculated from ANOVA as 55.5 %, 20.07 % and 20.43 % respectively.

The optimal level of the design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of design parameters. Table 7 shows the comparison of the predicted surface roughness with the actual surface roughness using the optimal MQL parameters, good between the predicted and actual surface roughness is being observed.

Table 7: Results of the confirmation experiment

	Optimal MQL parameters	
	Prediction	Experiment
Level	p2a2r2	p2a2r2
Surface roughness	0.839	0.868

4. Conclusions

This paper has presented an application of Taguchi method in the optimization of parameters of MQL system for turning operations. The following conclusions can be drawn based on the experimental results of this study:

- It can be found that Taguchi method provides a simple methodology for the optimization of the machining process and reduce experiment time and cost.
- The results of experiments shows that among the three controllable factors of MQL system (air pressure, spraying angle, ratio of emulsion) that air pressure and ratio of emulsion are the main parameters influence surface roughness in turning structure steel C45.
- The air pressure of 5 kgf/cm^2 was observed to be the most effective, which is also a pressure value commonly used for MQL systems in many previous studies.
- MQL has performed superior characteristics compare to wet and dry machining. However, when using MQL, the selection of parameters for the final quality of the products is the best depends on many factors (workpiece material, cutting tool material, cutting condition). This study has shown that the MQL application on turning structural steel C45 with the air pressure of 5 kgf/cm^2, the 8% ratio of emulsion and 25 degrees of spray angle improve surface finish significantly

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