RESEARCH ARTICLE OPEN ACCESS

Optimization of Minimum Quantity Lubricant (MQL) Conditions in Milling of mild Steel

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ABSTRACT: Minimum quantity lubrication (MQL) has been well established as an alternative to flood coolant processing. The optimization of MQL conditions is reducing the machining cost and improving the performance. In this study, the Taguchi method was applied to find the optimal values of MQL condition in the milling of mild steel with consideration of surface roughness and generated temperatures during machining. The L9 orthogonal array, the signal-to-noise (S/N) ratio was employed to analyze the effect of the performance characteristics of MQL parameters (i.e., cutting fluid, flow rate , and nozzle distance from at starting of machining zone) on good surface finish and reducing temperature. From the results, it is observed that lubricant played a major role to minimization of generated temperature and surface roughness followed by nozzle distance from machining.

Date Of Submission:28-11-2018 Date Of Acceptance:11-12-2018

I. INTRODUCTION.

MQL is an effective, environmentally-friendly solution and has been widely used in the machining processes (i.e. turning, drilling and milling). From Phafat et al. [1], consideration machining with MQL is a method in which a little amount of lubricant utilized at a flow rate less than 250 mL/h is mixed with compressed air and sprayed onto the cutting zone. MQL helps to increase the quality of the surface finish [2-4], get better tool life, reduce tool wear, decrease cutting temperature and decrease the cost of lubrication [5-11]. The efficiency of MQL has already been confirmed in many studies and application of turning and milling processes. In machining with MQL, lubricant, nozzle distance from machining zone and fluid flow are the main parameters. They will decide the effectiveness of MQL cutting. Applied lubricants in machining are everywhere, such as mineral oil, synthetic esters, fatty alcohols, etc. [7]. Even vegetable oil has been used and proven to be effective in machining [6,7]. However, vegetable oil has some poor performance characteristics for long term usage for this reason Suresh.et.all[12] improved poor performance characteristics of coconut oil and further more addition of nanoparticles which will increase thermal conductivity[13] several authors optimized MQL parameters and achieved positive results. Thakur et al. [14] conducted optimization of MQL parameters to get minimum tool wear in the high-speed turning of super-alloy Inconel 718. higher quantity of lubrication, lower frequency of pulses and an inclined direction of the cutting fluid. In the study of Gandhe et al. [15], experiments were carried out to optimize the MQL parameters in the turning of EN-8 steel. It showed that the cutting fluid used is the most significant factor affecting tool wear However, the studies conducted on the effects and optimization of the parameters in MQL, such as flow rate, nozzle distance from machining zone and type of lubricant used, generally temperature and Surface roughness is an important index used to estimate product quality in mechanical products. Optimizing The Taguchi method and ANOVA were also employed in the study of Gopalsamy et al. [16].
Therefore In the present study, the Taguchi method was applied to optimize MQL conditions for surface roughness and generated temperatures.

II. OPTIMIZATION OF MQL PARAMETERS:

For optimizing the MQL conditions the following experimental and DOE analysis carried which are discussed below sections.

2.1. Experimental Procedure

In this research, the nozzle distance from machining, the fluid flow and at two prepared coconut oil lubricant and one is pure coconut lubricant from literature of MQL conditions were optimized to obtain improved cutting performances in the milling process with consideration of surface roughness and generated temperatures in machining zone. The Taguchi used because it is a simple and robust method used to optimize the parameters of the process involving a significant reduction in cost and processing time [17]. In the experimental design, the Taguchi method uses the orthogonal arrays to obtain the best results with a minimum number of experiments. A signal to noise (S/N) ratio is used to measure the performance characteristics and to calculate the percent contribution of each process parameter by analysis of variance. The S/N ratio represents the amount of variation present in the quality characteristic in which the term S represents the mean value for the output characteristic, and the N represents the undesirable value for the output characteristic. The analysis of the S/N ratio could be classified into 3 types: the-bigger-is-the-better, the-smaller-is-the-better, and the-nominal-is-the-better [17,18]. Thus, the appropriate type is selected for each specific case. The purpose of this study is to optimize the parameters of the MQL condition to get the better surface roughness available. Therefore, the-smaller-is-the-better type was selected. It is calculated according to the following formula:

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

where: y_i is the observed data, n is the number of experiments which are repeated. With three parameters at three levels, Taguchi L9 orthogonal array was used to organize the experiments. The parameters with three levels of the MQL as the fluid flow, Nozzle distance from machining zone(mm) and lubricant are shown in Table 1. The lubricant factor includes pure coconut oil, modified coconut oil [12], and modified coconut with nanoparicle[13] and remaining other parameters fluid flow, nozzle distance and their range was took from various literatures. Vegetable oil has been used and proven to be effective in a number of recent studies [7,8]. The air at constant i.e 6kg/cm^2 pressure. This range has been commonly applied in industry. The range of fluid flow factor is from 50,100 and 150 mL/h. The selected range of fluid flow is near dry condition. The milling process information is shown in Table 2. The details of the milling tool are given in Table3.

Table 1:Parameters and levels.

Parameters	Level 1	Level 2	Level 3
Lubricant	Coconut oil(CO)	Modifi ed co	Modified oil with nanoparticle
Fluid flow (mL/h)	50	100	150
Nozzle distance from machining zone(mm)	40	50	60

Table 2: Milling process information

Item	Description
Machining operation	Slot milling
Machine tool	Conventional milling machine
tool	HSS
Workpiece	Mild steel
MQL spray	KENCO MQL setup
Surface roughness tester	Model SJ -401 of Mitutoyo
Temperature measurement	Infra red sensor
Cutting parameters	0.5inch/m feed, spindle speed 370 rpm, depth of cut 0.5cm

Table 3: Technical information of milling tool

Geometrical parameters	Description
Cutting length(mm)	100
Shank diameter	10
Tool diameter	10
Number of flutes	4
Helix angle (^{0})	35
Axial rake angle(^{0})	12

The milling process of the mild steel was performed by a conventional milling Machine. The. The tool used is high speed steel with four teeth end mill cutter with machining length of 10cm. All the tests were conducted under a fixed cutting conditions such as spindle speed 370 rpm, feed f = 0.5 inch /min and depth of cut d = 0.5 mm. The cutting parameters were selected based on work piece material, tool material, hardness of work piece, for doing the every experiment it took nearly 8 minutes of time. Based on these conditions the mql setup with machine tool shown in below figure 2. And machined specimens shown in fig1.

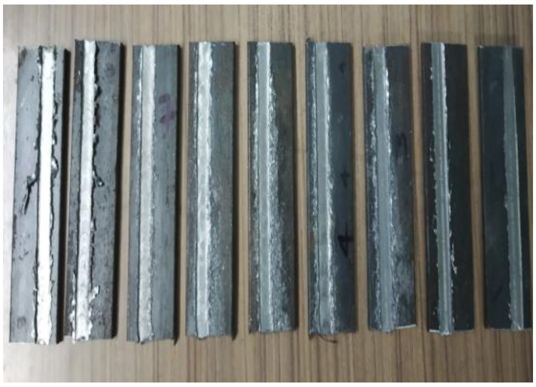

Fig.1: Machined specimens at constant cutting conditions from L9 DOE

Fig.2: Experimental set-up with a 60 mm of nozzle distance at constant cutting conditions with minimum quantity lubricant (MQL) setup.

The surface roughness and temperature measurement was done using SJ-401 surf-test instrument and infrared sensor respectively. From surface roughness tester the measurement of Ra (Based on the ISO standard, surface roughness average Ra was calculated as the arithmetic average of the absolute values of roughness profile) and infra red sensor is arranged the parallel to machining zone from that the maximum generated temperature was taken in each experiment. The MQL spray attached to the machine each experiment was repeated three times to reduce the possibility for experimental error to occur.

2.2. Results and Discussion

An analysis was carried out to determine the effect of MQL parameters (i.e., fluid flow, nozzle distance and lubricant) on surface roughness and generated temperature in machining zone. The statistical analysis was performed by using Minitab software, Version 16. The S/N ratio obtained from formulae and the result of Ra and generated temperature is shown in Table 4. The three factors observed were lubricant, fluid flow, and nozzle distance, respectively. Three levels of each factor were tabulated in below table.

Table 4: The surface roughness and Max.Temparature during machining results and S/N ratio.

Exp.no.	**Lubricant**	**Fluid Flow**	**Nozzle distance (mm)**	**Ra (μm)**	**Max.Temparature during machining(^{0}C)**	**SNRA1**
1	Pure coconut oil	50	40	3.25	74.1	-34.3944
2	Pure coconut oil	100	50	3.57	75.2	-34.5238
3	Pure coconut oil	150	60	3.95	77.6	-34.7982
4	Modified coconut oil	50	50	2.56	65.1	-33.2680
5	Modified coconut oil	100	60	2.53	64.1	-33.1336
6	Modified coconut oil	150	40	2.21	61.2	-32.7304
7	Modified coconut oil with nanoparticles	50	60	1.26	49	-30.7965
8	Modified coconut oil with nanoparticles	100	40	0.53	43.5	-29.7601
9	Modified coconut oil with nanoparticles	150	50	0.67	45	-30.0549

The mean of S/N response for surface roughness and generated temperature of each level of parameters is shown in Table 5. Table 5 shows that among all the obtained results to improve the surface finish and reducing the generated temperature lubricant which is the most influential factor and the second influential factor is nozzle distance from machining zone.

Table5: Response Table for Means

LEVEL	Lubricant(A)	Fluid Flow(B)	Nozzle distance(C)
1	39.61	32.54	30.80
2	32.95	31.57	32.02
3	23.33	31.77	33.07
Delta	16.29	0.97	2.27
rank	1	3	2

Figure 3 indicated the S/N response graph. From the S/N response analysis, in order to get the best Ra and minimum generated temperature, the optimum MQL parameters were modified oil with nanoparticle for the lubricant, 100 mL/h for the flow rate, and 40 mm distance from the nozzle. Based on the results it is inferred that more thermal conductivity of lubricant the lubricant at which the near to machining zone which flushing away the chips so that the high amount heat is taken by chips to decrease the temperature

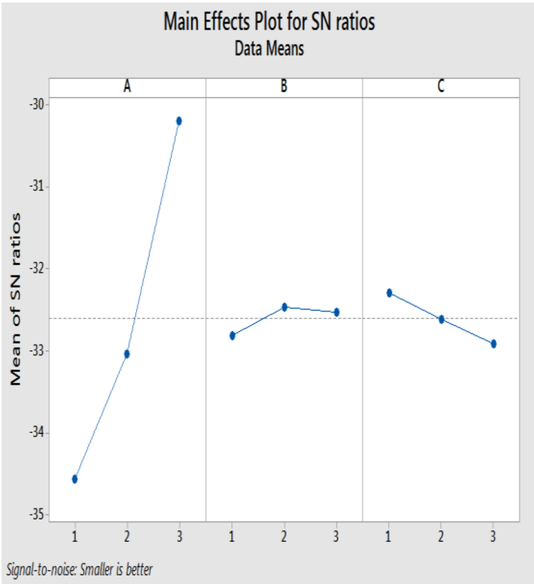

Figure 3: The effect of MQL parameters on surface roughness

III. CONCLUSIONS

In this study, the Taguchi method to optimize MQL conditions for surface roughness and generated temperature in machining zone. The best work piece were obtained in order to get improve the surface roughness under MQL conditions optimization.

In MQL conditions, modified coconut oil with nanoparticles, the 100 mL/h fluid flow and the 40 mm distance of nozzle provided the best results for surface roughness and generated temperature

The higher thermal conductivity of Lubricant and nearest distance of nozzle which these two parameters are most affecting the minimization of surface roughness and reducing generated temperature

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Suresh Babu Valeru"Optimization of Minimum Quantity Lubricant (MQL) Conditions in Milling of mild Steel"International Journal of Engineering Research and Applications (IJERA)