Optimization of Process Parameters in Minimum Quantity Lubrication by Taguchi Method

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***Abstract*—**In order to minimize all the problems of health hazards, non-economy and temperature in case flood cooling; the Minimum Quantity Lubrication (MQL) has been applied. In the present work , the effect of flow rate, frequency of pulsed jet, standoff distance of nozzle and composition of cutting fluid have been considered , to find out the best result in terms of cutting temperature and surface finish. The experimentation has been conducted during turning of AISI 304 alloy steel with minimum quantity lubrication with a pressure of 100bar having vegetable based cutting fluid. The temperature has been measured by infra red thermometer and surface finish bySJ-210 surf test. Taguchi's L18 orthogonal array has been used of designing the experiment. The vegetable oil based cutting fluid has been selected due to its environmental friendly behavior. Signal to noise ratio analysis has been used to optimize the result. ANOVA result shows the most significant parameter which affects temperature and surface finish. The result shows that MQL provides better performance than other fluid application ,while measuring temperature and surface finish**.**

***Index Terms*—**Minimum quantity lubrication,signal to noise,surface finsh,temperature**.**

I. Introduction

The purpose of cutting fluid in a machining operation is to cool the work piece, reduce friction, and wash away the chips. The cutting fluid contributes significantly toward machining cost and also possesses environmental threats. . The disposal of cutting fluids is also a big problem. The waste cutting fluids can pollute surface and groundwater. They can cause soil contamination, affect agriculture produce, and can lead to food contamination. Cutting fluids and the auxiliary equipments compromise nearly 7-17% of the total machining costs. Compared with the cost of the cutting tools (2-4%), the cutting fluid cost is significantly high. As a result, there is a need to reduce the use of the cutting fluids. Thus, ideally, cutting fluids should not be used at all. If it is not possible, then their use should be minimized.

A. Minimum Quantity Lubrication Systems (MQL)

The enormous reduction in the quantity of lubricant compared to the circulated quantities of conventional metalworking fluid systems is the key feature of MQL. In contrast to conventional Flood lubrication, minimum quantity lubrication uses only a few milliliters (ml) of lubrication per hour for the machining process. This greatly reduces health hazards due to emissions of metal working fluids on the skin and in the breathed-in air of employees at their workplaces.

Application of a targeted supply of lubricant directly at the point of use lubricates the contact surfaces between tool, work piece and chip. Tiny drops of lubricant penetrate through the capillary voids of the chip.

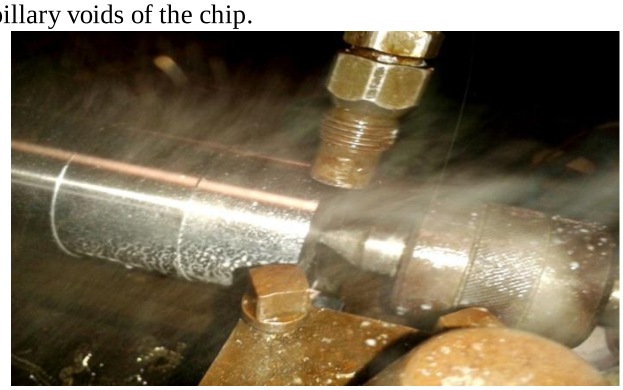

Fig.1. Minimum Quantity Lubrication(MQL)

B. Objective of The Study

The objective of this work is to determine the effect of minimum quantity lubrication on temperature and surface finish by experimental investigation and optimizing the cutting parameters by Taguchi's Design Of Experiment (DOE). Two types of cutting fluids such as mineral oil and vegetable based cutting fluids are selected for investigation and to compare the performance of these two.

II. Literature Survey

Experimental investigations were carried out using orthogonal cutting process in which the efficiency of MQL technique was compared to dry technique with respect to cutting temperature, cutting force, tool-chip contact length and chip thickness. The experimental results showed that the application of MQL based synthetic ester as the cutting fluid was more efficient for the machining process as it reduced the cutting temperature, cutting force, tool-chip contact length and produced better chip thickness compared to dry machining technique[1].Minimum Quantity Lubrication (MQL) is an effective tool to minimize the damage of cutting fluids on health and environment in cutting processes. Thus, optimal process parameters must be determined under MQL cooling/lubrication condition to determine the maximum productivity[2].MQL provides significant improvement in chip formation mode, reduced flank wear and improved tool life [3]. Vegetable based cutting fluid like coconut oil, palm oil; sunflower oil etc shows better surface roughness value, longer

Manuscript received November 19, 2015.

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tool life, improvement in metal removal rate and reduced environmental impact [4]. The cutting performance of Minimum Quantity Lubrication condition showed better results compared to dry and flooded conditions in reduction of surface roughness. Using Analysis of Variance (ANOVA) the individual factor effects are found out and concluded that the effect of feed rate is more on the surface roughness for all lubrication conditions compared to other factors [5]. The relationship between hardness and various process parameters namely spindle speed, feed rate and depth of cut has been developed. Taguchi method has been adopted for the design of experiments and the results have been analyzed by maximize S/N ratio [6]. The cutting temperature in hard turning of hardened AISI 4340 is less as compared to dry and wet turning. It gives 36 % decrease in cutting temperature. The MQL shows lower range of temperature which helps to improve tool life and the surface finish in hard turning of hardened AISI 4340 is better as compared to dry and wet turning. There is 30% improvement in surface finish using MQL [7]. Metal cutting fluid(MCF) and can be replaced by the (vegetable based cutting fluid) VBCFs, thus reducing the occupational health risks associated with petroleum oil based CFs and reducing the waste treatment costs due to their inherently higher biodegradability [8]. Signal to noise ratio approved that the significant parameter which affects surface finish is feed force followed by cutting speed and depth of cut [9]. Dry or near dry machining is often regarded as an effective strategy for reducing ecological impacts of the cutting processes. Due to the application limitations of dry or near dry machining, reduction of cutting fluid supply through machining parameter optimization offers a cost effective alternative. For solving this, an optimization model of machining parameters considering minimum cutting fluid consumption and cost is proposed[10].

III. Methodology

In this work, Taguchi robust design methodology is used to obtain the optimum conditions for temperature and surface finish in turning AISI 304 stainless steel under MQL conditions. Statistical software Minitab and design expert are used along with Taguchi method to obtain results for analysis of variance (ANOVA). Hence, the results obtained from the Taguchi robust design method is compared with the Minitab design expert software results.

A. *Taguchi's Robust Design Methodology*

The robust design method by Taguchi uses a mathematical tool called Orthogonal Array(O.A) to study large number decision variables with a small number of experiments. It also uses a measure of quality called Signal-to-Noise (S/N) ratio, to predict the quality. The principle of robust design methodology is to minimize the variation without eliminating the causes and maximizing S/N ratio. This is achieved by optimizing the product and process designs to make the performance insensitive to the various causes of variations.

B. *Signal to Noise Ratio(S/N Ratio)*

Taguchi created a transform function for the loss-function which is named as signal-to-noise (S/N) ratio. The S/N ratio as stated is a concurrent statistic. A concurrent statistic is able to look at two characteristics of a distribution and roll these characteristics into a single number or figure of merit. The S/N ratio combines both the parameters (the mean level of the quality characteristic and variance around this mean) into a single metric.

A high value of S/N implies that signal is much higher than the random effects of noise factors. Process operation consistent with highest S/N always yields optimum quality with minimum variation.. The equation for calculating S/N ratios for 'smaller the better', 'larger the better' and 'nominal is best' types of characteristics are as follows.

Larger the Better:

$$S/N = -10 \log (1/n) \sum_{i=1}^{n} (1/y^2) \quad (1)$$

Smaller the Better:

$$S/N = -10 \log (1/n) \sum_{i=1}^{n} (y^2) \quad (2)$$

Nominal is best:

$$S/N = -10 \log (1/n) \sum_{i=1}^{n} (y_i - y_0)^2 \quad (3)$$

Where n = no: of repetition

C. *Analysis Of Variance (ANOVA)*

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as "variation" among and between groups). In ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the *t*-test to more than two groups.

IV. Experiment Details

A. *Formulation of Cutting Fluid*

Since the quantity of cutting fluid used is extremely low in this new method, specially formulated cutting fluids with appropriate ingredients were used in the present investigation. The base was a commercially available vegetable oil. The formulation contained, in addition to coolant and lubricant, additives such as surfactant, evaporator, biocide and a deodorizing agent.

B. *Fluid Injection System*

An overall view of the special test rig developed for injecting the cutting fluid is presented in figure.2

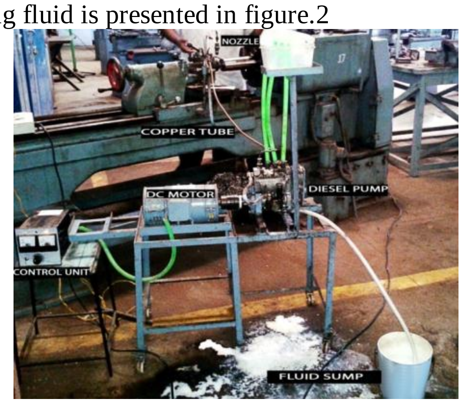


Fig. 2 Fluid Injection System

It consisted of a P-6 Bosch fuel pump generally used for diesel fuel injection in truck engines coupled to a variable electric drive. The test rigfacilitated the independent variation of the injection pressure the frequency of injection and the rate of injection. By selecting proper settings, the rate of injection could be made as small as 0.5 ml/min. Special fixtures were designed, so that the injection nozzle could be located in any desired position without interfering with the tool or work during actual cutting.

C. Selection of Process Variables

For the present experiment , cutting speed ,feed rate and depth of cut were kept constant throughout the experiment. Therefore the cutting parameters were as follows: cutting speed 100 m/min; feed rate 0.2mm/rev; and depth of cut 2 mm. These values were selected as per the recommendations from the tool manufactures and information available in the literature.

The process variables selected for the analysis are flow rate of the coolant, frequency of pulsed jet, standoff distance of the nozzle tip from the cutting point and the composition of cutting fluid in the coolant.

D. Variables Level Selection

Levels of process variables are selected after trial experiment. The levels of these varying flow parameters were selected as follows

[A] Standoff distance of nozzle: 40 and 50mm
[B] flow rate: 2.5,5and 7.5 ml/min
[C] Frequency of pulse: 300,500 and 700 cycles /min
[D] Composition of fluid: 5%,10% and 15%

E. Experiment Procedure

Turning operation was done on a 3 HP investa made gap bed lathe. The work piece material selected for the present work was AISI 304 stainless steel. A 80mm diameter work piece was selected for cutting experiment. cutting tool was SNMG 120 408 MTTT9225 insert with PSBNR 2525 M 12 tool holder made taegutech. Machining parameters such as speed feed and depth of cut was selected as per the recommendations by the tool manufacturer. Since this present work was about the effect of flow parameters on the temperature and surface finish, machining parameters were kept constant. So these parameters taken are 100m/min, 0.2 mm/rev and2mm respectively. Varying flow parameters selected are cutting fluid flow rate ,frequency of pulse, stand off distance of nozzle tip and composition of cutting fluid.

The coolant from the sump is pumped by a fuel pump which was driven by a DC motor. This coolant pass through a copper tube with a high pressure of 100 bar to the tip of the nozzle, from where it was reaches to the cutting zone. During the turning operation, the tool chip interface temperature was measured by a non contact infrared thermometer. The laser light source provided in the thermometer help to pin point the interface. During the measurement the devices is hold to a distance to spot ratio of 8:1 for accurate measurement. After each run the surface finish of machined surface is measured by using a SJ-210 surftester. The readings were taken at three different locations and take the average of the values.

F. Experimental orthogonal array

Taguchi's L18 orthogonal array was selected for experiment (1variable 2 level and 3 variables and 3 levels)

TABLE I
ORTHOGONAL ARRAY

Run	Stand off distance **[A]** (mm)	Flow rate **[B]** (ml/min)	Frequency of pulses **[C]** (pulses/min)	Composition of cutting fluid **[D]** (percentage)
1	50	2.5	300	15
2	50	7.5	300	15
3	50	7.5	700	10
4	50	7.5	500	5
5	40	5	300	5
6	50	2.5	500	5
7	40	2.5	500	10
8	40	2.5	700	15
9	40	2.5	300	5
10	40	7.5	500	15
11	50	5	300	10
12	50	5	700	5
13	40	5	700	15
14	40	7.5	700	5
15	40	5	500	10
16	40	7.5	300	10
17	50	2.5	700	10
18	50	5	500	15

V. ANALYSIS OF THE EXPERIMENT

A. Output Responses From The Experiment

After completing 18 run of experiments the output values measured were tabulated as follows

TABLE II
RESULT OF CUTTING EXPERIMENT

Run	Temperature (^{o}c)	Surface finish (micron)
1	87	3.61
2	67	3.93
3	71	3.87
4	77	2.17
5	71	3.43
6	89	2.94
7	87	2.83
8	85	3.72
9	88	3.46
10	65	2.09
11	71	3.73
12	68	2.61
13	68	2.57
14	75	3.64
15	69	2.77
16	73	3.67
17	86	3.85
18	72	2.81

B. Signal to Noise Ratio of Temperature and Surface Finish

Since the target of the experiment is to minimize the cutting temperature, and surface finish, lower – the- better S/N ratio was selected. The calculated S/N ratio of temperature and surface finish are tabulated as follows

TABLE III
SIGNAL TO NOISE RATIO OF TEMPERATURE AND SURFACE FINISH

Run	Temperature(^{O}C)	S/N ratio of temperature	Surface finish(Micron)	S/N ratio of surface finish
1	87	-38.7904	3.61	-11.1501
2	67	-36.5215	3.93	-11.8879
3	71	-37.0252	3.87	-11.7542
4	77	-37.7298	2.17	-6.72919
5	71	-37.0252	3.43	-10.7059
6	89	-38.9878	2.94	-9.36695
7	87	-38.7904	2.83	-9.03573
8	85	-38.5884	3.72	-11.4109
9	88	-38.8897	3.46	-10.7815
10	65	-36.2583	2.09	-6.40293
11	71	-37.0252	3.73	-11.4342
12	68	-36.6502	2.61	-8.33281
13	68	-36.6502	2.57	-8.19866
14	75	-37.5012	3.64	-11.222
15	69	-36.777	2.77	-8.8496
16	73	-37.2665	3.67	-11.2933
17	86	-38.69	3.85	-11.7092
18	72	-37.1466	2.81	-8.97413

C. Optimum Levels of Process Variables for Minimum Temperature and Surface Finish

In order to find the Optimum level of process variables for minimum temperature and surface finish, mean value of S/N ratio for each process variables at all levels are calculated and plot a graph(main effects plot) showing the variations.

From the main effects plot of both temperature and surface finish, it was found that the optimum combination for minimum temperature is A1-B2-C3-D3 and that for minimum surface finish is A1-B2-C2-D1

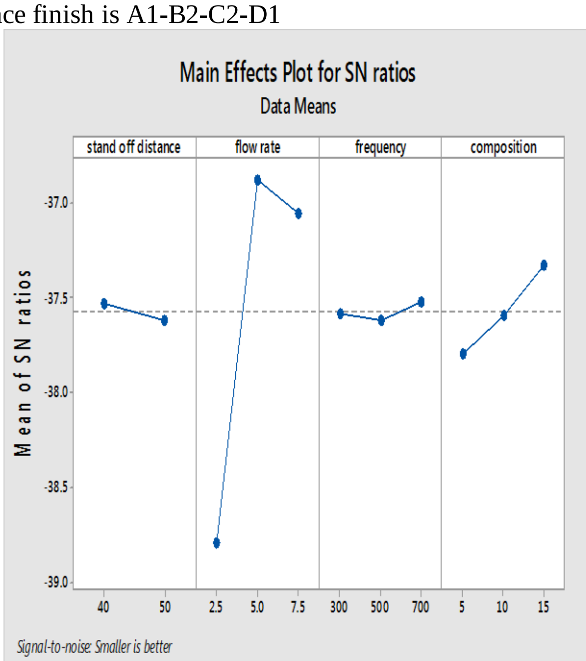


Fig.3. Main Effects Plot For Temperature

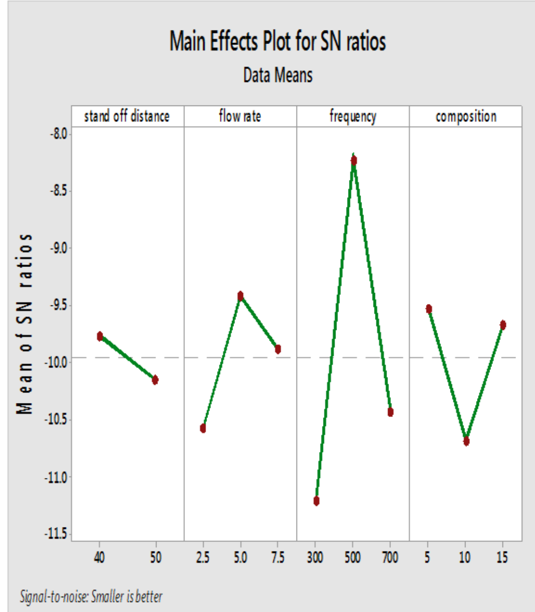


Fig. 4. Main Effects Plot For Surface Finish

D. Delta Ranking

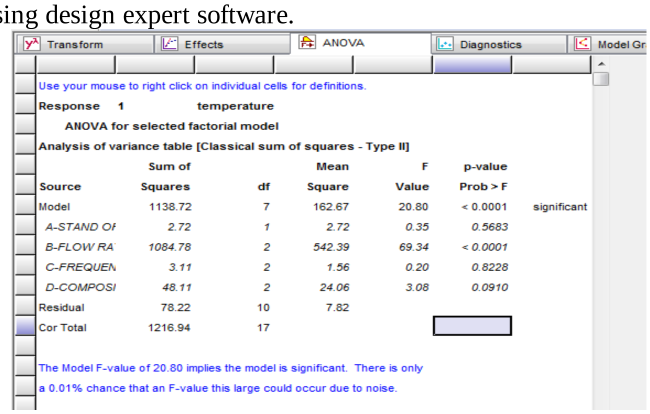
Once these SN ratio values are calculated for each factor and level, the Delta "Δ" of the SN for each parameter is calculated for temperature and surface finish. The larger the Δ value for a parameter, the larger the effect of parameter has on the process. This is because the same change in signal causes a larger effect on the output being measured.

Delta, Δ =(High average value of S/N – Low average value of S/N)

The influence of the parameters where in the decreasing order of flow rate ,composition of fluid, frequency of pulse and standoff distance for temperature and that for surface finish, ,it is in the decreasing order of ,frequency of pulses, flow rate ,composition of fluid and standoff distance.

E. Analysis of Variance (ANOVA)

In order to find the most significant factor which affects both temperature and surface finish, ANOVA analysis was done using design expert software.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Response 1 temperature

ANOVA for selected factorial model

Analysis of variance table [Classical sum of squares - Type II]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1138.72	7	162.67	20.80	< 0.0001	significant
A-STAND OI	2.72	1	2.72	0.35	0.5683	
B-FLOW RA	1084.78	2	542.39	69.34	< 0.0001	
C-FREQUEN	3.11	2	1.56	0.20	0.8228	
D-COMPOSI	48.11	2	24.06	3.08	0.0910	
Residual	78.22	10	7.82			
Cor Total	1216.94	17				

The Model F-value of 20.80 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.

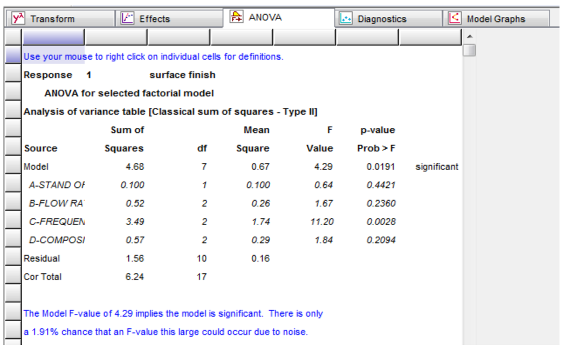
Fig. 5. ANOVA Table For Temperature(Design Expert)

From the ANOVA table of temperature it is found that the flow rate is the most significant factor having 69.34 as F-value and conclude that the model is significant in the selected levels of variables.

TABLE VIII

ANOVA TABLE FOR TEMPERATURE

Source	Sum of squares	Df	Mean square	F value	P-value (prob>f)	Remarks
Model	1138.7	7	162.6	20.8	< 0.0001	Significant
A	*2.72*	*1*	*2.72*	*0.35*	*0.5683*	
B	*1084.8*	*2*	*542.3*	*69.3*	*< 0.0001*	
C	*3.11*	*2*	*1.56*	*0.20*	*0.8228*	
D	*48.11*	*2*	*24.06*	*3.08*	*0.0910*	
Residual	78.22	10	7.82			
Cor total	1216.4	17	162.6			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Response 1 surface finish

ANOVA for selected factorial model

Analysis of variance table [Classical sum of squares - Type II]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	4.68	7	0.67	4.29	0.0191	significant
A-STAND OI	*0.100*	*1*	*0.100*	*0.64*	*0.4421*	
B-FLOW RA	*0.52*	*2*	*0.26*	*1.67*	*0.2360*	
C-FREQUEN	*3.49*	*2*	*1.74*	*11.20*	*0.0028*	
D-COMPOSI	*0.57*	*2*	*0.29*	*1.84*	*0.2094*	
Residual	1.56	10	0.16			
Cor Total	6.24	17				

The Model F-value of 4.29 implies the model is significant. There is only a 1.91% chance that an F-value this large could occur due to noise.

Fig.6. ANOVA Table For Surface Finish (Design Expert)

The ANOVA table of surface finish shows that the frequency of pulse is the most significant factor having 11.2 as F-value and conclude that the model is significant in the selected levels of variables.

TABLE IX

ANOVA TABLE FOR SURFACE FINISH

Source	Sum of squares	Df	Mean square	F value	P-value (prob>f)	Remarks
Model	4.68	7	0.67	4.29	0.019	Significant
A	*0.10*	*1*	*0.100*	*0.64*	*0.442*	
B	*0.52*	*2*	*0.26*	*1.67*	*0.2360*	
C	*3.49*	*2*	*1.74*	*11.20*	*0.002*	
D	*0.57*	*2*	*0.29*	*1.84*	*0.209*	
Residual	1.56	10	0.16			
Cor total	6.24	17				

F. Confirmation Experiment for Temperature and Surface Finish

By the optimum solution obtained through analysis, experimental runs were conducted for both Temperature and Surface roughness. The responses for the optimum solutions were predicted using Design expert V9. The predicted values and experimental values were compared and the percentage error for temperature was found to be 1.72 % and for surface finish was 0.90%.

TABLE X

CONFIRMATION EXPERIMENT FOR TEMPERATURE

Optimum parameters	Predicted value of temperature(^{O}C)	Actual value of temperature(^{O}C)	Error %
A1B2C3D3	66.83	68	1.72%

TABLE XI

CONFIRMATION EXPERIMENT FOR SURFACE FINISH

Optimum parameters	Predicted value of surface finish(micron)	Actual value of surface finish(micron)	Error %
A1B2C2D1	2.19	2.21	0.90%

G. Comparison with Mineral Oil MQL, Flooded and Dry Cutting Environment

For comparing the output values obtained in the vegetable oil based MQL system with other environment. The process variables level selected for the comparison cutting were the optimum values which gives minimum temperature and surface finish. The result obtained in the comparison cutting are tabulated as follows

TABLE XII. COMPARISON EXPERIMENT

Environment	Temperature (^{0}C)	Surface finish, Ra (μm)
Mineral oil MQL	72	3.41
Mineral oil flooded	84	4.27
Vegetable oil flooded	80	3.62
Dry cutting	110	4.56

VI. CONCLUSION AND FUTURE SCOPE

Vegetable oil based cutting fluid was applied in minimum quantity lubrication system for turning AISI 304 steel. Taguchi's L18 orthogonal array was used for designing the experiment. Four flow parameters at three level each was used as the process variables. Tool chip interface temperature and surface roughness (Ra value) of machined surface was measured for all the 18 run. A comparison cutting had also done with other environment like mineral oil MQL, vegetable and mineral oil flooded and dry cutting. The responses obtained from the experimental run were analyzed using S/N ratio , and the following conclusions were made. The MQL environment shows better results for both temperature and surface finish as compared to flooded and dry cutting conditions. In MQL the cutting fluid particles can reach up to tool chip interface in the form of small drops. During wet turning, the heat is extracted only by convective heat transfer, but MQL facilitates both convective and evaporative heat transfer leads to lowering of cutting temperature. Since the cutting temperature is reduced surface finish should improve accordingly.

The optimum solution for minimum temperature is first level of standoff distance(40mm), second level of flow rate(5ml/min),third level of frequency of pulse(700cycles/min) and third level of composition of cutting fluid(15%). The temperature value ranges from 68^0c to 89^0c. The most significant parameter which affects the value of temperature is flow rate and the least significant parameter is standoff distance.

The optimum solution for minimum surface finish is first level of standoff distance(40mm), second level of flow rate(5ml/min),second level of frequency of pulse(500cycles/min) and first level of composition of cutting fluid(5%). The surface finish value ranges from 2.09micron to 3.93 micron. The most significant parameter which affects the value of surface finish is frequency of pulse and the least significant parameter is standoff distance.

In future research finite element analysis is to be done for getting better result of temperature distribution using MQL system.

Acknowledgment

The authors wish to thank the faculty of engineering, especially the mechanical engineering department, College of engineering Perumon, for support, and, for help with the work validation of the new technology.

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