A STUDY ON PROCESS PARAMETERS EFFECT IN HARD TURNING OF EN24 STEEL USING MINIMUM QUANTITY LUBRICATION (MQL)

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Abstract: Dry and wet machining are the two cutting environments in metal cutting operation. Cutting fluids use supports economy of tools and maintains good surface properties with tight tolerances. Minimum quantity lubrication (MQL) is finding its way as manufacturing industries are facing problems with their employee health and pollution of environment with excessive use of cutting fluid. It is observed that if MQL properly directed, can reduce the quantity of cutting fluid and also can improve the machinability characteristics. In present study, experimental investigation is carried out on surface roughness to study the effect of various minimum quantity lubrication (MQL) parameters along with machine parameters such as cutting speed, feed and depth of cut. Taguchi design of experimental approach and ANOVA are applied to find optimal combination of process parameters and level of significance parameters to minimise the surface roughness. Based on ANOVA, it is found that feed has significant effect on surface roughness. The results are confirmed experimentally at 95% confidence level.
Key words: Hard turning; MQL; Taguchi approach; Surface roughness

1. INTRODUCTION

Reducing overall manufacturing cost while still maintaining desirable product quality is really a key point in front of all manufacturing industries especially related to machining operations. Use of modern cutting tools, minimum use of cutting fluid, optimum cutting speed and feed rates etc. can help to reduce the problems faced by manufacturers. Further, this should be continued keeping machinability in mind as all the factors listed above are greatly affecting it. Number of researchers have focused on appropriate prediction of machinability related characteristics like surface roughness, tool wear, chip morphology, residual stresses, temperature generated during machining etc. Although dry machining is economical, cutting fluid is used in machining to improve the tribological process. It improves surface of workpiece along with improvement in tool life. The large usage of cutting fluid during machining increases total machining cost sometimes it is observed that even cost of cutting fluid is higher than cutting tools. (Klocke and Eisennblatter 1997, Byrne and Scholta 1993). Therefore, attempts to reduce use of cutting fluid, if possible, can benefit economics of the machining process significantly. Dry and MQL techniques uses very less cutting fluid sometimes equal to zero in machining. In minimum quantity lubrication commonly used rate of fluid flow is of 50-500 ml/h range, seen to be very less than the amount used in flooded cooling condition (wet lubrication) (Dhar et. al., 2007). Occupational Safety and Health Administration (OSHA) regulations, refers to allowable quantity of exposure of the spray inside the plant is equal to 5 mg/m^3 and is probably be decreased to 0.5 mg/m^3. With use of MQL, overall performance in turning has been found effective to dry and wet lubrication condition. Some of the parameters studied to observe the performance of MQL are force in cutting, life of tool, surface roughness, temperature generated in cutting and tool-chip contact length (Varadarajan et. al., 2002). The Taguchi statistical approach applied in turning of hard component in minimal fluid application (HTMF) shows the feed as the highest contributing factor followed by pressure, type of coating, quantity of fluid, frequency of pulses and cutting speed on surface roughness (Vikram Kumar and Ramamoorthy, 2007). Another Taguchi study on AISI H11 with 40, 45 & 50 HRc, cutting parameters and hardness effect were observed on surface roughness and cutting force. Result shows that low level of feed, high level of cutting speed and workpiece hardness affect on surface roughness. Similar dry turning study of AISI 4140 with 50 HRc is conducted on CNC. A study conducted with L9 orthogonal array uses a Taguchi method for optimising turning parameters. Feed, interaction of cutting parameters with each other were noted as important factor (Asiltrk and Akkus, 2011). A study on AISI 4340 under MQL condition shoes significant reduction in wear of tool, surface roughness and inaccuracy of dimension as MQL reduces temperature generated at chip-tool and work-tool interface (Dhar et. al., 2007 and Dhar et.al. 2006). Good results are also observed with use of MQL in turning AISI 1040. MQL reduces temperature in cutting, reduces friction between chip and tool, maintains sharpness of cutting edges which results into good dimensional accuracy (Dhar et.al. 2006). The literature shows that many experiments are performed with surface roughness as output parameter under dry, wet and MQL lubrication condition. In much of the literature the cutting conditions are considered as the input parameters. To the best of the knowledge of the authors, no significant study is reported involving various MQL parameters. This suggests that the MQL specific parameters can be worked out to check their effectiveness on the surface roughness. Recently, some have worked on MQL specific parameters with variation in pressure of cutting fluid coming out of nozzle, cutting fluid quantity with machining parameters. However, they have considered two levels of all parameters. The set up developed here is capable of changing the quantity of mixture of cutting fluid and air coming out of nozzle and the distance between nozzle block exit point and cutting point. Hence, in the present experiment a study is conducted using MQL specific parameters viz quantity of mixture of cutting fluid and air, distance of nozzle block from the cutting point along with machining parameters on surface roughness. The Taguchi approach is used in the experiment to analyse and discuss the results obtained.

2 EXPERIMENTAL DETAILS

2.1. Component and Machine tool

The present work shows hard turning of AISI 4340 (EN 24) steel with 42(+/-)2 HRc. Total 25 components are used for trials. The component sizes are 30 mm and length 160 mm. The typical chemical compositions of EN24 steel is given in Table 1. (CMTI, 2011). Cutting test is conducted on CNC lathe using MQL set up.

Table 1. AISI 4340 Material Composition

C	Si	Mn	Cr	Ni	Mo
0.35 – 0.45	0.1 – 0.35	0.4 – 0.7	0.9 – 1.3	1.25 – 1.75	0.2 – 0.35

The carbide insert with DCLNR 25 25 M tool holder is used with following geometry to machine the component: CNMG 12 04 08 C - square shape, 12 - cutting edge length, 08 - nose radius, N - relief angle O^0.

2.2. Input Parameter selection

The cutting conditions play very important role in all machining operations. Further, for understanding the effect of MQL process, cutting fluid mixture (cutting fluid and air) rate and distance in cutting point-nozzle block through which mixture is directed onto the cutting point of insert are considered as two more input parameters. Five levels of each input parameters are considered to get the better picture of significance of process parameters (Dave et. al. 2013). Based on the recommendations of manufacturer catalogue and discussions with some of the industry experts the values of cutting speed, feed and depth of cut were selected. The levels of distance between cutting point to exit of nozzle block and quantity of mixture of cutting fluid and air, are selected so that the mixture will be directed and sprayed directly at the and into the cutting zone and also to avoid the excess flow of cutting fluid. With this it is possible to have a good velocity of stream of mixture of cutting fluid and air exactly into the cutting zone during operation. MQL range reported in the literature is used to select the cutting fluid mixture rate (Dhar et. al. 2006). Maximum flow rate is choosen to be 500 ml/hr and minimum near dry condition (i.e. 100 ml/hr). Table 2 shows various input parameters in an experiment with levels and values.

Table 2. Input Parameters with their levels

Input Parameters	Level 1	Level 2	Level 3	Level 4	Level 5
Discharge (E)	100	200	300	400	500
Distance of nozzle (D)	2.5	3.5	4.5	5.5	6.5
Cutting Speed (V)	100	110	120	130	140
Feed (f)	0.1	0.15	0.2	0.25	0.3
Depth of cut (d)	0.1	0.2	0.3	0.4	0.5

2.3. Selection of Orthogonal Array

A Taguchi method greatly improves engineering processes as it reduces time required and cost involved in trials as the orthogonal array developed using Taguchi approach provides appropriate model with number of experimentation. Performance of parameters in Taguchi approach is tested using signal to noise ratio (S/N). Further ANOVA is used to analyze effect of individual input parameters. It uses three different characteristics to classify an objective. Optimal level of process parameters are then selected based on higher values in S/N table. Initially Taguchi's approach is observed to optimise single performance characteristics but there are products and/or processes working with many performance characteristics which make it difficult to find the optimal process setting. The newly developed orthogonal array provides a balanced design for multiple quality characteristics. Orthogonal array thus developed, helps in study of various input parameters at a time and then used to find each factors effect independently which further reduces efforts, resources and time (Dave et.al., 2013).

Table 3. L25 orthogonal array structure

Trial No.	Dis-charge	Distance of nozzle	Cutting speed	Feed	Depth of cut
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	1	5	5	5	5
6	2	1	2	3	4
7	2	2	3	4	5
8	2	3	4	5	1
9	2	4	5	1	2
10	2	5	1	2	3
11	3	1	3	5	2
12	3	2	4	1	3
13	3	3	5	2	4
14	3	4	1	3	5
15	3	5	2	4	1
16	4	1	4	2	5
17	4	2	5	3	1
18	4	3	1	4	2
19	4	4	2	5	3
20	4	5	3	1	4
21	5	1	5	4	3
22	5	2	1	5	4
23	5	3	2	1	5
24	5	4	3	2	1
25	5	5	4	3	2

As outlined in section, there are five input parameters selected for experimentation with five levels each. L25 orthogonal array is used with 25 experimental runs (Ross, 1997 and Taguchi et.a l., 2004). L25 orthogonal array structure is shown in Table 3 with various input parameters.

2.4. Selection of Response Parameter

In present analysis, surface roughness of EN 24 components in MQL condition is studied. Surface roughness of machined components is measured using Surf test tester (Ra - μm) and a cut of distance is set to 0.8 mm.

2.5. Quality characteristics selection

Generally, many parameters affect on various operations/ processes which sometimes directly/ indirectly decide the desired values of output. Noise in experiments disturbs the output. The objective of Taguchi experiment is to minimise the variations in output though noise is present. Following are the expressions to find out quality characteristics (Dave et. al., 2015).

For larger is better (LB):

$$ni = -10 \cdot \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2}\right) \quad (1)$$

For nominal is best (NB):

$$ni = -10 \cdot \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} yi^2 variance\right) \quad (2)$$

For smaller is better (SB):

$$ni = -10 \cdot \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} yi^2\right) \quad (3)$$

where yi is the observations and n number of replication. The objective of experiment is to decide the cutting conditions and MQL specific parameters required to achieve minimum surface roughness (Ra). So, smaller is better characteristic is used for the present study further calculations (Phadke, 1989 and Taguchi et. al., 2004).

3. RESULT AND DISCUSSIONS

In present study, experiment is performed with two replications (i.e. n=2). On line measurement of surface roughness is not possible therefore the off line measurement of surface roughness is done using surface roughness tester. Present study requires minimising the surface roughness of component therefore Ra is measured at three different locations 120^0 apart on a plane and on three measurements per plane as shown in figure 1. The noise during the experiments viz. performance of machine, mounting of component, usage of machine etc. may influence the geometrical accuracy. Single measurement done after conducting experiments may not be in a position to give precise value therefore more number of observations are recorded with 3 different planes. Average measured values of surface roughness are shown in table 4.

Similar procedure is repeated for second set of trials. Smaller the better criterion shown in equation (3) is used to calculate S/N ratio and the average values of S/N ratios are used to sketch main effect plot. Mean value table of S/N ratio provides the optimum parameters combination with maximum value of each parameter in respective column and are plotted in Figure 2.

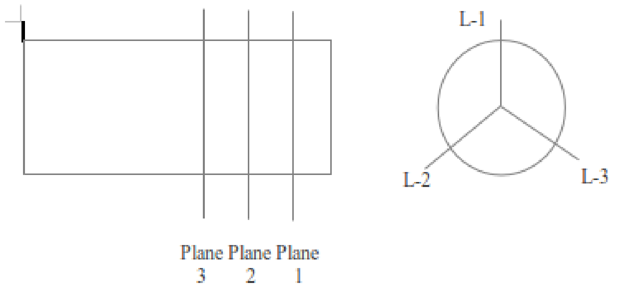

Fig. 1. Measurement of Ra

The S/N ratio analysis indicates following sequence for better surface roughness: [A5 B3 C3 D1 E1] flow rate of air & cutting fluid mixture 500 ml/hr (level 5), distance of nozzle from cutting point 4.5 cm (level 3), cutting speed 120 m/min (level 3), feed 0.1 mm/rev (level 1), depth of cut 0.1 mm (level 1). Significance of each input parameter is checked by performing Analysis of variance (ANOVA). The statistical significance of each individual parameter is tested using a P-value test. Relative power is indicated by percent contribution (% P). The experiment carried out shows the variations observed in individual parameters significantly with percentage contribution. Higher percentage contribution will have a small variation on the performance (Phadke, 1989 and Taguchi et. al., 2004). From ANOVA table it is observed that, quantity of mixture (factor A) and feed rate (factor D) are having p-values below 0.05 showing important effect on surface roughness at 95% confidence level (Phadke, 1989 and Ross, 1997 and Taguchi et. al. 2004).

From table 5, it can be seen that the feed and quantity of mixture of cutting oil and air have highest effect on surface roughness in MQL process. This can be noted from the percentage contribution of above mentioned input parameters.

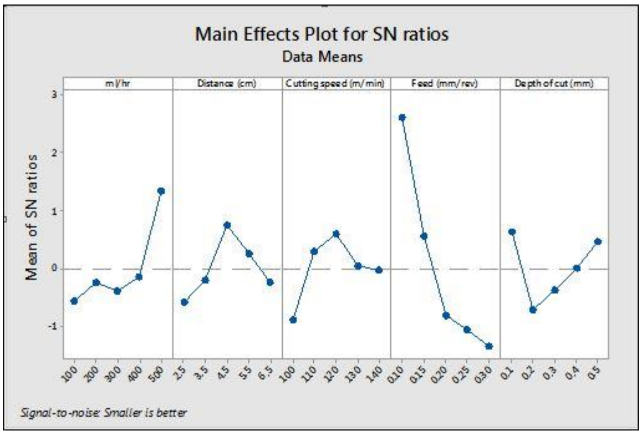

Fig. 2. Mean S/N ratios versus input parameters level

Table shows, feed is the most significant factor related with surface roughness with 63.12% contribution. It can be seen that increase in feed, increases a slight depression in the smoothness of a surface. This slight depression may get deeper and wider, as feed further increases. Also as the feed goes on increasing, the turning process shifts from continuous to intermittent, the distance point of tool travels from the actual point to next point, which can be the reason of increase in surface roughness values.

It can also be noted from a table that quantity of cutting fluid mixture is the second most significant factor related with surface roughness with 13.96% contribution. As the quantity of mixture increases, it develops the thin film of lubrication in between tool point and workpiece. The thin film after separating the two, smoothens the movement of tool point over work surface. This further reduces the friction and in turn reduces the chances of damage to work surface.

Table 4. Measured average surface roughness values in Trial 1 and Trial 2

Trial No	Discharge (E), [ml/hr]	Distance of nozzle (D), [cm]	Cutting speed (V), [m/min]	Feed (f), [mm/rev]	Depth of cut (d), [mm]	Average Ra, [µm] (Trial 1)	Average Ra, [µm] (Trial 2)
1	1	1	1	1	1	0.88	0.87
2	1	2	2	2	2	1.07	1.03
3	1	3	3	3	3	0.9	1.28
4	1	4	4	4	4	1.05	1.23
5	1	5	5	5	5	1.18	1.2
6	2	1	2	3	4	1.05	1.22
7	2	2	3	4	5	1.06	1.06
8	2	3	4	5	1	0.99	1
9	2	4	5	1	2	0.83	0.87
10	2	5	1	2	3	1.15	1.11
11	3	1	3	5	2	1.34	1.27
12	3	2	4	1	3	0.81	0.8
13	3	3	5	2	4	0.91	0.91
14	3	4	1	3	5	1.15	1.14
15	3	5	2	4	1	1.15	1.14

16	4	1	4	2	5	1.02	1.01
17	4	2	5	3	1	1.06	1.03
18	4	3	1	4	2	1.14	1.33
19	4	4	2	5	3	1.27	1.06
20	4	5	3	1	4	0.69	0.72
21	5	1	5	4	3	1.22	0.87
22	5	2	1	5	4	1.21	1.18
23	5	3	2	1	5	0.53	0.52
24	5	4	3	2	1	0.66	0.66
25	5	5	4	3	2	1.02	1.08

Table 5. Table of ANOVA for surface roughness

Factor	Dof	SS	MS	F	P value	%
A: Quantity of mixture	4	11.79	2.94	7.56	0.0378	13.96
B: Distance	4	5.27	1.31	3.38	0.1324	6.24
C: Cutting speed	4	6.13	1.53	3.94	0.1063	7.27
D: feed	4	53.26	13.31	34.18	0.002	63.12
E: Depth of cut	4	6.36	1.59	4.08	0.1007	7.54
ERROR	4	1.55	0.38		0.5	1.84
TOTAL	24	84.37				

Table 6. Confirmation test details for Surface Roughness

Sr No	Quantity of mixture of cutting oil and air	Distance of nozzle block	Cutting speed	Feed	Depth of cut	Surface roughness
1	500	4.5	120	0.1	0.1	1.13
2	500	4.5	120	0.1	0.1	1.11
3	500	4.5	120	0.1	0.1	1.06
				Predicted (S/N)		3.9198
				Confirmation (S/N)		3.9013

4. CONFIRMATION ANALYSIS OF EXPERIMENT

4.1. Evaluation of optimum performance characteristics

Levels of significant parameters predict optimum value of performance characteristics. So the expression used for calculating mean for surface roughness is as under (Ross, 1997).

$$n_{pred} = T + \Sigma (m_i - T) \qquad (4)$$

where T is total mean of response of S/N ratio, m_i is S/N ratio at optimum parameter . The estimated mean for surface roughness is calculated using following expression:

$$n_{pred} = [T + (A5 - T) + (D1 - T)] = 3.9198$$

where A and D are the two factors whose p values is less than 0.05. Therefore A and D are considered for further calculations. The confidence interval (CI_{CE}) of a confirmation run is calculated using following equation (Dave et. al., 2013 and Ross, 1997)

$$CI_{CE} = \sqrt{F_\alpha(1, fe)\, MS_e \left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \qquad (5)$$

where $F\alpha(1, fe)$ is F ratio required at $(1 - \alpha)$ and f_e is error DOf, MS_e is error mean square term, R is repetitions run and n_{eff} is given by (Dave et. al. 2013)

$$n_{eff} = \frac{N}{1 + Dof\ total} \qquad (6)$$

Thus, CI_{CE} for R_a is found to be 3.9198 which is in a range of 2.4768 to 5.3628.

4.2 Confirmation experiments

Validation of the conclusion drawn is accessed through confirmation experiment.As the two trials of initial experiments are carried out, three trials of confirmation are conducted using optimum combination of process parameters (Dave et. al. 2013). Table 6 gives S/N ratio of surface roughness. Surface roughness S/ N ratio for three trial runs is (Ra) = 3:9013 which fits in limit of predicted optimal range 2.4768 to 5.3628. The error in predicted and confirmed values $n_{predicted}$ = 3:9198 and $n_{confirmation}$ = 3.9013 is 0.47%.

The optimum values of each input parameter are Quantity (500 ml/hr), Distance (4.5 cm), Cutting speed (120 m/min), Feed (0.1 mm/rev), Depth of cut (0.1 mm). The increase in quantity of mixture generates the thin film of lubrication in between cutting point and component. This leads to reduction in friction providing smooth surface finish. The distance of nozzle block is neither too far nor to near to the cutting point, which results into exact focusing of mixture in the cutting zone. As reported by earlier investigators, the high cutting speed, low feed and low depth of cut is seen to achieve the best surface roughness.

5. CONCLUSIONS

Present experiment is conducted to study the effect of quantity of mixture of cutting oil and air, distance of nozzle block, cutting speed, feed rate and depth of cut in MQL environment. Trials are conducted on AISI 4340 with R_a considered as response parameters. The conclusions drawn from the experiment are:

The analysis of MQL specific parameters and machining conditions allows investing the effect of each individual on surface roughness.

This shows that the feed and quantity of mixture have statistically important effect on surface roughness.

The surface roughness is strongly influenced by feed and the quantity of mixture of cutting oil and air, (13.96%) and (63.12%) respectively.

The optimum combination of turning parameters are A5 B3 C3 D1 E1 (i.e. flow rate of air & cutting fluid mixture 500 ml/hr (level 5), distance of nozzle from cutting point 4.5 cm (level 3), cutting speed 120 m/min (level 3), feed 0.1 mm/rev (level 1), depth of cut 0.1 mm (level 1)).

The best surface roughness was observed at the lower level of feed and the highest level of quantity of mixture of cutting oil and air.

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Received: June 5, 2016 / Accepted: December 10, 2016 / Paper available online: December 20, 2016