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Parameter Optimization for Turning EN 24 Steel Using Minimum Quantity Lubrication (MQL)

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A B S T R A C T

The aim of the study is to investigate the effect of minimum quantity lubrication (MQL) on response characteristics during turning of EN 24 steel with CVD coated tungsten carbide (CCMT 090T308) insert. The turning experiments were carried out based on the Taguchi design of experiments. Turned surface was analysed with SEM image. Three input parameters such as cutting speed, feed rate and MQL flow rate were considered, carried out the turning operations, utilized the acquired results optimized the surface roughness, cutting force and cutting temperature. The results indicate that minimum quantity lubrication shows better performance over dry turning in terms of surface roughness, cutting force and cutting temperature

1. INTRODUCTION

In metal cutting process, the main function of cutting fluid is to remove heat from cutting zone and provide lubrication. The temperature in cutting zone is high because of the friction between tool and workpiece. High temperature can affect the workpiece quality and tool life. To overcome these disadvantages cutting fluids are used. But use of cutting fluids increases the health hazard as well as can cause a lot of environmental problems [1]. Globally the manufacturing companies have been using approximately 38 million metric tonnes of cutting fluids [2]. The disposal of cutting fluids increases the total manufacturing cost. To reduce the total manufacturing cost as well as wastage of cutting fluids and to minimize the negative effect of cutting fluids on environment, alternative cutting fluid were evaluated by researchers. One of the alternative is minimum quantity lubrication (MQL). MQL technique supplies minimal amount of cutting fluid to cutting zone with the help of nozzle. In MQL wastage of cutting fluids can be effectively reduced and total manufacturing cost also be decreased. MQL technique reduces the wastages of cutting fluid by 3-4 times compared with conventional cooling [3].

Form the past few years, they found that MQL technique is more effective than conventional cooling [4-7]. Dhar et al. [8] demonstrated the impact of MQL on output parameters on turning of AISI-4340 steel. By the application of MQL technique, the cutting zone temperature and friction at between chip-tool interfaces were reduced which led to the reduction of surface roughness and tool wear. Again, Dhar et al. [9] found that if MQL properly used, it provides environmental friendliness and improves the machinability. Cakir et al. [10] study the effect of input parameters including MQL flow rate on surface roughness during turning of aluminium alloy. Authors found that with increase in feed rate and cutting speed surface roughness increases whereas with increase in MQL flow rate surface roughness reduces. Sarikaya et al. [11] evaluated the multi response optimization of MQL parameters. Authors found that MQL technique is a good tool for improvement of machinability. Gupta et al. [12] studied the effect of MQL technique on surface roughness during turning of titanium alloy using RSM. From the results it is clear that RSM can be efficiently used for reduction of machining cost. Gupta et al. [13] did the optimization of machining parameters during turning of titanium alloy. Authors concluded that application of MQL during machining of titanium alloy successfully reduces the output responses. Sreejith [14] evaluated the effect of different machining environment during machining of aluminium 6061 alloy. They found that MQL technique is better option compared with dry as well as flood cooling. Zhang et al. [15] reported that when biodegradable vegetable oil used as cutting fluid in minimum quantity cooling lubrication improve the machinability. Author also claimed that the application of this technique can be improved the tool life and reduced cutting forces. Hwang et al. [16] compared MQL technique with conventional cooling technique during turning of AISI 1045. They reported that the MQL turning was more efficient over wet turning particularly for surface roughness and cutting force. Amini et al. [17] evaluated the effect of MQL technique on turning of AISI 4142 steel. Authors claimed that under MQL environment the tool life and surface quality improves compared with dry turning. Form literature survey, it was clearly observed that a lot of researchers have been studied the MQL technique and revels the advantages of MQL technique over dry and conventional cooling.

Based on the literature review, it was observed that very less work has been reporting regarding the optimization of parameters under MQL during turning process. The aim of this study is to optimize the process parameters and MQL flow rate during turning of EN-24 steel using Taguchi design.

2. MATERIAL AND EXPERIMENTAL CONDITION

EN-24 Steel was used as workpiece material for turning experiments. The Table 1 represents the chemical composition of EN-24steel. Table 2 represents the details of equipment's and parameters. The turning experiments were carried out on HMT NH 26 Centre lathe. The CVD coated tungsten carbide (CCMT 090T308) insert was used for turning of EN-24 steel. The fabricated MQL set-up is shown in Fig. 1.

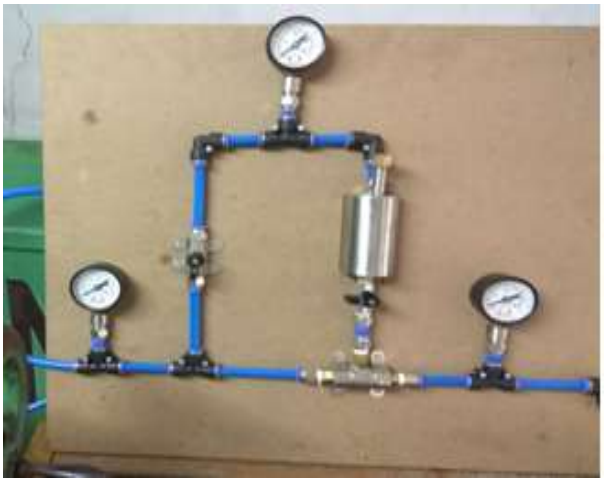

Fig. 1. Minimum quantity lubrication set up.

Table 1. Chemical composition of EN 24 steel.

Elements	C	Mn	Si	S	P	Cr	Ni	Mo
Content (%)	0.38-0.43	0.65 -0.85	0.20-0.35	0.03	0.03	0.90-1.40	1.6-2.00	0.2-0.30

Table 2. Equipment's and parameters.

Workpiece Material	EN-24 Steel (300mm X 80mm)
Tool Holder specification	SCLCR 1212F09
Cutting Tool	CCMT 09T308
Machine Tool	HMT NH 26 Centre lathe
Cutting Fluid	Soluble oil
Surface Roughness	Surfcom 13OA
Cutting Forces	Tri-axial Turning force dynamometer
Cutting Temperature	Infrared thermometer, MT-5
Process parameters Cutting Speed(m/min) Feed rate(mm/rev) MQL flow rate(ml/h) Depth of cut(mm)	 40, 80, 120 (m/min) 0.08, 0.16, 0.24 (mm/rev) 0, 90, 180 (ml/h) 0.5 mm

MQL set-up was used to supply the air and cutting oil in form of mist MQL. The fabricated set-up consists of nozzle, air control valve, air compressor, oil container, mixing camber and pressure gauges. The high velocity air supplied through air compressor, air and cutting oil were mixed at mixing chamber and supplied to the cutting zone through nozzle in the form of mist. A surface roughness tester (Surfcom 130A) was used for measurement of surface roughness (Ra). The surface roughness (Ra) was measured three times and average value was calculated. In this study, the cutting forces were measured by Tri-axial Turning force dynamometer (Model No. AWON-CCT -50, Manufactured by: Real Scientific Engg. Corpn., India). Cutting temperature was measured by Infrared thermometer (MT-5).

3. EXPERIMENTAL PROCEDURES

The designing of experiments becomes difficult if there were large number of parameters. When the number of input process parameters increases the number of experiments also increases. The experiments were planned based on Taguchi's L_9 array using MINITAB 17. The details of levels and parameters were given in Table 3.

Table 3. Input parameters and their levels.

No.	Input process parameters				Parametric levels		
	Input Parameters		Symbol	Unit	1	2	3
1	A	Cutting speed (Y_1)	v_c	m/min	40	80	120
2	B	Feed rate (Y_2)	f	mm/rev	0.08	0.16	0.32
3	C	MQL flow rate(Y_3)	MQL	ml/h	0	90	180

Table4. Experimental results and S/N ratios for output responses.

Run	Y_1	Y_2	Y_3	SR (μm)	CT (°C)	CF (N)	SR (S/N)	CT (S/N)	CF (S/N)
1	40	0.08	0	2.23	250	74	-6.96610	-47.9588	-37.3846
2	40	0.16	90	1.35	198	43	-2.60668	-45.9333	-32.6694
3	40	0.24	180	1.15	180	39	-1.21396	-45.1055	-31.8213
4	80	0.08	90	1.12	176	45	-0.98436	-44.9103	-33.0643
5	80	0.16	180	0.99	190	38	0.08730	-45.5751	-31.5957
6	80	0.24	0	1.98	286	80	-5.93330	-49.1273	-38.0618
7	120	0.08	180	0.85	150	34	1.41162	-43.5218	-30.6296
8	120	0.16	0	1.87	220	69	-5.43683	-46.8485	-36.7770
9	120	0.24	90	1.23	185	50	-1.79810	-45.3434	-33.9794
SR = Surface roughness (Ra, μm), CF = Cutting force, CT = Cutting temperature									

4. ANALYSIS OF RESULTS

4.1 Optimal parameters for surface roughness

The effect of input process parameters on output performance parameters can be evaluated by S/N (signal to noise ratio) ratio. The lower value of S/N ratio for surface roughness means better performance. Fig. 2 shows the S/N ratio for surface roughness. Form the S/N ratio graph it can be clearly observed that the best parametric combination for surface roughness is $A_3B_1C_3$. This means that the surface quality is best at higher cutting speed, lower feed rate and higher MQL flow rate. This is due the fact that at higher MQL flow rate cutting fluid penetrates easily to cutting zone and reduces friction between tool-chip interfaces hence improves the surface quality. Table 5 shows the analysis of variance for surface roughness (Ra). Table 5 also represent the % contribution of input parameters on surface roughness height. The most significant parameters for surface roughness (Ra) is cutting MQL flow rate with 91.03% of contribution.

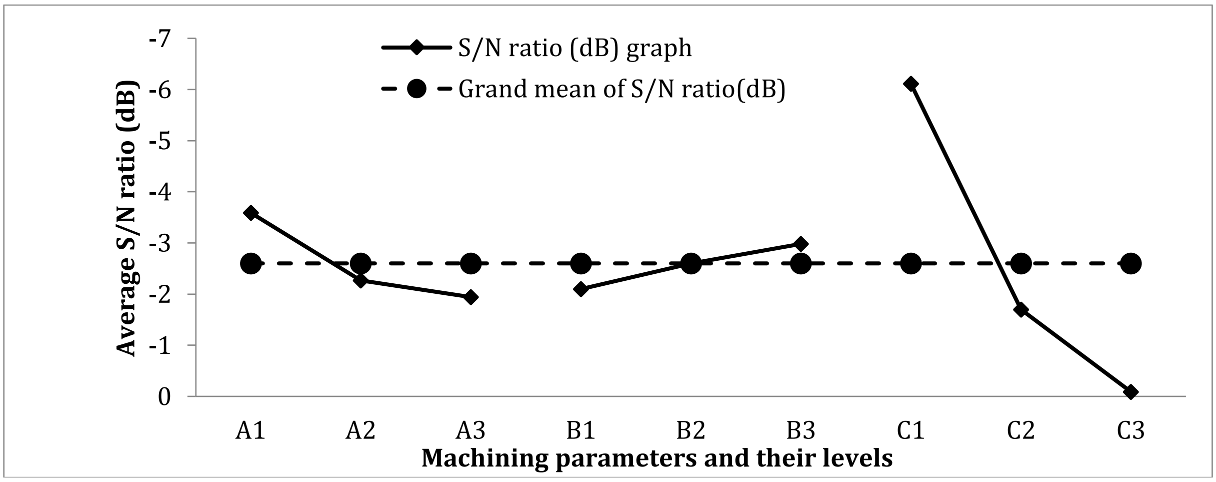

Fig. 2. S/N ratio for surface roughness (Ra).

Table 5. Analysis of variance (ANOVA) for surface roughness (Ra).

Symbol	Machining parameter	Dof	Sum of squares	MS	F value	% Contribution
A	Cutting speed	2	4.58	2.29	11.04	6.8%
B	Feed rate	2	0.97	0.48	2.35	1.45%
C	MQL flow rate	2	60.73	30.36	146.14	91.03%
Error		2	0.41	0.20		
Total		8	66.71			

4.2 Optimal parameters for cutting force

From Fig. 3 is can be clearly observed that the best parametric setting for cutting force is $A_3B_1C_3$ this means that at level-3 i.e. 120m/min of cutting speed, at level-1 i.e. 0.16 mm/rev of feed rate and at level-3 i.e. 180ml/h of MQL flow rate will give efficient results for cutting force.

4.3 Optimal parametric combination for cutting temperature

The optimal combination of input parameters i.e. cutting speed, feed rate and MQL flow rate for cutting temperature can be identified from S/N ratio (dB) graphs. At low cutting speed (parameter and level: A_1) and feed rate (parameter and level: B_1) the cutting temperature is comparatively low over other condition of cutting, it is may be due to less friction at cutting zone. In case of dry turning the cutting temperature is high because of high friction but turning with MQL (flow rate 180 ml/h, parameter and level: C_3) the coefficient of friction in the cutting zone reduced due to effective cooling thereby the cutting temperature was low as compared to the dry turning. From Table 7, it can be concluded that cutting speed and MQL flow rate are the significant parameters. The optimal parametric setting for cutting temperature is $A_1B_1C_3$.

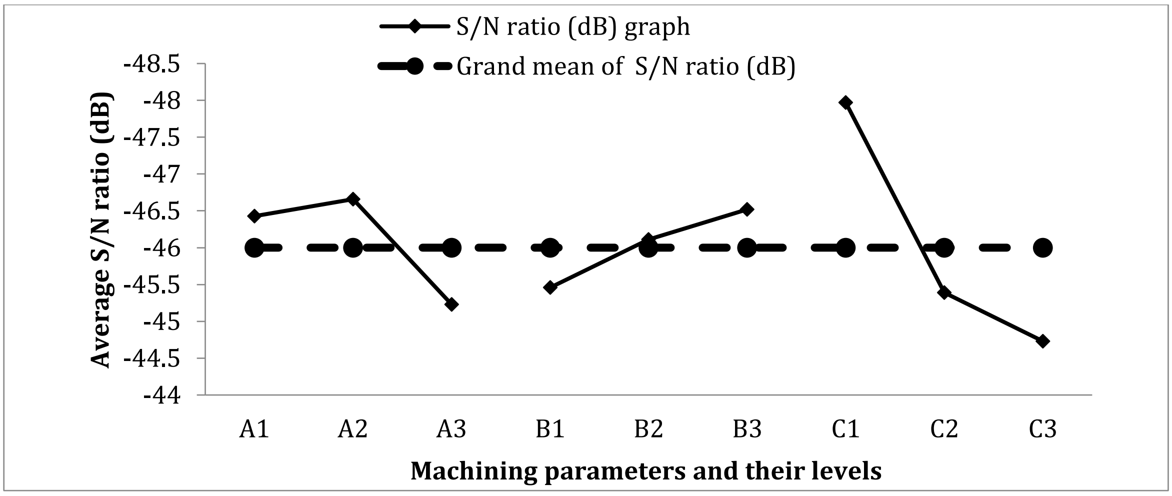

Fig. 3. S/N ratio for cutting force.

Table6. Analysis of variance (ANOVA) for cutting force.

Symbol	Machining parameter	Dof	Sum of squares	MS	F value	% Contribution
A	Cutting speed	2	2.92	1.46	3.92	12.6%
B	Feed rate	2	1.72	0.86	2.19	7.4%
C	MQL flow rate	2	17.63	8.81	22.37	76.41%
Error		2	0.788	0.39		
Total		8	23.07			

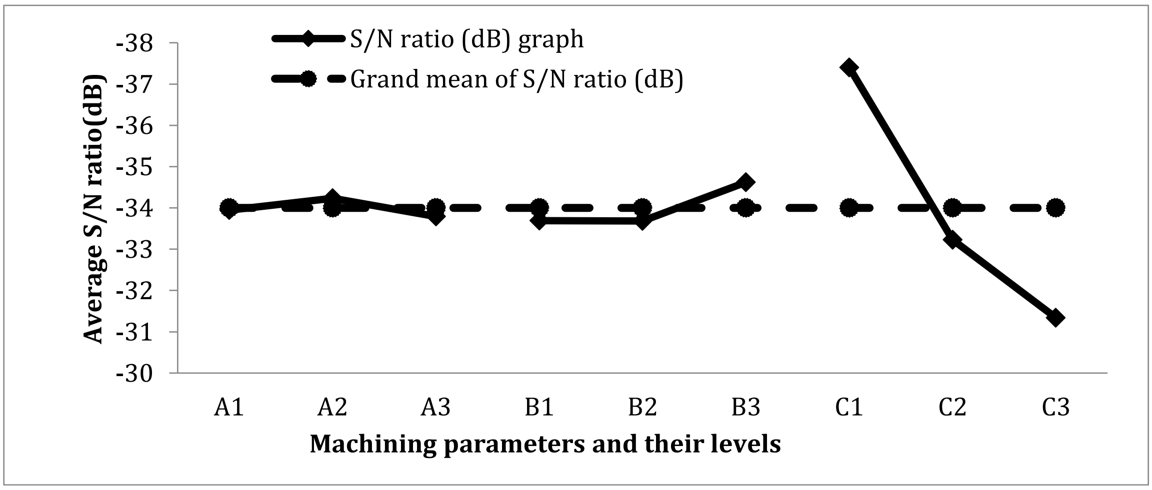

Fig. 4. S/N ratio for Cutting temperature.

Table 7. Analysis of variance (ANOVA) for cutting temperature.

Symbol	Machining parameter	Dof	Sum of squares	MS	F value	% Contribution
A	Cutting speed	2	2.30	0.15	0.63	3.8%
B	Feed rate	2	1.74	0.87	3.63	2.8%
C	MQL flow rate	2	57.66	28.83	119.65	95.16%
Error		2	0.48	0.24		
Total		8	60.19			

4.4 Analysis of variance(ANOVA) for output responses

The percentage contribution of input process parameters on output responses and F-test values were shown in Tables5, Table 6 and Table 7. The tables show that during turning of EN 24 steel the most significant, significant and less significant parameters. It was clearly observed that the most significant parameter is MQL flow rate, the significant parameter is cutting speed and the less significant parameter is feed rate.

4.5 Analysis of Turned surface with SEM image

Fig. 5 shows the SEM images of turned surface. It was clear from the SEM micrographs that surface finish in MQL turning is better as compared with dry turning. In dry turning, due to high friction between tool-chip interface cutting edge wear occurs rapidly. Because of higher tool wear, turning process is no more smoother which leads to increase the surface roughness. In MQL turning, due to the presence of cutting fluid and flow of cutting fluid cause of reduction in friction between tool-chip interfaces, which leads in reduction of tool wear. So the turning with MQL is generate smooth surface finish.

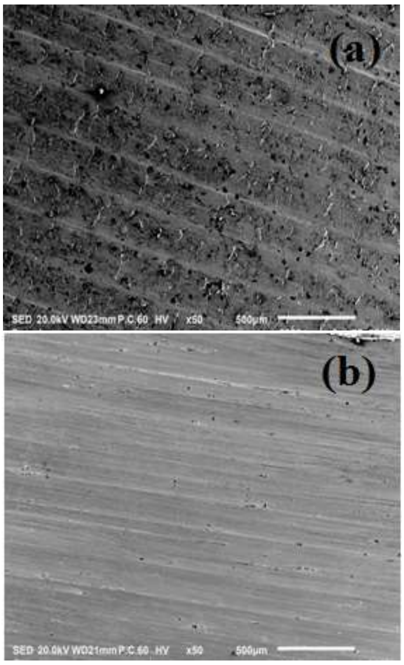

Fig. 5. SEM images of turned surface at (a) cutting speed = 40m/min, feed rate = 0.08 mm/rev, with dry environment; (b) cutting speed = 120 m/min, feed rate = 0.08 mm/rev, with MQL flow rate =180ml/h.

5. CONCLUSIONS

In the present research, investigated the effect of MQL on turning response characteristics. Taguchi method based design of experiments L_9 (3^4) orthogonal array was used for experiments. Surface roughness, cutting force and cutting temperature were measured during turning of EN-24 steel.

Based on the experimental results the following conclusions have been drawn are as listed as:

- The surface roughness can be reduced during turning by introducing minimum quantity lubrication (MQL) technique.
- Experimental results revels that, the cutting force in dry turning was high as compared to turning with MQL. Because MQL brings down temperature effectively at cutting zone and subsequently protect the tool wear and maintaining the effectiveness of tool for a long duration.
- Cutting temperature in dry turning was high as compared to turning with MQL. The application of MQL during turning gives better cooling and lubricating effect, it is because of utilized the arosolization cutting fluid during turning, which effectively enters the cutting region and reduces the temperature.
- From ANOVA, it is clear that the parameter MQL flow rate has a significant influence on surface roughness, cutting force and cutting temperature.

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