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Research Article

A COMPARATIVE STUDY OF FACE MILLING OF D2 STEEL USING AL_2O_3 BASED NANOFLUID MINIMUM QUANTITY LUBRICATION AND MINIMUM QUANTITY LUBRICATION

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ABSTRACT

This study aims to investigate the effects of process parameters: feed, depth of cut and flow rate, on the temperature during face milling of the D2 tool steel under two different lubricant conditions, Minimum Quantity Lubrication (MQL) and Nano fluid Minimum Quantity Lubrication (NFMQL). Deionized water with the flow rate range 200–400 ml/h was used in MQL. 2% by weight concentration of Al_2O_3 nano particles with deionized water as a base fluid used as NFMQL with the same flow rate. Response surface methodology RSM central composite design CCD was used to design experiment run, modeling and analysis. ANOVA was used for the adequacy and validation of the system. The comparison shows that NFMQL condition reduced temperature more efficiently during machining.

Keywords: face milling, temperature, response surface methodology, steel

INTRODUCTION

To control elevated temperatures during machining different cooling techniques are used. Conventional cooling, also known as flood cooling, is one of the oldest and commonly used techniques in the manufacturing industry. Lubrication plays an important role in the field of manufacturing by reducing temperature and increasing the tool life. But in flood cooling the coolant costs is 16% of the total manufacturing cost (Sarhan, Sayuti et al. 2012). To reduce this cost Minimum Quantity Lubrication (MQL) technique is introduced. In MQL, coolant with a very low flow rate is sprayed with the help of compressed air (Klocke and Eisenblätter 1997). According to the author, MQL uses three times less fluid, as compared to the flood cooling with the flow rate approximately 50–500 ml/h. To improve the results obtained from the MQL, nano particles are dispersed in the fluid. The addition of nano-particles in the fluid will increase the thermal conductivity of the fluid. This will help to reduce temperature more efficiently, as compared to MQL (Hadi and Atefi 2015).

M. Sayuti et al. experimented on duralumin AL-2017-T4 using carbon onion nano particles during milling and stated that 46% reduction occurs in surface roughness was reduced, as compared to an ordinary lubricant; carbon onion reduces the friction coefficient at the point of interface (Sayuti, Sarhan et al. 2013). Bizhan Rahmati et al. used tungsten carbide tool with two flutes for the milling of AL 6061-T6 also used MoS2 Nano particles, with ECOCUT HSG 905S as the base fluid, in different concentrations and find out that best surface finish is achieved with 0.5% concentration of Nano particles in the base fluid (Rahmati, Sarhan et al. 2014). Bin Shen et al. compared flood cooling and minimum quantity lubrication with Nano lubrication using different Nano particles, such as Al_2O_3, Nano Diamond and found that Nano Fluid with 2.5% of Al_2O_3 gives best surface finish than other, in case of Diamond Nano particles 200 nm particles gives good surface finish than 100 nm particles (Shen, Shih et al. 2008).

Nano particle has good stability in the fluids due to their smaller size, they will increase the thermal conductivity of the fluid up to next level without leaving any negative change such as pressure drop (Daungthongsuk and Wongwises 2007). M. Amrita et al. carried out experiments by using nano fluid as MQL in turning of AISI1040 steel. Air compressor with an air atomizing nozzle was used for the MQL conditions with a flow rate of 10 ml/min. The results showed that temperature of the work piece and the tool decreased up to 20% as compared with the conventional coolant (Amrita, Srikant et al. 2014). Das et al. studied the behavior of Aluminum oxide Nano particles and conclude that the behavior of Nano particles was very temperature dependent, so it has increased the use of Nano particles in elevated temperature applications (Putra, Thiesen et al. 2003).

Industrial sector is still in quest of new strategies to minimize the workpiece-tool temperature during the machining process. So, in such circumstances many researchers have proposed and validated that MQL is an efficient method to decrease the temperature. It has been proved by many researchers that MQL gives better lubrication during cutting machining process which gives better result than dry machining. However, very few or no work has been reported on the nano fluid minimum quantity lubrication (NFMQL) face milling of D2 tool steel using Response surface Methodology (RSM) technique. The aim of the current study is to develop mathematical models for the prediction of temperature during the face milling of D2 steel under two different lubrication conditions (i) MQL and (ii) NFMQL, and their comparison. The best predicted model will help the practitioner to get the desired results using the optimum values of the input parameters. Furthermore, the study of temperature is necessary for workpiece surface analysis.

EXPERIMENT

Material selection

Difficult to machine materials are those materials which produce tool wear, high forces and elevated temperatures (Shokrani, Dhokia et al. 2012). The selected material for the current research is D2 steel, known as tool steel, with high carbon and high chromium composition. The hardness of difficult to machine materials is high, D2 steel hardness ranges from 55 to 62HRC. The percentage of chemical composition of the material has been provided in table 1. Milling cutters, center lathe, drills dies are famous applications of the selected material. Work pieces are prepared using end milling cutter having the dimensions of $60\times40\times10$ mm^3.

Tool selection

Due to the hardness of the D2 steel a tool with high wear resistance is preferred for the face milling of the D2 steel. For this purpose tungsten carbide inserts were used in current study. Because tungsten carbide inserts have high wear resistance (Li and Liang 2007). Single insert tool is used with a diameter of 8 mm.

Lubricant selection

Two lubricants selected for the current study (i) deionized water for the MQL condition and (ii) deionized water with the addition of Al_2O_3 nano particles in it for the NFMQL condition. According to the Cong Mao the proper suspension of Al_2O_3 nanoparticles in deionized water decreased the coefficient of friction by 34.2%, as compared to the pure deionized water (Mao, Huang et al. 2014). In deionized water almost all of the mineral ions such as sodium, copper, iron and calcium are removed and produced purified form of water. During Experiment Deionized water is used to remove the effects of mineral ions on the performance parameter and minimize the risk of reaction between the mineral ions and nano particles.

Table 1. Chemical composition of D2 steel

Element	C	Si	Mn	Cr	Mo	V	P	S	Ni	Fe
%	1.56	0.30	0.40	11.9	0.78	0.80	0.023	0.015	0.05	Balance

Process parameters selection

Feed rate, depth of cut and the flow rate are the selected input parameters for the face milling of the D2 steel under MQL and NFMQL conditions. Input parameters and their ranges are selected from the detailed literature review of the MQL process and are presented in Table 2. Whereas the spindle speed 1000 rpm is kept constant for all the experiments.

Experimental setup

The experiments were carried out with the help of CNC milling machine. Milling width is 40×40 mm^2 for all the experiments. Lubricant sprayed over the tool work piece interface using spray nozzle. The nozzle was placed at the angle of 45° to the work piece. Temperature was measured during the experimentation with the help of infrared thermometer (Raytek-Rayngner MX4). It has a wide range of temperature measurement from -30 to 900°C. Figure 1 shows the complete experimental setup in detail.

Experimental Design

Experimental design for the current study has been developed using Response surface methodology (RSM) with the help of three input parameters total 17 experiments were carried out for each lubrication environment.

RESULTS AND DISCUSSION

Mathematical model

The input variables that affect the temperature significantly in MQL environment are feed rate, depth of cut and flow rate. On the other side, the same significant parameters are observed for the NFMQL. Values of R^2, adjusted R^2 and predicted R^2 for both the environments are close to 1 which shows their accuracy is presented in table 4 and 5 respectively. Both models are significant. Final mathematical models for the prediction of the temperature in MQL and NFMQL environment are shown in the Eq. 1 and 2 respectively.

$$\text{Temperature MQL} = +151.50 + 20.13 * A + 13.63 * B - 20.75 * C + 11.00 * A * B - 8.75 * A * C + 2.25 * B * C - 12.75 * A^2 + 1.75 * B^2 - 1.50 * C^2 \quad (1)$$

$$\text{Temperature NFMQL} = +119.00 + 17.50 * A + 15.38 * B - 17.88 * C + 7.50 * A * B - 9.00 * A * C + 5.25 * B * C - 12.62 * A^2 + 0.13 * B^2 - 7.38 * C^2 \quad (2)$$

Table 2. Input parameters and their ranges

Sr. No.	Input parameters	Units	Level 1	Level 2	Level 3
1	Feed rate	mm/min	100	150	200
2	Depth of cut	mm	0.2	0.6	1.0
3	Flow rate	ml/hr	200	300	400

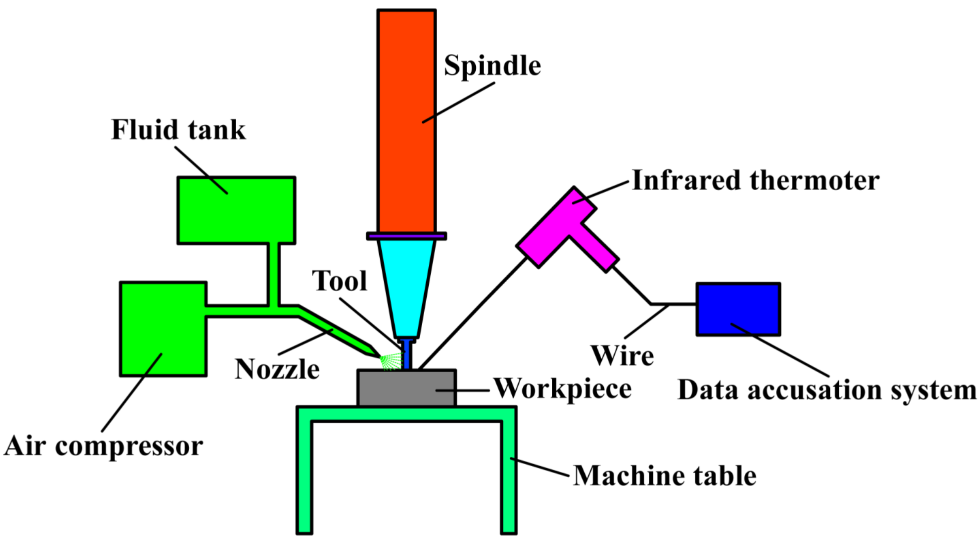

Figure 1 Experimental setup

Table 3. Design Matrix with observed results

Sr. No.	Input parameters			Performance parameter	
	Feed rate	Depth of cut	Flow rate	Temperature °C	
	mm/min	mm	ml/hr	MQL	NFMQL
1	150	0.5	300	146	117
2	200	0.8	300	189	149
3	100	0.2	300	114	79
4	150	0.8	400	143	113
5	150	0.2	200	165	121
6	100	0.5	400	108	71
7	200	0.5	400	128	89
8	150	0.5	300	157	119
9	200	0.2	300	135	98
10	150	0.5	300	148	124
11	100	0.5	200	129	91
12	100	0.8	300	124	100
13	200	0.5	200	184	145
14	150	0.5	300	155	116
15	150	0.2	400	116	77
16	150	0.8	200	183	136

Table 4. ANOVA table for MQL

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	9651.75	9	1072.417	39.41501	0.0001	significant
A	3240.125	1	3240.125	119.0858	< 0.0001	
B	1485.125	1	1485.125	54.58346	0.0003	
C	3444.5	1	3444.5	126.5972	< 0.0001	
AB	484	1	484	17.78867	0.0056	
AC	306.25	1	306.25	11.25574	0.0153	
BC	20.25	1	20.25	0.744257	0.4214	
A^2	650.25	1	650.25	23.89893	0.0027	
B^2	12.25	1	12.25	0.45023	0.5272	
C^2	9	1	9	0.330781	0.5861	
Residual	163.25	6	27.20833			
Lack of Fit	78.25	3	26.08333	0.920588	0.5263	not significant
Pure Error	85	3	28.33333			
Cor Total	9815	15				
Std. Dev.			5.216161	R-Squared		0.983367
Mean			145.25	Adj R-Squared		0.958418
C.V. %			3.591161	Pred R-Squared		0.857044
PRESS			1403.111	Adeq Precision		19.82425

Model Validation

To validate the developed model four experiments were carried out on different values of the input parameters rather than the values of experimental design. The error between predicted and actual values is calculated with the help of Eq. 3 (Sarfraz, Jahanzaib et al. 2016). Table 6 contains the predicted and actual values with the calculated errors.

$$Pcentage\ error = \left|\frac{actual\ value - predicted\ value}{predicted\ value}\right| \times 100 \quad (3)$$

Response surface plots for Temperature

The graphs explain the impact of the feed rate, depth of cut and flow rate on the temperature during the experimentation. In Figure 2 effects of feed rate and depth of cut on temperature are shown. Temperature increases with the increase in depth of cut and same for the feed rate in MQL condition. Feed rate affects more significantly than that of the depth of cut. On the other hand, the same behavior has been noticed for the NFMQL condition.

Table 5. ANOVA table for NFMQL

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	8411.688	9	934.63194	53.28068	< 0.0001	significant
A	2450	1	2450	139.6675	< 0.0001	
B	1891.125	1	1891.125	107.8076	< 0.0001	
C	2556.125	1	2556.125	145.7173	< 0.0001	
AB	225	1	225	12.8266	0.0116	
AC	324	1	324	18.47031	0.0051	
BC	110.25	1	110.25	6.285036	0.0461	
A^2	637.5625	1	637.5625	36.34561	0.0009	
B^2	0.0625	1	0.0625	0.003563	0.9543	
C^2	217.5625	1	217.5625	12.40261	0.0125	
Residual	105.25	6	17.541667			
Lack of Fit	67.25	3	22.416667	1.769737	0.3254	not significant
Pure Error	38	3	12.666667			
Cor Total	8516.938	15				
Std. Dev.			4.188277	R-Squared		0.987642
Mean			109.0625	Adj R-Squared		0.969106
C.V. %			3.840254	Pred R-Squared		0.865732
PRESS			1143.556	Adeq Precision		22.42441

Table 6. Validation experimentation

Input parameter				Response		
Run	Feed rate	Depth of cut	Flow rate		Temperature	
					MQL	NFMQL
1	115	0.30	250	**Experimental**	141	95
				Predicted	135	99
				Error %	**4.4**	**4.0**
2	135	0.70	350	**Experimental**	139	111
				Predicted	143	113
				Error %	**2.7**	**1.7**
3	165	0.4	275	**Experimental**	152	123
				Predicted	156	122
				Error %	**2.5**	**0.8**
4	185	0.6	325	**Experimental**	162	127
				Predicted	160	125
				Error %	**1.2**	**1.6**

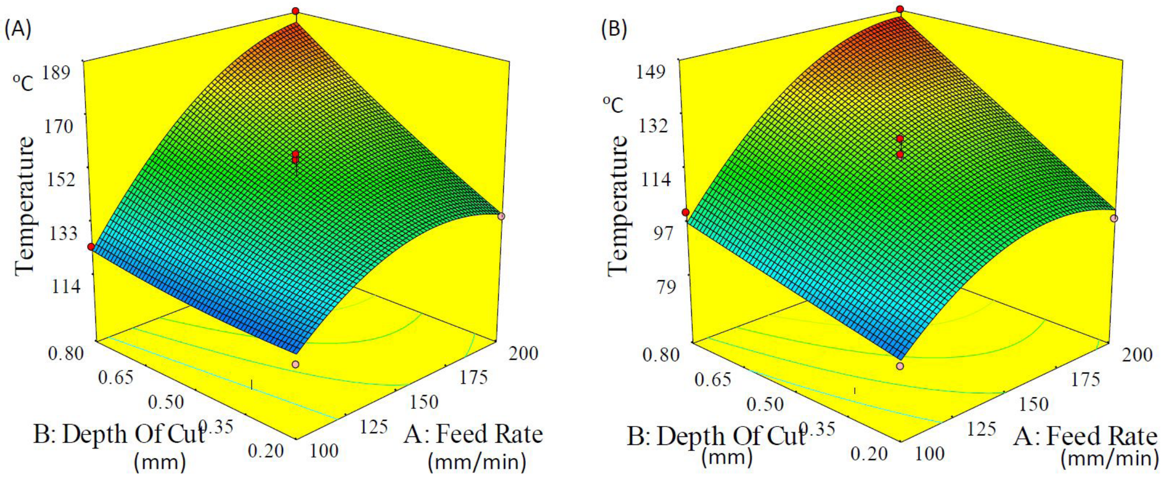

Figure 2. Response surface plots for temperature between feed rate and depth of cut (A) MQL (B) NFMQL

Figure 3 presents the impact of flow rate and feed rate on the temperature during the experimentation. According to the results of MQL condition, temperature increases with the increase in feed rate and decrease by increasing flow rate. Same behavior has been spotted for the NFMQL.

Effects of depth of cut and flow rate on temperature have been provided in Figure 4. Temperature increases with the increasing depth of cut and decreases with the increase in flow rate in case of MQL condition. For NFMQL condition same trends has been observed.

Comparison

Table 7 contains the temperature results of MQL and NFMQL conditions along with the percentage reduction in temperature. According to the results NFMQL condition reduce temperature more effectively than the MQL condition. In NFMQL the solid nano particles absorb more heat due to conduction, as compared to the fluid.

CONCLUSION

The main aim of this study is to investigate the behavior of the temperature during face milling of the D2 tool steel under two different lubricant conditions, Minimum Quantity Lubrication (MQL) and Nano fluid Minimum Quantity Lubrication (NFMQL). The study investigates the effects of process parameters' feed rate, depth of cut and flow rate on the response. According to the

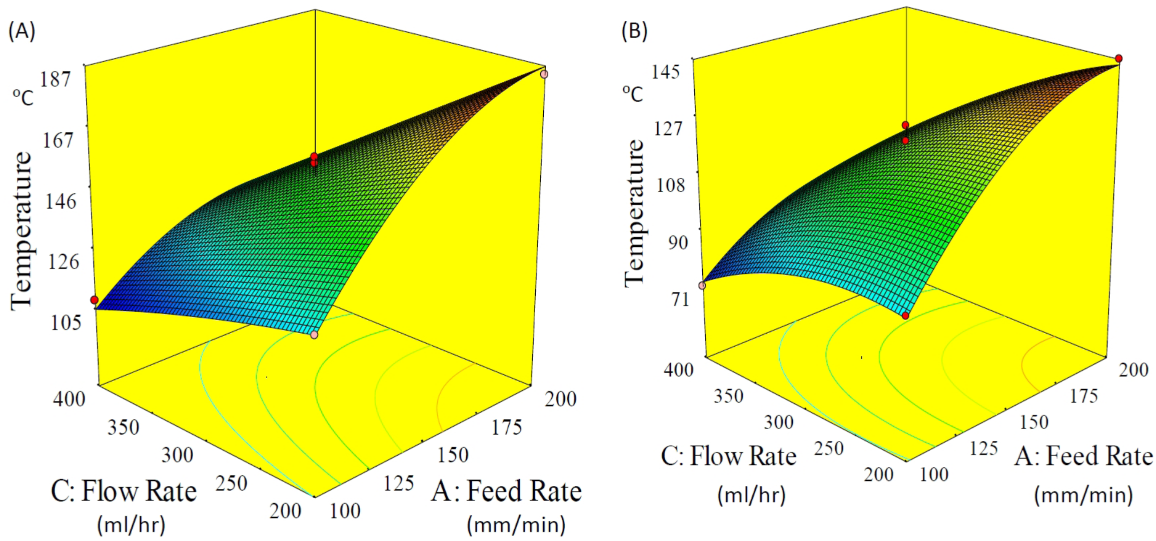

Figure 3. Response surface plots for temperature between feed rate and flow rate (A) MQL (B) NFMQL

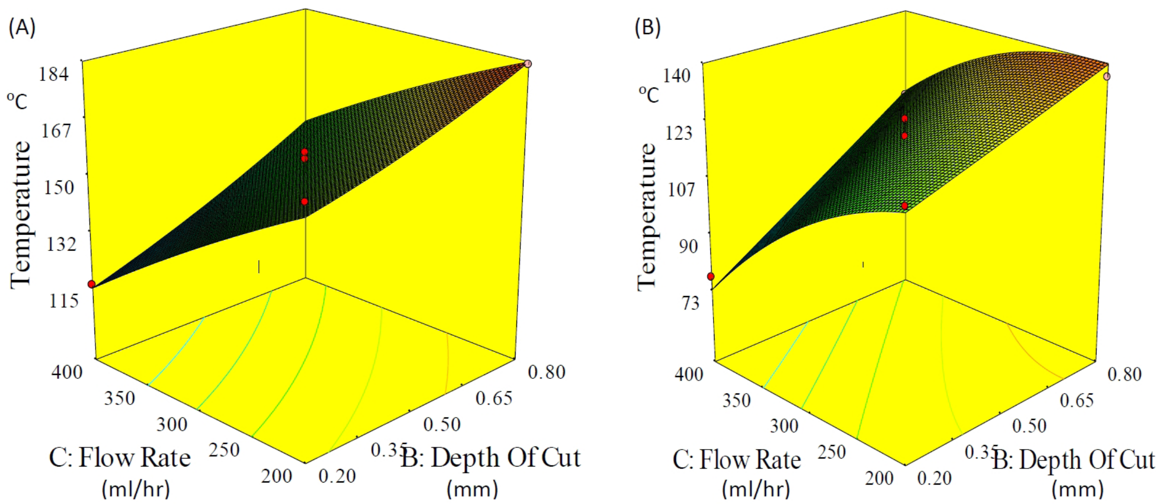

Figure 4. Response surface plots for temperature between flow rate and depth of cut (A) MQL (B) NFMQL

Table 7. Comparison between MQL and NFMQL

Sr. No.	Temperature		% Reduction
	MQL	NFMQL	
1	146	117	0.20
2	189	149	0.21
3	114	79	0.31
4	143	113	0.21
5	165	121	0.27
6	108	71	0.34
7	128	89	0.30
8	157	119	0.24
9	135	98	0.27
10	148	124	0.16
11	129	91	0.29
12	124	100	0.19
13	184	145	0.21
14	155	116	0.25
15	116	77	0.34
16	183	136	0.26

results, all the input parameters affects temperature significantly.

The comparison shows that NFMQL shows better results for the temperature. On average 25% reduction in temperature is noticed during NFMQL condition, as compared to simple MQL.

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