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Optimization of Machining Parameters for Minimal Temperature in Turning A-286 Superalloy under Minimum Quantity Lubrication using RSM

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Abstract

Lubricant is used only in the smallest amount while machining in (MQL) minimum quantity lubrication. Due to its enhanced ability to remove heat from the machining zones, minimum quantity lubrication is a widely used lubrication system. In this experimental work, the usage of MWCNT (Multi Walled Carbon Nano Tubes) nanofluids with MQL in turning A286 superalloy is presented. Experiments were executed using L_{18} orthogonal array. Cutting speed, feed rate and cutting temperature were used to investigate the effectiveness in various environmental machining conditions (dry condition, oil condition, and nanofluid condition). The findings shows that MWCNT nanofluids with minimum lubrication were successful in lowering the cutting temperature.

Keywords: Turning, Cutting speed, Feed, Cutting temperature, A286 superalloy, Minimum quantity lubrication, Nanofluids.

Introduction

MQL, sometimes known as near-dry machining, is a clean manufacturing process. In MQL, the cutting zone is sprayed with a significantly less amount of cutting fluid. For the majority of industrial applications, flow rates between 10 and 100 mL/h are often used. In this paper it was observed that the addition of multiwall carbon nanotubes to cutting fluid can help lower the temperature in the cutting zone because it improves the fluid's thermal conductivity and increases its capacity to carry heat, both of which contribute to a lower cutting zone temperature [1]. The experimental findings shows that tool wear is significantly influenced by the temperature of the tool-chip contact area; the higher the temperature, the quicker the tool wear. In some circumstances, cryogenic CO2-assisted minimum quantity lubrication technology can take the role of cutting fluid in hard-to-machine materials [2]. It was noticed that when compared to single texture tool, the suggested hybrid texture tool considerably lowered the cutting temperature (T_m), tool flank wear (V_B), and surface roughness (Ra) to obtain maximum values of 26%, 31%, and 34%, respectively. Furthermore, the hybrid texture tool tool had a lower built-up edge when compared to single texture tool [3].

The multi-objective optimization result demonstrates that the optimized machining factors resulted in the least surface roughness of 1.16 m, maximum MRR of 52.1 mm^3/min, and minimum cutting force of 33.75 N. In conclusion, the MWCNTs-based copra oil nanolubricant multi-objective optimization improved the manufacture of machine parts for sustainable additive manufacturing [4]. It was observed that the best cooling approach for minimising tool wear and surface roughness was determined by the minimum quantity lubrication method. In all experimental trials involving ceramic grades, SiAlON inserts produced superior outcomes [5].

Materials and methods

Nanofluid

With groundnut oil serving as a base fluid, the current research has been carried out employing MWCNTs nanofluids. Unlike the rings of a tree or a folded telescopic antenna, multi-walled carbon nanotubes (MWCNTs) are a particular type of carbon nanotube in which numerous single-walled carbon nanotubes are nestled inside one another. Groundnut oil is processed

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for around 60 minutes in a probe ultrasonicator to disperse MWCNTs in it.

Design of experiments

For experimental work, the controlling process parameters were chosen to be cutting speed, feed, and environment. The two process parameters are varied at three levels, one parameter varied at two levels. Hence, an L_{18} orthogonal array was used. The experimental trials were done to reduce methodological error. The process parameters and their levels are listed in Table 1. The measured responses are listed in Table 2.

Table 1. Process parameters and levels

Symbol	Factors	unit	1	2	3
f	Feed	(mm/rev)	0.1	0.2	–
B	Environment	–	Dry	Oil	Nanofluid
V_C	Cutting Speed	(m/min)	65	85	106

Experimentation

Experiments were performed to examine the performance of dry, oil and nanofluids in turning process. For each environment condition, the experiments were conducted six times with varying cutting speed & feed, and the outcomes were recorded. The experiments were conducted on a Super Jobber CNC (Computerized Numerical Control) turning lathe centre.

Work material

A286 superalloy with a 25 mm diameter and 100 mm length is the work material. It is an iron-based superalloy useful for applications in requiring high strength, corrosion resistance up to 704°C and lower stress applications at higher temperatures. Chemical composition of the work material includes Fe: 52 % Ni: 26 % Cr: 14 %.

Table 2. Experimental design for L_{18} array (Turning)

Exp. No.	Environment (B)	Cutting Speed (m/min)	Feed (mm/rev)	Temperature (°C)
1	Dry	65	0.1	105
2	Dry	85	0.1	131
3	Dry	106	0.1	165
4	Oil	65	0.1	52
5	Oil	85	0.1	68
6	Oil	106	0.1	85
7	Nanofluid	65	0.1	36
8	Nanofluid	85	0.1	45
9	Nanofluid	106	0.1	63
10	Dry	65	0.2	113
11	Dry	85	0.2	142
12	Dry	106	0.2	171
13	Oil	65	0.2	61
14	Oil	85	0.2	75
15	Oil	106	0.2	93
16	Nanofluid	65	0.2	43
17	Nanofluid	85	0.2	51
18	Nanofluid	106	0.2	72

Results & Discussion

ANOVA for temperature

Due to the interaction of the tool with the workpiece at high-speed rotation, a certain amount of heat is generated throughout the machining process. In the ANOVA (Table 3), Environment is concluded to be the dominating factor which has the largest F- value of 5899.99.

The R^2 and adequate precision for temperature

The ability of the model was scrutinised with the closeness of the R^2 value. From (Table 4), the R^2=0.99 close to 1 which is enviable [6]. Adequate precision is used to evaluate the signal-to-noise ratio and the value achieved was 97.7675.

Table 3. ANOVA for cutting temperature

Source	Sum of Squares	Df	Mean Square	F-value	P-value	
Model	29850.43	8	3731.30	985.52	< 0.0001	Significant
A-Environment	22338.01	1	22338.01	5899.99	< 0.0001	
B-Cutting speed	4880.33	1	4880.33	1289.01	< 0.0001	
C-Feed	280.02	1	280.02	73.96	< 0.0001	
AB	494.62	1	494.62	130.64	< 0.0001	
AC	4.08	1	4.08	1.08	0.3261	
BC	0.0001	1	0.0001	0.0000	0.9963	
A^2	1892.25	1	1892.25	499.79	< 0.0001	
B^2	16.13	1	16.13	4.26	0.0690	
Residual	34.07	9	3.79			
Cor Total	29884.50	17				

Table 4. R-Square and adequate precision for cutting temperature

Std. Dev.	1.95	R^2	0.9989
Mean	87.17	Adjusted R^2	0.9978
C.V. %	2.23	Predicted R^2	0.9951
		Adequate Precision	97.7675

The normal plot of residuals was covered in the graph (figure 1). In general, points that lie on or near a straight-line exhibit evidence of a normal distribution in the residuals. It demonstrates that residuals that follow a straight line suggest evenly distributed errors. The location of a value or collection of values that the model cannot identify is determined by a graph of actual vs predicted value [7], which shows that each value is regularly separated by a line inclined at 45 degrees obtained in (figure 2).

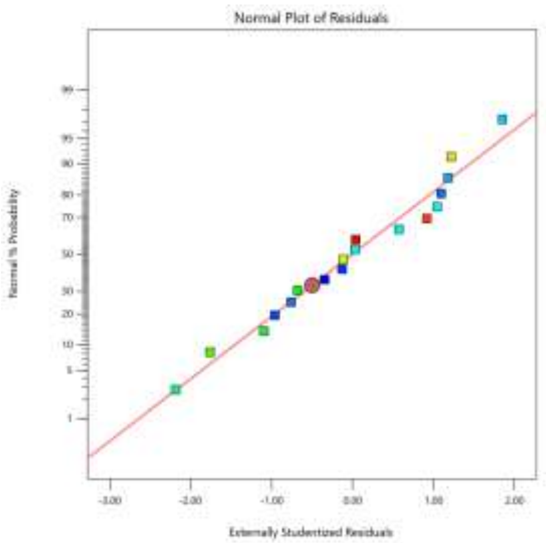

Figure 1. Normal probability plot for temperature

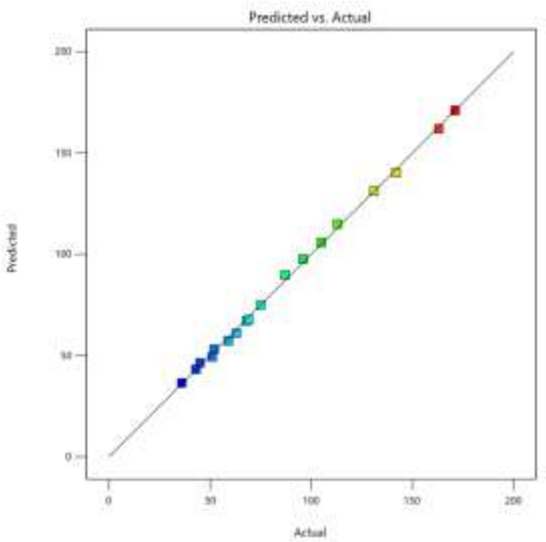

Figure 2. Actual vs predicted values for temperature

Predicted response for temperature

Figure 2 exhibits the difference between the predicted and actual values of temperature. The inaccuracy is small and tolerable, because it makes a straight line. The F-value and P-value are consistent with the temperature values seen in the (table 3). The amount of predicted cutting temperature values can be measured using eq. (1).

Predicted Temperature = 40.82184 - (52.10587×A) + (0.550066×B) + (90.78113×C) - (0.383525×A×B)-(11.66667×A×C)-(0.002643×B×C) + (21.75×A^2) + (0.004781×B^2)

Effects of environment on temperature

ANOVA (Table 3) shows that environment is the most dominating factor among the parameters considered. For this study, dry condition, oil and nano fluids are used as environment for predicting temperature.

Effects of dry environment on temperature

The highest average temperature has been attained in dry conditions at both feed rate. This is caused due to high friction between the work piece and the tool, as well as a lack of coolant or lubrication. Under these circumstances, a high temperature of 171° C was obtained.

Effects of oil environment on temperature

In comparison to a dry situation, the average temperature has decreased by around 48 % in presence of oil [8]. This is happened as a result of the oil's ability to absorb heat away from the tool and work piece. The maximum temperature observed at 93° C when oil is used as a coolant.

Effects of nanofluid environment on temperature

The maximum temperature observed is 72° C when Nano-Fluid is used as coolant, which is composed of oil and MWCNT nanoparticles [9] under Minimum Quantity Lubrication (MQL). The average temperature at nanofluid condition is 64% lower than in the dry condition and 28% lower than in the oil condition. The heat created by the tool and work piece during machining is taken up by the MWCNT nanoparticles since they are effective heat absorbers.

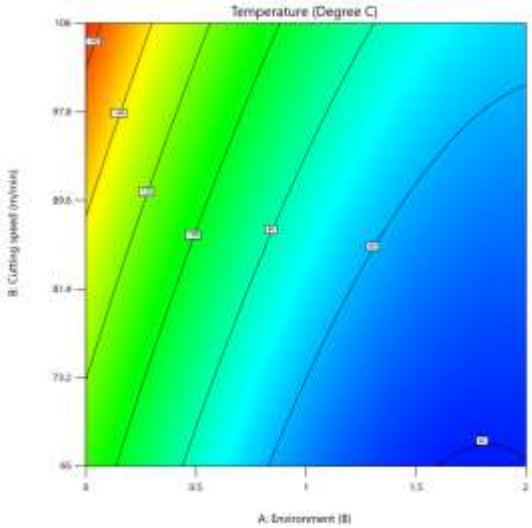

Figure 3: Interaction effects of temperature on environment and cutting speed

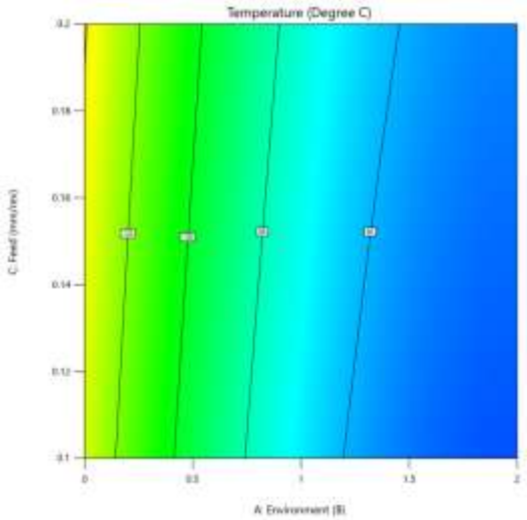

Figure 4. Interaction effects of temperature on environment and feed

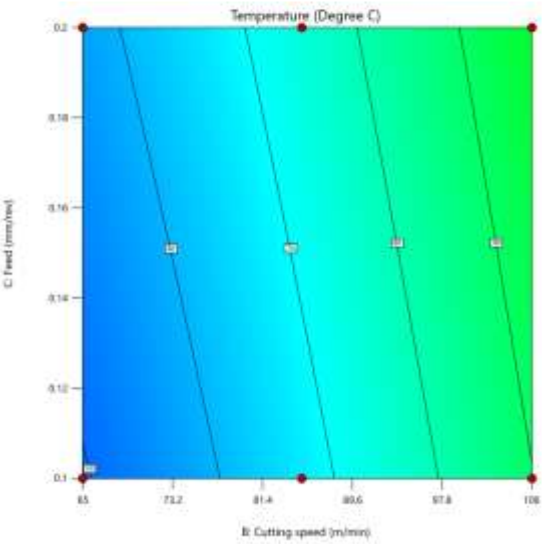

Figure 5. Interaction effects of temperature on cutting speed and feed

Figure 3 shows the interaction effects of temperature on environment and cutting speed [10]. Due to increase in cutting speed the cutting temperature is increased. Better lubricative environment conditions with lower cutting speed results in maximum reduction of machining temperature. Figure 4 demonstrates the interaction effects of temperature on environment and feed [11]. Lowering the feed with better lubrication environment reduces temperature effects. Figure 5 depicts the interaction effects of temperature on cutting speed and feed. Lowering both cutting speed and feed reduce the cutting temperature while machining.

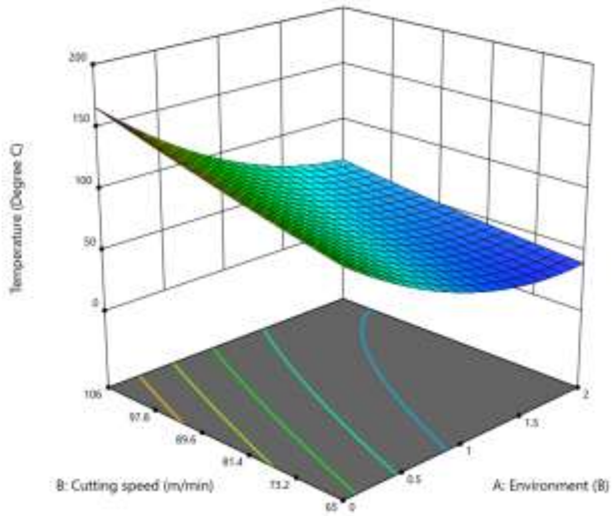

Figure 6. Variation of temperature against environment and cutting speed

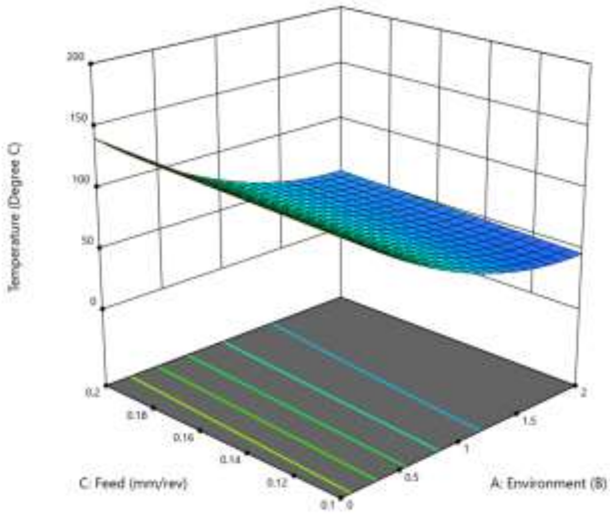

Figure 7. Variation of temperature against environment and feed

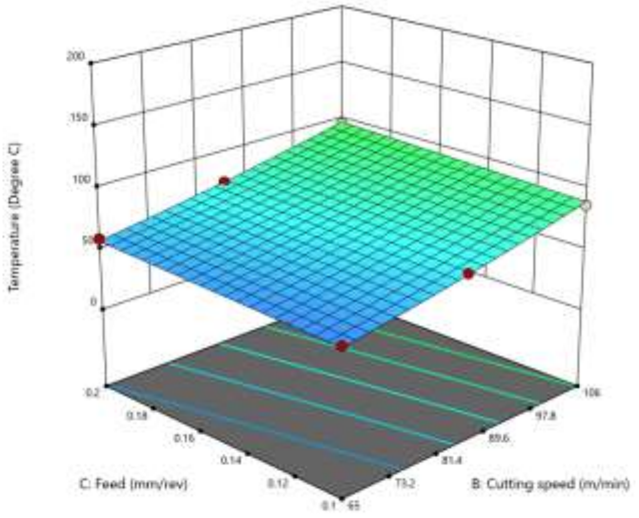

Figure 8. Variation of temperature against cutting speed and feed

Figure 6 depicts the variation of temperature against environment and cutting speed. When machining is done, environment is the significant parameter which alters the cutting temperature of the machining zone to the minimum level [12]. Figure 7 shows the variation of temperature against environment and feed. Feed does not have much influence over temperature. Whereas, environment converts cutting temperature to the most minimal amount with its lubrication conditions [13]. Figure 8 demonstrates the variation of temperature against cutting speed and feed. Here, cutting speed concludes to be the most influencing parameter. Since, the revolution of the spindle at faster rate only ensures the work material to achieve maximum material removal rate.

Desirability analysis for temperature

The desirability analysis modifies the response values in the series between 0 and 1, with the goal of reducing temperature. The optimal machining values were attained for turning process with maximum value of desirability index [14]. The feed rate was set as 0.1 mm/rev, the environment as 1.77 rounded off to 2 (nano fluids), and the cutting speed as 65 m/min for the optimal turning process. Each ramp had a point (figure 9) that indicated the required height for each turning parameter, and its elevation highlights the importance of desirability.

Mean square error calculation

MSE= (Actual – Predicted)^2 / 2

Which assesses the average squared difference between the actual and predicted values. The average MSE estimated for cutting temperature is 0.94653.

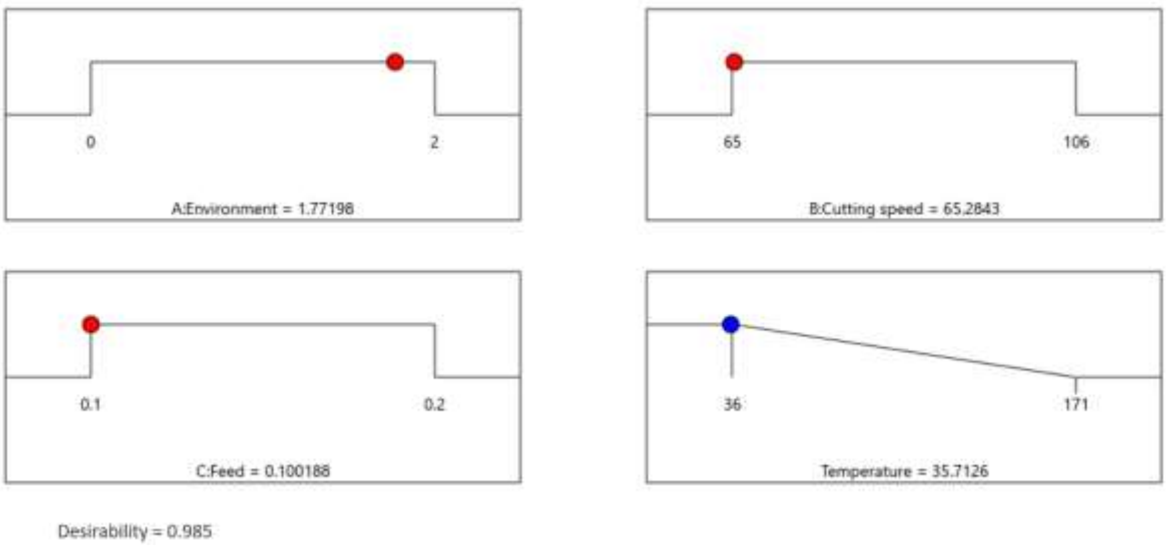

Figure 9. Optimum desirability ramp graph for all the input and response

Conclusions

In the present research, statistical and experimental findings have been performed in turning on A286 superalloy. The optimal machining parameters were determined using RSM. ANOVA reveals that environment is the key factor which influences the response. Cutting speed and feed are not considered as significant parameter. Additionally, a close comparison between the actual and predicted values was established. The cutting temperature is reduced by 66 % while machining with MWCNT nano fluids with optimal settings of feed at 0.1 mm/rev and cutting speed at 65 m/min. Temperature is decreased effectively as a result of the penetrating ability of MWCNT nano fluids in the machining zone, which leads to an effective cooling and lubrication under MQL machining.

Conflict of interest

Author declares there are no conflicts of interest.

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