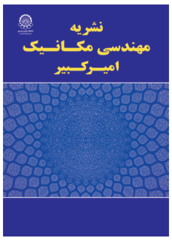

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Experimental Study of Cryogenic Cooling Effect on Tool Wear and Power Consumption During Turning of AISI304

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ABSTRACT: Performance of cutting fluids in machining of different materials is critical importance in order to improve the efficiency of any machining process. The objective of this research is investigation the effects of cryogenic cooling on tool wear and power consumption in the turning process of AISI 304 austenitic stainless steel. Cutting speed and cutting time each at three levels were selected as cutting variables. Response surface methodology (RSM), employing a face-centered central composite design scheme, has been used to plan and analyze the experiments. The relationships between machining parameters and output variables were modeled using RSM. Analysis of variance (ANOVA) was performed to check the adequacy of the mathematical model and its respective variables. The results showed a good agreement between the measured tool wear and power consumption and predicted values obtained by developed models. Suitable mathematical models for the response outputs were obtained using the ANOVA technique, in which significant terms were chosen according to their p values less than 0.05 (95% of confidence interval). When experiments and analysis of results were done, it is observed that tool wear was decreased till 67.5% and power consumption was decreased till 24% in cryogenic cooling method when compared with dry machining.

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1- Introduction

Stainless steels are iron-based alloys that contain a minimum of approximately 11 % Cr [1]. The AISI 304 austenitic stainless steel is the most widely used grade among the other grades of austenitic stainless steel [2] that is categorized under a group of materials that are very hard to machine [3, 4]. AISI 304 steel finds its application in aerospace industries, aircraft fittings, aerospace components such as bushings, shafts, valves, special screws, cryogenic vessels, components for severe chemical environments and automotive industries. They were also being used for welded construction in aerospace structural components [5-7]. In this study, the influence of cryogenic cooling method on tool wear and power consumption in AISI 304 turning operations were investigated.

2- Material and Method

All the experiments were carried out on a TN50 BR lathe machine. The workpiece material was AISI 304. The CVD coated carbide inserts from Korloy company were used as the cutting tool material for all the experiments. The liquid nitrogen was used as a coolant for experiments.

3- Design of Experiments

Face-centered CCD scheme, a popular variant of the central composite design involving three levels for each factor, was used to plan the experiments [8,9]. Table 1 shows the input parameters in both coded and actual formats.

The total data obtained from machining experiments for the tool wear are shown in Table 2 with the corresponding process responses.

On the other hand, Table 3 illustrates the obtained data for the power consumption.

Table 1. Inputs and their levels for the face-centered CCD

Parameter	Notation	Unit	Coded level		
			-1	0	1
Cutting speed	A	m/min	100	130	160
Machining time	B	min	2	3	4

Table 2. Experimental results for the tool wear

Run no.	Coded factor		Actual factor		Dry	Cryogenic
	A	B	V_C	T	V_B, mm	V_B, mm
1	-1	-1	100	2	0.084	0.068
2	1	-1	160	2	0.226	0.185
3	-1	1	100	4	0.223	0.081
4	1	1	160	4	0.812	0.461
5	-1	0	100	3	0.087	0.070
6	1	0	160	3	0.453	0.315
7	0	-1	130	2	0.135	0.074
8	0	1	130	4	0.332	0.121
9	0	0	130	3	0.257	0.112
10	0	0	130	3	0.259	0.084
11	0	0	130	3	0.238	0.108
12	0	0	130	3	0.196	0.103
13	0	0	130	3	0.229	0.120

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Table 3. Experimental results for the power consumption

Run no.	Coded factor		Actual factor		Dry P , kW	Cryogenic P , kW
	A	B	V_C	T		
1	-1	-1	100	2	0.038	0.029
2	1	-1	160	2	0.047	0.042
3	-1	1	100	4	0.050	0.038
4	1	1	160	4	0.060	0.054
5	-1	0	100	3	0.045	0.035
6	1	0	160	3	0.051	0.046
7	0	-1	130	2	0.048	0.037
8	0	1	130	4	0.056	0.050
9	0	0	130	3	0.052	0.044
10	0	0	130	3	0.052	0.045
11	0	0	130	3	0.053	0.043
12	0	0	130	3	0.054	0.042
13	0	0	130	3	0.053	0.044

4- Results and Discussion

Figs. 1 and 2 detail 3D surface graphs for the interaction effects of cutting speed and machining time on the tool life. Fig. 1 shows that the longest tool life is achieved with the combination of lowest cutting speed and cutting time. According to this figure, by increasing either cutting speed or cutting time, tool life values decreases drastically. Fig. 2 displays the estimated response of the tool wear for the corresponding cutting speed and cutting time in cryogenic machining. Initially, the tool wear increases slightly with the increase in cutting speed and it remains constant for cutting speed around 130 m/min. beyond that, tool wear increases dramatically with the increase in cutting speed.

By analyzing experimental results, it is observed that the tool wear increased from 18.1% to 67.5% in cryogenic cooling method when compared with dry machining.

By scrutinizing the corresponding graph shown in Fig. 4, it can be inferred that the power consumption in dry machining gets a higher value as the machining time increases while keeping the cutting speed at a constant level. From Fig.5, it can be deduced that the power consumption tends to increase steadily with both cutting speed and machining time increase. As depicted in Fig. 6, the use of liquid nitrogen led to a lower power consumption. By analyzing experimental results, it is observed that power consumption increased from 10% to 24% in cryogenic cooling method when compared with dry machining.

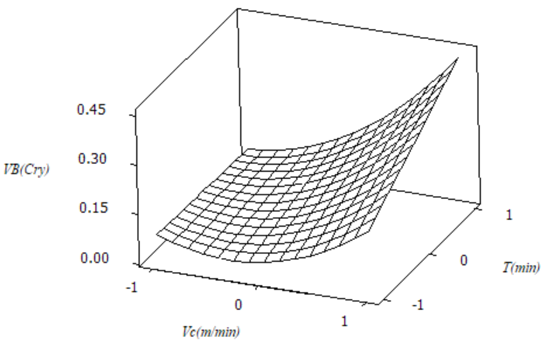

Fig. 1. 3D surface graph for interaction effects of cutting time and cutting speed on the tool life in dry machining

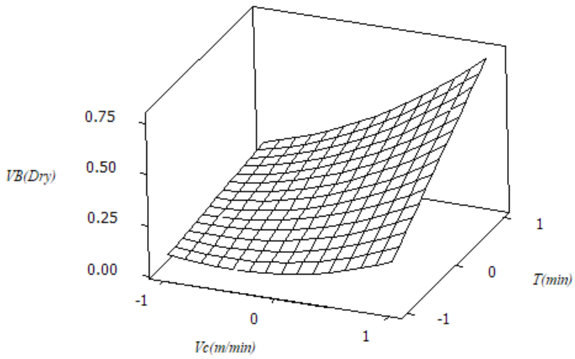

Fig. 2. 3D surface graph for interaction effects of cutting time and cutting speed on tool life in cryogenic machining

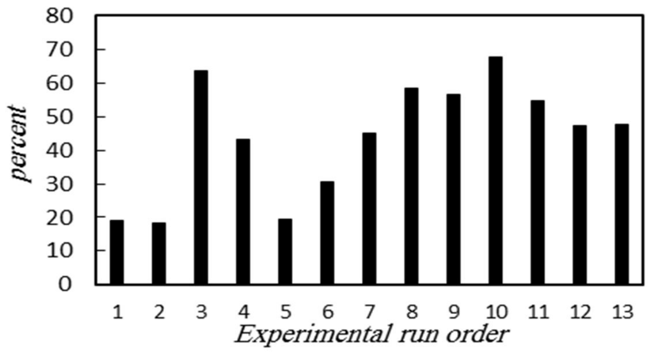

Fig. 3. Percent of tool wear improvement in cryogenic status

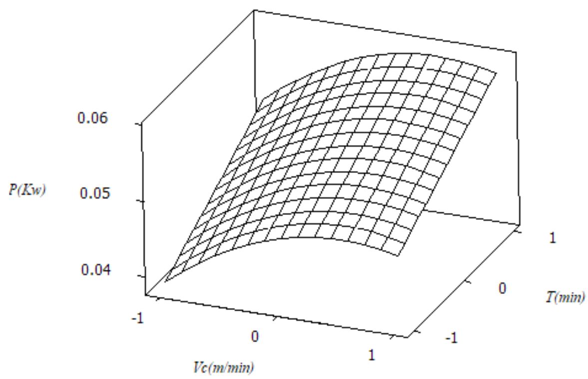

Fig. 4. 3D surface graph for interaction effects of cutting time and cutting speed on power consumption in dry machining

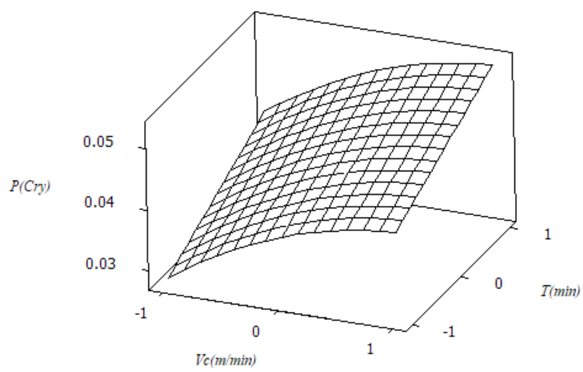

Fig. 5. 3D surface graph for interaction effects of cutting time and cutting speed on power consumption in cryogenic machining

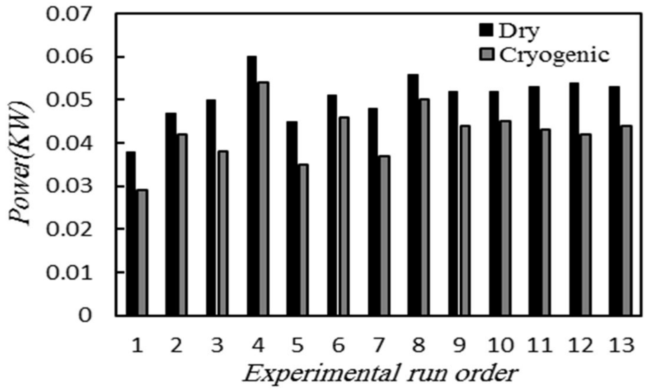

Fig. 6. Comparison of power consumption in cryogenic and dry turning

5- Conclusions

Following conclusions can be drawn from this study:

1. Cutting speed and machining time had a significant effect on tool wear and power consumption.
2. Maximum amount of flank wear and power consumption are achieved at the maximum values of cutting speed and cutting time.
3. Tool wear was decreased higher than 67% in cryogenic cooling method when compared with dry machining.
4. Power consumption was decreased to 24% in cryogenic cooling method when compared with dry machining.

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