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Effect of Significant Machining Parameters Towards Turning Cutting Performance

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ABSTRACT

Selection of significant machining parameters before the cutting process is necessary to produce the best outcome in the machining performances. The use of cutting fluids due to their cooling capabilities helps in producing a good finished product. In the present paper, MQL equipment was developed by attaching it to the CNC lathe CT-200 machine. The two-level factorial was employed to study the performance effect of different machining parameters such as cutting speed, feed rate, depth of cut and air pressure. The paper deals with the turning of AA7075 under MQL conditions. From the experimental results, it is proposed that the optimal combination for minimizing cutting temperature from the present investigations was cutting speed at 400 m/min, feed rate at 0.1 mm/rev, depth of cut at 0.3 mm and air pressure at 0.3 MPa. The Pareto chart suggests that the selected factors were found to be significant and the corresponding interactions between cutting speed (m/min), feed rate (mm/rev), depth of cut (mm) and air pressure (MPa) were also significant. It is concluded that the effect of lubrication condition was more followed by the depth of cut, feed rate, air pressure and cutting speed for cutting temperature. But for surface roughness, the effect of lubrication condition was more followed by feed rate, depth of cut, air pressure and cutting speed. While for tool wear, the effect of lubrication condition was more followed by the depth of cut, air pressure, cutting speed and feed rate.

1. Introduction

The machining process plays a very important role in the manufacturing of products. It is perhaps most versatile in the manufacturing industries, in which desired components or parts are achieved through the removal of material in the form of metal chips [1]. In most machining processes, a large amount of heat was generated at the machining zone or cutting zone due to friction between the cutting tool and workpiece interface [2]. In dry machining, the required surface quality and tool life cannot be achieved due to high heat generation at the cutting zone, which affects the hardness and sharpness of the cutting tool [3]. The increased temperature may cause premature breakage of the cutting tool and poor surface finish of the workpiece [2,3].

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The aerospace materials have attracted a lot of research to study the mechanical and thermal buckling of functionally graded materials [4]. Cutting fluids [3] have been the conventional choice in the manufacturing industry to deal with the generated heat during machining. Cutting fluids play a crucial role in cooling the tool-workpiece interface by removing the chips away from the machining zone and lubricating the tool-workpiece interface [3]. This conventional way of cooling serves the purpose up to some extent but the excessive use of cutting fluids pollutes the environment and maybe hazardous for a human beings. Also, cutting fluids accounts for about 16–20 % of the total cost of manufacturing in the industry. To reduce the flow and usage of cutting fluids several alternative methods have been considered among various techniques available for the application of coolant flow, researchers have been focusing on minimum quantity lubrication (MQL) as it minimizes the use of coolant by spraying the mixture of air and cutting fluid in an optimized manner instead of flooded cooling.

Another technology in a machining cutting fluid is the addition of nanoparticles in the base fluid to form a better cutting fluid known as nanofluid. Nanofluid refers to cutting fluids [5-7] obtained by dispersing a certain amount of nanoparticles into the base fluids. When a little quantity of nanoparticles is consistently suspended and dispersed in the base fluids, it can give overstated upgrades in the thermal characteristics of the base fluids [8]. The various types of nanoparticles such as Al_2O_3 [9], graphite, diamond, boric and MoS2 with excellent properties are frequently employed to improve the lubricity of coolants. Past researchers studied the impact of Al_2O_3 nanoparticles [10] in turning, lessening in tool wear, temperature dissipation, cutting forces and surface roughness.

The objective of the present work is to find the set of optimum conditions for the selected control factors which are cutting speed, feed rate, depth of cut and air pressure, to reduce cutting temperature, surface roughness and tool wear. The two-level factorial methodology is used to determine the optimum conditions for the selected control factors.

2. Methodology

The selection of parameters depends on a total number of factors and the levels of each factor. The control factors which are four including (cutting speed, depth of cut, feed rate and air pressure). Several levels for each control factor two, consist of high value and low value. The cutting speed value is 400 and 600 m/min. The feed rate value is 0.1 and 0.3 mm/rev. The depth of cut value is 0.3 and 0.9 mm. The air pressure value is 0.3 and 0.5 MPa. Table 1 shows all the factors and their levels for these experiments. The reason for the low value of the parameters due to this turning experiment is for the finishing process that involved the use of machines that are precise intolerances and also the use of a finishing insert.

Table 1
Control factors & levels

Factors / Levels	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Air Pressure (MPa)
1	400	0.1	0.3	0.3
2	600	0.3	0.9	0.5

Based on the above values, the minimum number of experiments to be conducted is 16 which has been generated by the design expert software. The standard design of the experiment considering the control factors and two levels of values are tabulated in Table 2, concerning which the corresponding experiments are carried out. A thorough literature survey helped in the proper select work material, control factors, methodology, coolants and etc. In the present work, Beiling X-

Ten 150 are mixed with water in the ratio of 95:5 (water: coolant), which is a base fluid and stabilizers used are for proper mixing and stirring. Analysis of Variance (ANOVA) was employed to study the performance characteristics for the selected control factors at two different levels, under MQL lubrication conditions for the workpiece material AA7075. The response studied are cutting temperature, surface roughness and tool wear.

Table 2
Standard two-level factorial experimental design

Std	Run	Block	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Air Pressure (MPa)
7	1	Block 1	400.00	0.90	0.30	0.30
8	2	Block 1	600.00	0.90	0.30	0.30
9	3	Block 1	400.00	0.30	0.10	0.50
4	4	Block 1	600.00	0.90	0.10	0.30
14	5	Block 1	600.00	0.30	0.30	0.50
6	6	Block 1	600.00	0.30	0.30	0.30
2	7	Block 1	600.00	0.30	0.10	0.30
1	8	Block 1	400.00	0.30	0.10	0.30
12	9	Block 1	600.00	0.90	0.10	0.50
16	10	Block 1	600.00	0.90	0.30	0.50
10	11	Block 1	600.00	0.30	0.10	0.50
3	12	Block 1	400.00	0.90	0.10	0.30
15	13	Block 1	400.00	0.90	0.30	0.50
11	14	Block 1	400.00	0.90	0.10	0.50
5	15	Block 1	400.00	0.30	0.30	0.30
13	16	Block 1	400.00	0.30	0.30	0.50

In the present paper, the experiments are carried out using proper selection considering the control parameters such as cutting speed (A) depth of cut (B), feed rate (C), air pressure (D) and at two different levels. Turning operations are carried out using CNC Lathe CT-200 by Gildemeister considering the MQL cutting conditions [12]. As MQL setup [13] is being developed and maintaining the flow at 40 to 60 ml/min and air pressure around 3 - 5 bar. The cutting tools used for machining [6] are VCGT 160404 TH K10 carbide tools inserts. Figure 1 shows the machining process under MQL cooling conditions which reduces the amount of coolant used while Figure 2 shows the MQL setup attached to the tool magazine of the CNC machine. Figure 3 shows the measuring device for cutting temperature while Figure 4 shows the surface roughness instrument that measures the roughness of a workpiece surface. Figure 5 shows the electronic balance used to weight the insert before and after the cutting process to calculate wear in form of weight loss while Figure 6 shows the machine CNC lathe CT-200 used for this experiment.

Fig. 1. Machining under MQL condition

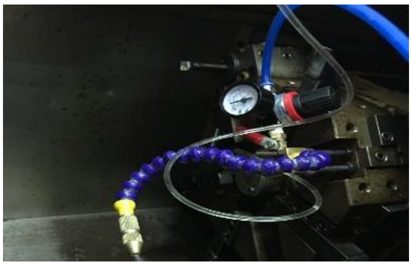

Fig. 2. MQL setup

Fig. 3. Cutting temperature measuring device

Fig. 4. Surface roughness measuring device

Fig. 5. Tool wear measuring device

ig. 6. Machine CNC Lathe CT-200

3. Results

3.1 Effect of MQL Machining Process Parameters

The input parameters for the screening process are cutting speed, depth of cut, feed rate and air pressure while the responses studied are cutting temperature, surface roughness and tool wear. Table 3 presented the results of machining for a screening process to select the two most significant parameters to be used in the next experiment while the other two parameters will be kept constant at a certain value. The range of value used in this experiment are taken from page 303 of the book with the title of Mechanical and Metal Trades Handbook [11], the writer is Ulrich Fisher and this book was published back in 2010. This process was done in a coolant MQL environment and using AA7075 as the workpiece [14] with 8 finishing inserts used as a cutting tool along with the experiment.

Table 3
Screening results

Experiment Number	Cutting Temperature	Surface Roughness	Tool Wear
1	27	3.297	0.21
2	31.7	3.277	0.12
3	25.8	0.892	0.02
4	28.3	1.523	0.13
5	27.6	2.353	0.01
6	24.8	1.885	0.12
7	23.5	2.331	0.02
8	21.1	0.771	0.12
9	29.3	1.587	0.02
10	29.5	2.164	0.14
11	25.6	0.391	0.01
12	28	1.069	0.12
13	29.4	2.426	0.11
14	27.1	2.488	0.14
15	26.4	2.023	0.14
16	26.6	2.271	0.11

Two-level factorial method has been successfully employed to obtain the significant process parameters and to improve the cutting performances for the selected AA7075. A total of 16 experiments were performed as per the design of the experiment the develop a two-level factorial and the output studied which are cutting temperature, surface roughness and tool wear were measured and the corresponding results tabulated in Table 3.

3.1.1 Effect of machining parameters on cutting temperature

In the present work, cutting temperature was measured by using a Non-Contact Laser Infrared Thermometer Gun (DT 8280) at a distance of 20 mm from the cutting zone. Table 4 shows the details output of cutting temperature. It indicates that the lowest result obtained for cutting temperature was 21.1 °C when cutting conditions with 400 m/min of cutting speed, 0.3 mm depth of cut, 0.1 mm/rev of feed rate and 0.3 MPa of air pressure while the highest result obtained was 31.7 °C when cutting conditions with 600 m/min of cutting speed, 0.9 mm depth of cut, 0.3 mm/rev of feed rate and 0.3 MPa of air pressure. This result indicates that by using a lower value of cutting speed, depth of cut, feed rate and air pressure, the lowest cutting temperature can be achieved. Table 5 tabulated the details output of cutting temperature extracted from experimental data in Table 4.

Table 4
Optimum parameters for cutting temperature

Data Recorded	Cutting Speed (m/min)	Depth of Cut (mm)	Feed Rate (mm/rev)	Air Pressure (MPa)	Cutting Temperature (°C)
Lowest	400	0.3	0.1	0.3	21.1
Highest	600	0.9	0.3	0.3	31.7

Table 5
ANOVA analysis of cutting temperature

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	76.31	4	19.08	9.56	0.0014	significant
A-Cutting Speed	4.95	1	4.95	2.48	0.1436	
B-Depth of Cut	52.20	1	52.20	26.15	0.0003	
C-Feed Rate	12.78	1	12.78	6.40	0.0280	
D-Air Pressure	6.38	1	6.38	3.19	0.1015	

Figure 7 shows the Pareto chart of cutting temperature, the Pareto chart by design expert which shows the rank of significant parameters that are depth of cut (B), feed rate (C), air pressure (D) and cutting speed (A). Figure 8 is the Pareto chart by percentage contribution where the two most significant parameters that give the most effective cutting temperature during the cutting process are depth of cut and feed rate with the % contribution value of 53.12 % and 13.01 %, while the two less significant parameters were air pressure and cutting speed. Based on this result, the depth of cut and feed rate should be included for response surface method (RSM) machining parameters.

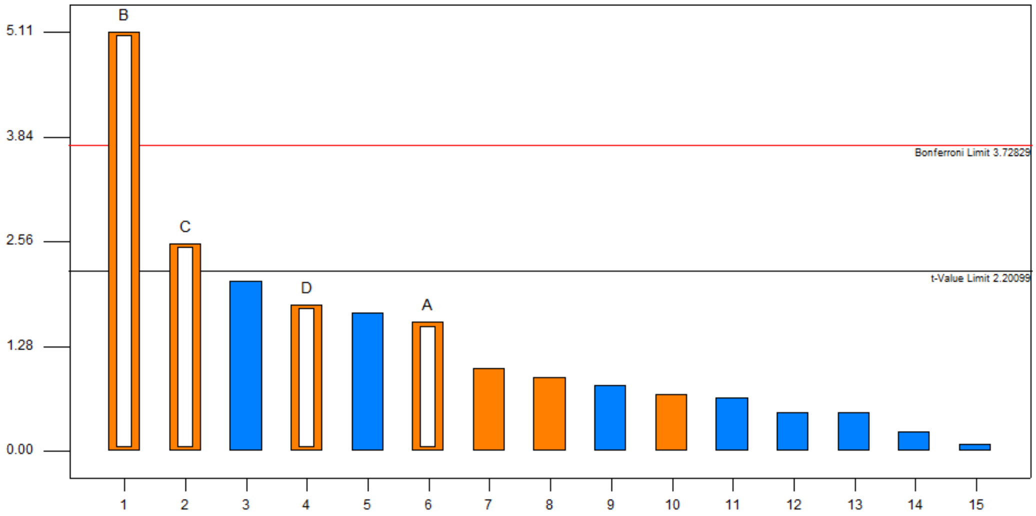

Fig. 7. Pareto chart of different machining parameters towards cutting temperature

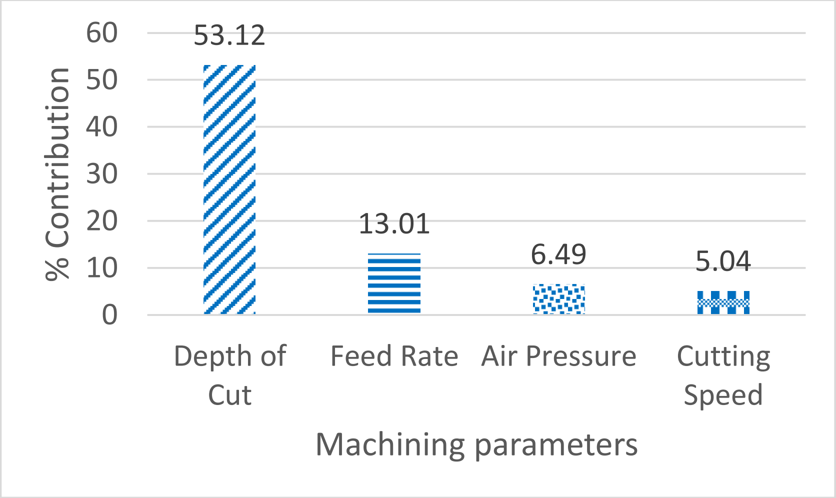

Fig. 8. Effect value of different machining parameters towards cutting temperature

3.1.2 Effect of machining parameters on surface roughness

Surface roughness plays an important role in the performance of a product and product failure before the expected life owing to appalling surface. In the present work, the surface roughness of the workpiece was measured by a Profilometer, Mitutoyo SJ-210 Surface Roughness Tester. To measure a proper surface roughness value, the measured surface length should be around 15 mm. Table 7 tabulated the details output of surface roughness extracted from experimental data in Table 6. It indicated that there is a maximum reduction of surface roughness in the conditions of 600 m/min cutting speed, 0.3 mm depth of cut, 0.1 mm/rev feed rate and 0.5 MPa air pressure which produce a value for Ra of 0.391 µm. From output data, it was also observed that the highest surface roughness was obtained when using 400 m/min cutting speed, 0.9 mm depth of cut, 0.3 mm/rev feed rate and 0.3 MPa air pressure which produce Ra with the value of 3.297 µm. This result showed that, by using the higher value of cutting speed and air pressure and combined with the lower value of depth of cut and feed rate, the lowest surface roughness value can be achieved.

Table 6
Optimum parameters for surface roughness

Data Recorded	Cutting Speed (m/min)	Depth of Cut (mm)	Feed Rate (mm/rev)	Air Pressure (MPa)	Surface Roughness (µm)
Lowest	600	0.3	0.1	0.5	0.391
Highest	400	0.9	0.3	0.3	3.297

Table 7
ANOVA analysis of surface roughness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	6.34	4	1.59	4.12	0.0279	significant
A-Cutting Speed	4.692E-003	1	4.692E-003	0.012	0.9140	
B-Depth of Cut	1.51	1	1.51	3.92	0.0731	
C-Feed Rate	4.67	1	4.67	12.14	0.0051	
D-Air Pressure	0.16	1	0.16	0.42	0.5311	

The effect of feed rate, depth of cut, air pressure and cutting speed on the surface roughness of AA7075 is shown in Figure 9. Figure 9 is the Pareto chart by the design expert which shows the rank of significant parameters that are feed rate (C), depth of cut (B), air pressure (D) and cutting speed (A). Figure 10 is the Pareto chart by percentage contribution where the two most significant parameters that give the most effect on cutting temperature during the cutting process are feed rate and depth of cut with the % contribution value of 44.16 % and 14.27 %. The chart shows that the two most significant parameters that affect the surface roughness are also similar to the result of cutting temperature which are depth of cut and feed rate and follow by air pressure and cutting speed. So, for the RSM machining, the feed rate and depth of cut should be considered important machining parameters that needed to be studied.

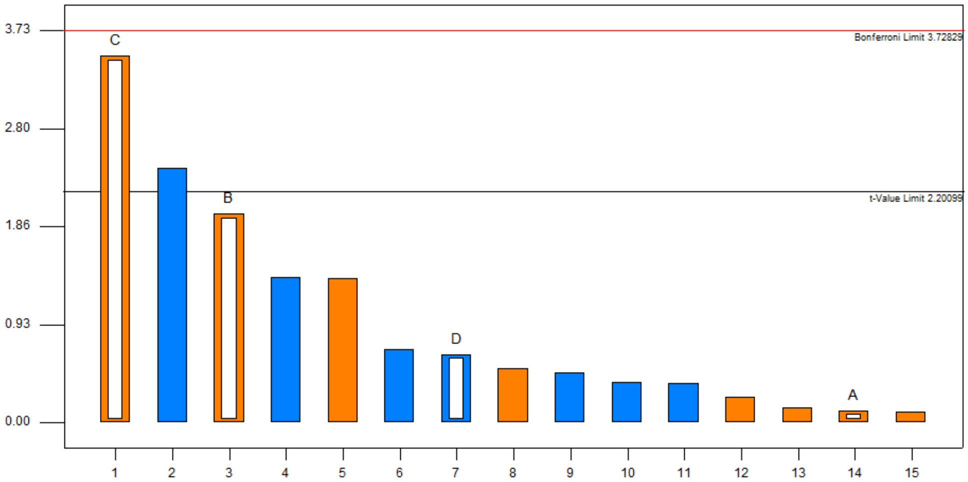

Fig. 9. Pareto chart of different machining parameters towards surface roughness

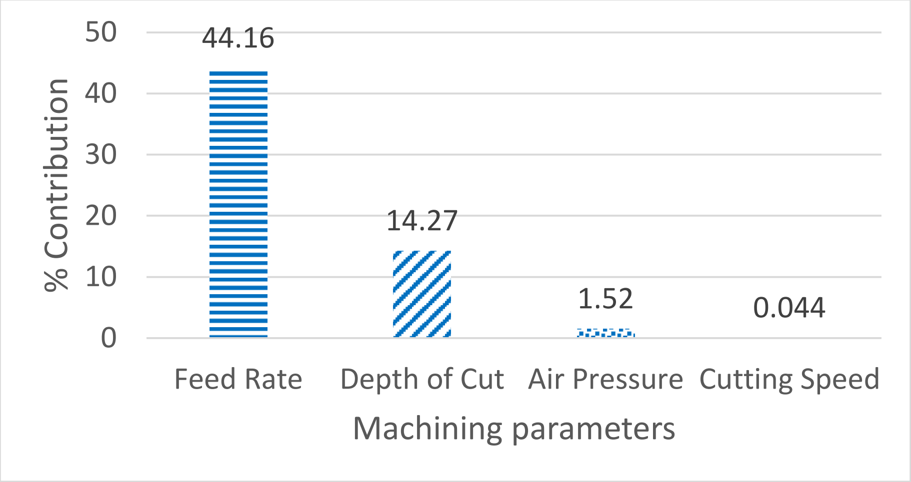

Fig. 10. Effect value of different machining parameters towards surface roughness

3.1.3 Effect of machining parameters on tool wear

Tool wear is a major parameter that characterizes the efficiency of the machining process. In the present work, tool wear was measured using an electronic balance. The type of wear was recorded and measured was basic wear in form of weight loss. The data were recorded in percentage of weight loss before and after the cutting process was done. Based on the result of machining in Table 8, it revealed that the lowest result obtained was 0.01 % when using 600 m/min of cutting speed, 0.3 mm of the depth of cut, 0.1 mm/rev of feed rate and 0.5 MPa of air pressure, while the highest result obtained was 0.21 % when using 400 m/min of cutting speed, 0.9 mm of the depth of cut, 0.3 mm/rev of feed rate and 0.3 MPa of air pressure. This shows that by using the higher cutting speed and air pressure plus the lower value of depth of cut and feed rate, the lowest tool wear can be obtained. Additionally, Table 9 tabulated the details output of tool wear extracted from experimental data in Table 8.

Table 8
Optimum parameters for tool wear

Data Recorded	Cutting Speed (m/min)	Depth of Cut (mm)	Feed Rate (mm/rev)	Air Pressure (MPa)	Tool Wear (%)
Lowest	600	0.3	0.1	0.5	0.01
Highest	400	0.9	0.3	0.3	0.21

Table 9
ANOVA analysis of tool wear

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.042	4	0.011	9.18	0.0016	significant
A-Cutting Speed	0.010	1	0.010	8.71	0.0132	
B-Depth of Cut	0.012	1	0.012	10.54	0.0078	
C-Feed Rate	9.025E-003	1	9.025E-003	7.86	0.0171	
D-Air Pressure	0.011	1	0.011	9.61	0.0101	

Figure 11 shows the Pareto chart effect on tool wear, where the Pareto chart by design expert shows the rank of significant parameters that are depth of cut (B), air pressure (D), cutting speed (A) and feed rate (C). Figure 12 is the Pareto chart by percentage contribution where the two most significant parameters that give the most effect on cutting temperature during the cutting process are depth of cut and air pressure with the % contribution value of 22.09 % and 20.13 %. While the others two less significant parameters are cutting speed and feed rate. This Pareto chart shows a bit different parameters effect compared to the Pareto chart effect of cutting temperature and surface roughness. However, the obvious selection of the two most significant parameters can be made. The depth of cut and air pressure can be used as the RSM machining parameters.

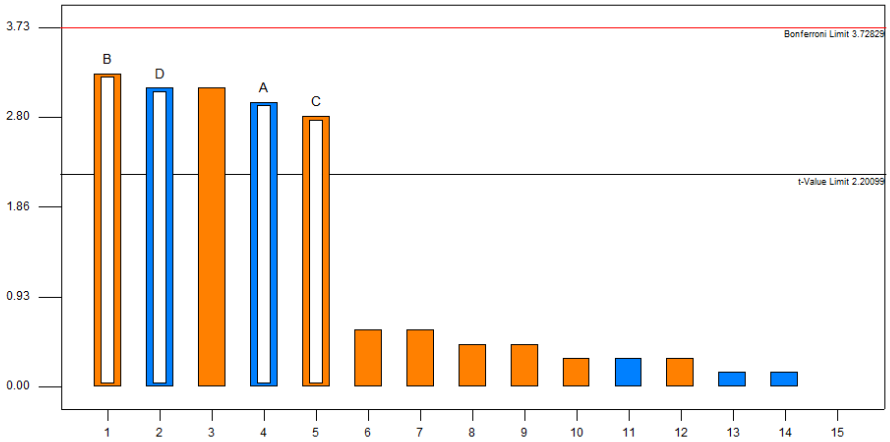

Fig. 11. Pareto chart of different machining parameters towards tool wear

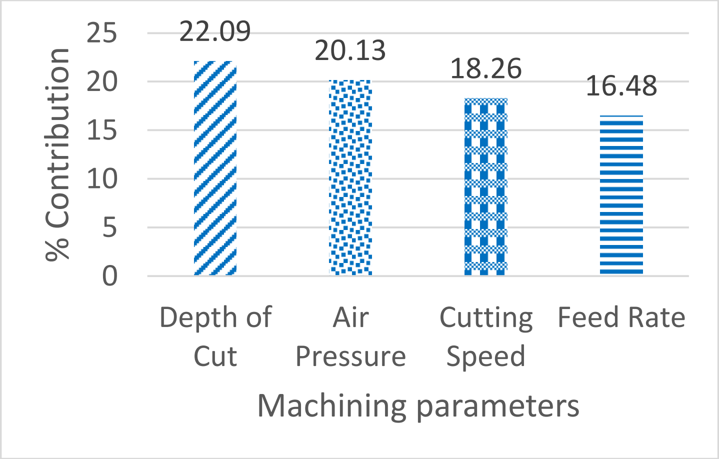

Fig. 12. Effect value of different machining parameters towards tool wear

4. Conclusions

Based on the results of the screening process and Pareto charts, it showed that the most significant machining parameters are depth of cut and feed rate, while the other two parameters which are cutting speed and air pressure are not that significant and will be kept constant for next phase of the research due to out of three responses, the top two parameters that give most effects are always depth of cut and feed rate. The depth of cut value will vary from 0.3, 0.6 and 0.9 mm and feed rate value vary from 0.1, 0.2 and 0.3 mm/rev for the future experiment. For the constant parameters, cutting speed will be kept at 600 m/min due to higher cutting speed provide better results in surface roughness that led to a smoother surface, while the air pressure will be kept at 0.5 MPa due to higher air pressure providing good results in tool wear because it can give a strong pressure for the cutting fluid to flow from the hopper to the MQL setup. MQL has been proved to be suitable because it complies with the requirements of the 'green' machining [15]. For cutting temperature, the percentage different between two most significant parameters which are depth of cut and feed rate, is around 40 %. While for surface roughness the gaps between feed rate and depth of cut are around 30 %. Tool wear effect value of depth of cut and air pressure as two most significant parameters is about 2 % only.

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