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Research article

Investigating on process variables effect of AISI 304 stainless steel machining using minimum quantity lubricant on cutting force

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Abstract

In the machining process, the friction between the tool and the surface being machined, in addition to the destructive effects on tool wear and surface quality, increases the cutting force. By applying lubricant, it is possible to reduce the friction force in the machining process, and as a result, the cutting force is reduced. Due to the harmful environmental effects of excessive use of lubricants, the method of minimum quantity lubricant (MQL) can be helpful. In this method, fluid is applied with controlled flow and pressure. In this research, the effect of machining conditions on the cutting force for the machining process of AISI 304 stainless steel, using the method of minimum quantity lubricant has been investigated. The results show that with the increase in the cutting speed, the cutting force has decreased. Also, with the increase of injection pressure when applying the lubricating fluid using the method of the minimum quantity lubricant, a significant increase in the cutting force has been observed.

Keywords: Cutting force, Minimum quantity of lubricant (MQL), AISI 304 stainless steel, Cutting speed, Injection pressure

1- Introduction

The application of cooling and lubricating fluid in machining processes is executed in different ways. Due to the harmful environmental effects caused by the excessive use of lubricants, the method of minimum quantity lubricant (MQL) can be helpful. In this method, fluid is applied with controlled flow and pressure.

In the machining method with the minimum amount of lubrication (MQL) using a nozzle, the air that contains fine particles of oil hits the tool head and cutting edges with direct pressure, and in addition to cooling the workpiece and the tool, it causes contact surface lubrication and friction reduction. Fluid pressure in other methods is also applied in the machining process [1], but the only method is minimum quantity lubricant (MQL), which minimizes the use of cutting fluid. The cutting fluid is often vegetable oil. The advantages of machining with the minimum amount of lubrication include:

- Preventing wastage of lubricant
- Increasing tool life
- Increased safety in working conditions
- Reduction of machine tools cleaning operations need
- In the long run, there will be a lot of cost savings
- Prevention of workpiece color changing with lubricant reaction base
- Reduction of machine tools maintenance operations
- Dry chips
- Reducing the environmental impact due to lubricants

Also, among other advantages of machining using the method of the minimum amount of lubrication compared to dry and wet (with conventional lubrication) machining, the reduction of cutting temperature can be mentioned, which improves the mutual function between the tool and the chip and reduces the wear of the cutting edges.

Applying the system of the minimum amount of lubrication improves the life of the tool and the smoothness of the machining surface than dry and wet machining. The dimensional accuracy and the quality of the machined surface are improved with the help of the method of the minimum amount of lubrication and with the reduction of wear and damage caused by the tip of the worn tool, by this method, and machining can be achieved at higher speeds. Also, some of the influencing parameters in the minimum amount of lubrication include air pressure, coolant or lubricant flow rate, as well as machining conditions, including cutting speed, feed rate, etc., in machining with the minimum amount of lubrication method, is important and effective [2]. Fig. 1 shows a schematic illustration of using the minimum quantity lubricant system during the turning process.

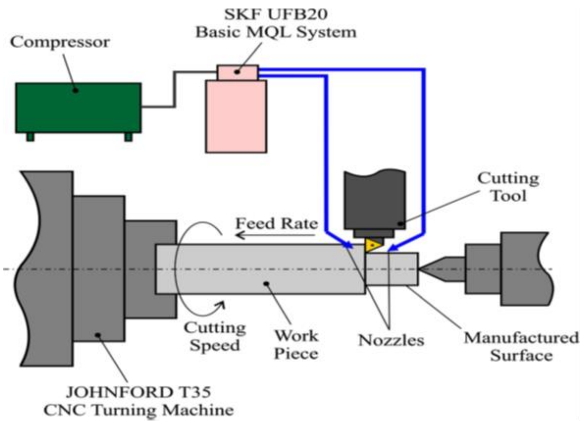

Fig. 1 Schematic illustration of using the minimum quantity lubricant during the turning process [3]

Kumar et al. investigated the surface roughness during the machining of AISI 4340 steel with the minimum amount of lubrication. They aim to investigate the role of the minimum lubrication technique in the machining process with CBN tools on the machined surface quality of AISI 4340 steel. Cutting speed, feed rate, and workpiece hardness have been selected as process variables in their study [4].

Hadad et al. investigated the turning of AISI 4140 stainless steel with a minimum lubrication system. They found that machining with the minimum amount of lubrication increased the life of the cutting tool and improved the quality of the machined surface [5]. Ali et al. investigated the effect of the minimum amount of lubrication method during the machining of medium carbon steel without carbide at different cutting speeds and found that tool wear and surface roughness using the method of the minimum amount of lubrication in machining compared to the dry machining process is reduced, mainly due to the decrease of machining temperature [6]. The heat transfer effect of conventional fluid is an important topic for some researchers [7].

Chaudhari et al. investigated the optimization of machining process parameters with the method of the minimum amount of lubrication using the Taguchi method. They chose the Taguchi L9 design of experiments. The analysis of their results showed that if the cutting speed is high, the cutting depth and feed rate are low, it is suitable to achieve the minimum roughness value of the machining surface [8]. The use of the Taguchi method in the investigation of other machining processes has also been reported [9].

Ekinovic et al. investigated the effect of carbon steel St52-3 machining parameters with the method of the minimum amount of lubrication. They implemented the method of the minimum amount of lubrication in two ways. In the first state, a mixture of fine particles of oil and air is used, and in the second state, a mixture of air and fluids other than oil is used. In their research, the effect of the process parameters of the minimum lubrication method of the oil-in-water mixture system on cutting forces during the machining of carbon steel St52-3 has been investigated. They concluded that machining using the method of the minimum amount of lubrication is very acceptable from an environmental point of view because the machining is executed with vegetable oil, which does not pollute the environment. The oil consumption in the minimum lubrication method is much less compared to the conventional cooling and lubricating system. Also, in their experiments, the cutting force using the minimum amount of lubrication method was reduced by about 17%, saving and consuming less energy [10]. Najiha et al. investigated the flow behavior in the nozzle of the minimum amount of lubrication system in the milling process. In their research, the design of the minimum amount of lubrication nozzle was utilized to investigate the behavior of the mixture of lubricant and air under certain pressures. Their research showed that air pressure plays an important role in the formation of lubricant dust. Air pressure causes the transfer of lubricant drops [11]. Khan et al. tested the effect of the minimum amount of lubrication using vegetable oil on AISI 9310 alloy steel. They presented the effects of turning with a cooling system of the minimum amount of lubrication with the use of vegetable oil during the machining of AISI 9310 low-alloy steel compared to dry and wet machining in terms of turning temperature, the form of chips, tool wear and surface roughness. Their results showed that machining with the minimum amount of lubrication, compared to dry and wet machining, reduces the cutting area's temperature and increases the turning tool's life. In addition, machining with the method of the minimum amount of lubrication is more compatible with the environment due to less pollution [12]. Balazinski et al. investigated the effect of minimum lubrication conditions on the machining of 7075-T6 aluminum alloy. Their results showed that machining using the minimum amount of lubrication system increases the life of cutting tools and reduces production costs compared to wet machining [13].

In this research, the process of AISI 304 stainless steel machining using the method of the minimum amount of lubrication was carried out. Considering the importance of the friction force between the tool and the surface being machined and its destructive effects on important parameters such as tool wear and the quality of the machined surface of the workpiece, there is a need to investigate the effects of the friction force on the cutting force. Therefore, in this research, the cutting force has been investigated as a parameter dependent on friction force, and the effect of variables such as fluid pressure and cutting speed on cutting force has been studied.

2- Research Method

In this research, machining experiments have been performed on round AISI 304 stainless steel parts with a length of 270 mm and a diameter of 30 mm.

In the machining process with the method of the minimum amount of lubrication, a small amount of lubricating liquid is mixed with the air, inside the tank and is sprayed on the machining area. To produce lubricating fluid in the method of the minimum amount of lubrication, which is the combination of air and oil in the form of a spray, an air, and oil mixing device (MQL device) is needed. Figs. 2 and 3 respectively show the MQL device and the machining process of the AISI 304 stainless steel workpiece using the MQL lubrication system.

Fig. 2 Minimum quantity lubricant (MQL) device

Turning experiments were performed on a lathe (model TN50BR, Tabriz Machinsazi company). Also, the forces along with the graphs of each machining test were measured and recorded for each test using a four-component dynamometer (model 9272 manufactured by Kistler company).

Fig. 3 Machining process of AISI 304 stainless steel workpiece using the MQL lubrication system

In this research, the effect of machining conditions with the minimum amount of lubricant on cutting force has been investigated. Table 1 shows the design of experiment variables levels for the conditions of fluid injection pressure, fluid injection flow rate, cutting depth, feed rate, and cutting speed which were applied in this research. The full factorial design of experiments was conducted.

Table 1: The experiments design variables' levels

Process variable	Level(s)
d (mm)	1
f (mm/rev)	0.08
V (m/min)	35, 50, 70
Q (ml/min)	5
P (bar)	3, 5, 7

According to Table 1, process variables include cutting depth (d), feed rate (f), cutting speed (V), fluid flow rate (Q), and fluid injection pressure (P).

3- Results and Discussion

In this research cutting force, as an important parameter was measured for each experiment. Table 2 shows the cutting forces measured for conducted experiments.

Table 2: Measured cutting forces for conducted experiments

No.	P (bar)	Q (ml/min)	d (mm)	f (mm/rev)	V (m/min)	F (N)
1	3	5	1	0.08	35	452
2	5	5	1	0.08	35	443.89
3	7	5	1	0.08	35	515.49
4	6	5	1	0.08	50	443.7
5	5	5	1	0.08	50	487.39
6	7	5	1	0.08	50	487.17
7	3	5	1	0.08	70	391
8	5	5	1	0.08	70	452.69
9	7	5	1	0.08	70	476.68

Fig. 4 shows the variation of cutting forces according to process variables.

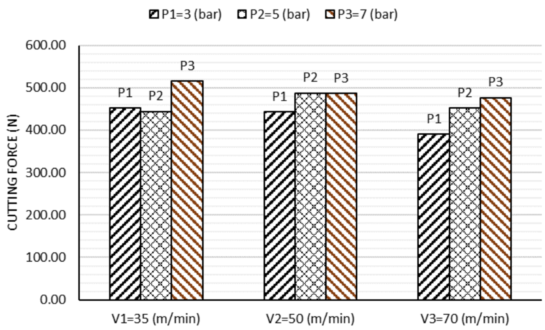

Fig. 4 The variation of cutting forces according to process variables (feed rate of 0.08 mm/rev and fluid flow rate of 5 ml/min)

As it is obvious from Fig. 4, with the increase in the cutting speed, the cutting forces decrease. This reduction can occur due to the reduction of the amount of adhesive friction and as a result of the reduction of friction force and cutting force following the increase in cutting speed.

Table 3 shows the maximum amount and percentage of the decrease in cutting force with increasing cutting speed.

Table 3: The maximum amount and percentage of cutting force decrease with increasing cutting speed

P	$F_{V=35}$	$F_{V=50}$	$F_{V=70}$	dF_{max}	(dF_{max}/F_{min})%
3	452	443.7	391	61	15.6
5	443.89	487.39	452.69	34.7	9.8
7	515.49	487.17	476.68	38.81	8.1

As it is clear from Table 3, the highest amount and percentage of reduction of cutting force (61 N-15.6%) with increasing cutting speed are related to the lowest fluid injection pressure. Because at lower fluid injection pressure, due to the reduction of dispersion of fluid spraying and more effective concentration of the sprayed fluid on the tool-chip-workpiece friction areas, the amount of friction force decreases more effectively with the increase of cutting speed. This results in a further reduction of the cutting force at low cutting speeds (35 m/min).

In addition, Fig. 4 shows that with the increase of the fluid injection pressure in the machining process using the minimum amount of lubrication on AISI 304 stainless steel, the cutting force increases. This increase can be due to the decrease in the concentration of the application of the lubricating fluid to the machining area and therefore as a result of the increase in the friction force in the machining process. Table 4 shows the amount and percentage of reduction in cutting force by reducing fluid injection pressure from 7 to 3 bar.

Table 4: The amount and percentage of reduction in cutting force by reducing fluid injection pressure from 7 to 3 bar

V	$F_{P=7}$	$F_{P=3}$	dF	$(dF/F_{P=3})$%
35	515.49	452	63.49	14
50	487.17	443.7	43.47	9.8
70	476.68	391	85.68	21.9

As it is obvious from Table 4, at higher cutting speed (70 m/min), the reduction of cutting force (85.68 N-21.9% reduction) is more evident with the reduction of fluid pressure. This is because at higher cutting speeds, in the case of a more decentralized application of fluid spraying, and as a result, the effective concentration of the fluid in lubrication decreases due to the increase in friction, which causes a more intense increase in the cutting force with an increase in the fluid spraying pressure. In other words, at high cutting speeds, the lubricants are consumed much faster in the friction areas and the higher pressure of the fluid spray due to the reduction of the fluid spray concentration and the reduction of the performance of the lubricant in the friction areas during machining, increases the friction force and as a result the cutting force.

On the other hand, at high cutting speeds, if the fluid spray pressure is applied with a lower amount due to more and more effective concentration of the fluid on the friction areas between the tool-chip-workpiece during machining, and more effective application of lubrication in the machining process, the friction force during machining is significantly reduced.

4- Conclusion

In this research, the process of AISI 304 stainless steel machining using the method of minimum quantity lubricant was carried out. Due to the effect of friction at tool-chip-workpiece contact areas on the cutting force level, the cutting force was measured during the conducted experiments. The conditions parameters in the machining process using the MQL system were considered. The effect of fluid injection pressure and cutting speed as two important process parameters were investigated. The following results are a summary of the results of this research:

- The maximum amount of cutting force decrease is 61 N (15.6%) by an increase of cutting speed from 35 to 70 m/min. This cutting force reduction occurred for fluid injection pressure of 3 bar.
- The increase of the cutting speed results in cutting forces decrease due to the reduction of the adhesive friction.
- The maximum amount of cutting force decrease is 85.68 N (21.9%) by reduction of fluid injection pressure from 7 to 3 bar.

This cutting force reduction occurred for a cutting speed of 70 m/min.

- The decrease of fluid injection pressure causes the cutting force to decrease because of friction force reduction due to a more effective concentration of lubricant on the tool-chip-workpiece contact area. In other words, increasing the fluid injection pressure result in more deconcentrated fluid spraying. the beginning of a sentence.

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