Effect of Nozzle Angle and Nozzle Distance on Turning of Al-6082 Alloy under Minimum Quantity Lubrication (MQL) Condition

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Abstract

Minimum Quantity Lubrication (MQL) is an alternative for machining operations in which dry conditions are not applicable and high surface quality are of more interest. The formation of built up edge during machining of aluminum alloys is difficult to control and hence requires optimal quantities of cutting lubricant to minimize the defects. The present paper aims at investigating the effect of MQL process parameters on turning characteristics of Al-6082 alloy based on Design of Experiments approach. MQL setup was fabricated for supply of cutting fluid during cutting. Response Surface Methodology was adopted to correlate the process parameters with surface finish, resultant cutting force and cutting temperature. While nozzle angle influenced the cutting force, nozzle distance was the influencing factor for cutting temperature. The response surface methodology indicated minimum cutting force of 5.84 kgf and cutting temperature 27.95 ^{0} C at nozzle distance of 40 mm, nozzle angle of -5º and air pressure 4.5 bar for cutting force and cutting temperature respectively. Minimum surface roughness of 2.91 µm was observed at nozzle distance of 50mm, nozzle angle of -5 deg and air pressure of 4.5 bar.

Keywords: *Minimum Quantity Lubrication (MQL), Turning, Response Surface Methodology, Al 6082*

1.0 Introduction

Productivity in industries is a function of design and manufacturing costs. The total manufacturing cost comprises of 17% cooling and 4 % tooling techniques which can be further reduced by efficient solutions. Among these costs, tooling costs are more significant due to high speed machining of difficult-to-cut materials which can controlled by suitable cooling methods. Conventional flooding method is much popular which

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employs enormous cutting fluid into interface zone of tool and workpiece for cooling purpose in order to decrease the temperature of the tool bits and hence minimize tool wear rate [1].

Minimum quantity lubrication (MQL) is an alternative for conventional flood cooling method in order to control the environmental hazards and economic impacts. It is also a substitute for dry machining operations where high surface quality is of less interest. MQL is a near dry lubrication or micro lubrication condition at which minute amount of cutting fluids at a flow rate of 50 to 500 ml/h is adopted [2, 3]. A cutting fluid for MQL is selected based on primary characteristics such as cutting performance and secondary characteristics such as biodegradability, oxidation stability and storage stability. The applications in which the friction and adhesion phenomena play a major role require the usage of minimal quantities of fluids. The advantages of MQL include coolant delivery with environment friendly system, less waste disposal, biodegradable fluids, minimized health hazard and storage space [3]. Aluminium alloy 6082 is a medium strength structural alloy possessing excellent corrosion resistance. The higher strength can be imparted by the addition of large amount of manganese which controls the grain structure [4].

Some of the researchers have reported the effect of MQL parameters on the cutting performance of various steel and aluminium alloys. Tawakoli et al. [5] investigated the grinding performance of nanofluid under various spraying parameters. The authors concluded that air pressure is critical in order to enhance the nanofluid mist to penetrate into the grinding zone. Increase in air pressure caused decrease in grinding characteristics such force, roughness and temperature. The grinding performance improved at shorter spraying distance rather than longer spraying distance[6].

Mulyadi et al. [7] investigated the effect of nozzle position on tool wear in end milling processes of H13 tool steel. A combination of lower pressure (150 psi) air, higher flow rate (20 ml/min) and a larger spray distance (35 mm) resulted in longer tool life and broken chips. The authors reported that ACF spray system can extend tool life up to 40 to 50% over flood cooling [8]. Yan et al. [9] reported extended tool life and minimized surface roughness at nozzle feed position of 120°, elevation angle 60°, and nozzle distance of 20 mm during end milling of 50CrMnMo steel. Lopezdelacalle et al [10] established a relation between nozzle position and feed direction in order to optimize the effect of MQL. The nozzle position of 135° allowed MQL jet reaching the tool edge in a very efficient way. Mohammad Jafar et al. [11] found that when the oil mist was supplied from two nozzles facing the tool rake and flank face at the same time resulted in decrease in tool - chip interface temperature during turning of AISI 4140 steel. Also two nozzle settings were optimal in reducing cutting force and surface roughness [12].

From the review of literature [1-12], it was found that most of the authors had worked on flood coolant during machining but MQL is very promising for many green machining applications. Several fundamental issues associated with MQL such as optimal conditions for the nozzle operations and environmental concerns have not been addressed yet. Hence this paper focuses on the development of MQL setup for optimizing the nozzle angle and nozzle distance from the work piece and assessment of performance of Al-6082 alloy during its machining under these optimal MQL conditions.

Fig. 1. Experimental set up for Nozzle fixture with MQL

2.0 Experimental Details

The turning process of a material was carried out in lathe incorporated with MQL set up as shown in Fig. 1. MQL set up was developed by using twin fluid nozzle in which there were two inlets for the air pressure and lubricant is passed through the outlet in the form of mist. Compressed air from the reciprocating compressor was controlled using a pressure regulating value and the lubricant was controlled using an infusion set. The lubricant gets atomized in the nozzle with the droplet sizes ranging from 15 to 40 µm. Mustard oil was used as the lubricant. The atomized lubricant from the nozzle was sprayed on to the interface of the tool (HSS tool) and work piece (Ø32mm and 150 mm length). The nozzle angle, nozzle distance and pressure were selected as experimental parameters. Nozzle angle was varied in three levels namely 0º, 5º and -5º as shown in Fig. 2. Experiments were conducted according to the L_9

array formulated using MINITAB 17.0 software and cutting force, cutting temperature were measured using lathe tool dynamometer and infrared gun respectively. Surface roughness of the machined specimens was measured using SURFTEST SJ-210.

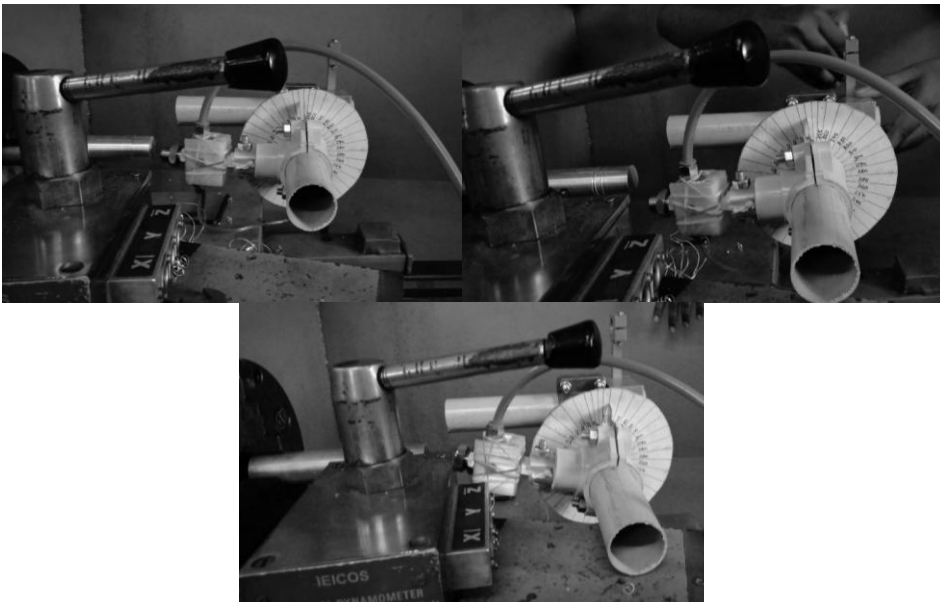

Fig. 2. a) Nozzle angle 0^0 , **b)** Nozzle angle 5^0 and **c)** Nozzle angle- 5^0

3.0 Results and Discussion

3.1 Analysis of effect of MQL parameters on turning responses of Al 6082

From the main effects plot (Fig 3) for mean cutting force, it was found that increase in nozzle distance caused increase in mean cutting force. This was due to the high kinetic energy droplets obtained when the nozzle is placed nearer. Droplets with relative higher kinetic energy have the ability to penetrate through the flow field on the tool and spread on the tool surface, which is desirable for cutting lubrication [13]. As the nozzle angle increased from -5° to 5°, mean cutting force increases since droplets of oil mist that adhere to the insert are thrown away from the insert surface while the tool moves to the contact zone [8]. As pressure increases from 3.5 to 4.5 bar, flow rate of lubricant causing decrease in mean cutting force. From the ANOVA of mean cutting force presented in Table 1, it is observed that nozzle angle significantly influenced the mean cutting force.

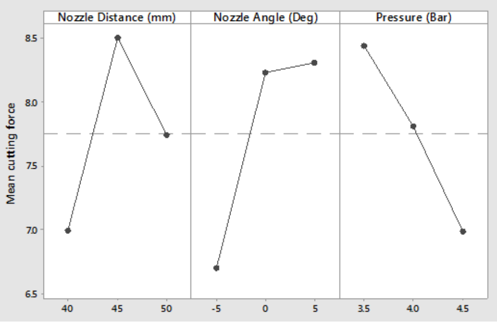

Fig. 3. Main effects plot for cutting force

Table 1. ANOVA for Mean cutting force (kgf)

Factors	DOF	Adj SS	Adj MS	F-Value	P-Value
Nozzle Distance (mm)	2	3.4091	1.7045	13.13	0.071
Nozzle angle (Deg)	2	4.9364	2.4682	19.01	**0.050**
Air pressure (Bar)	2	3.1973	1.5987	12.31	0.075
Error	2	0.2596	0.1298		
Total	8	11.8024			

Main effect plot for mean cutting temperature under MQL conditions is as shown in Fig. 3. It was found that as the nozzle distance increased, the mean cutting temperature increased from 28.50 ^{0} C to 30 ^{0} C since nozzle distance increases from 40 to 50 mm, lubrication becomes minimum at the tool and work piece. However, when the pressure is increased from 3.5 to 4.5 bar, the mean cutting temperature also decreases from 29.60 ^{0} C to 28.75 ^{0} C which indicates increase in flow rate of lubricant. From the ANOVA table of mean cutting temperature presented in Table 2, nozzle distance (mm) was found to be the significant factor influencing the mean cutting force.

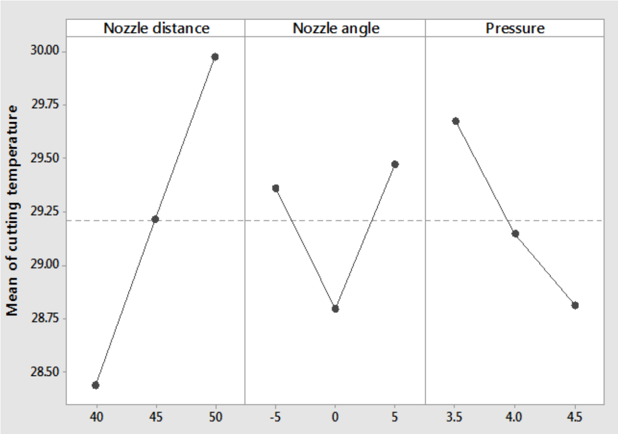

Fig. 4. Mean effect plot for cutting temperature

Table 2. ANOVA for Mean cutting Temperature (^{0} C)

Factors	DOF	Adj SS	Adj MS	F-Value	P-Value
Nozzle Distance (mm)	2	3.5355	1.7678	12.49	**0.074**
Nozzle angle (Deg)	2	0.7972	0.3986	2.82	0.262
Air pressure (Bar)	2	1.1320	0.5660	4.00	0.200
Error	2	0.2830	0.1415		
Total	8	5.7477			

From the main effect plot for surface roughness plot as shown in Fig 4, it is found that the surface roughness increased from 3.25 to 3.5 µm with increase in nozzle distance from 40 to 45 mm. Increase in nozzle angle from -5° to 5° did not had significant effect on surface roughness. However, when the pressure was increased from 3.5 to 4.5 bar, the surface roughness also decreased from 3.35 µm to 3.15 µm which could be due to the usage of high pressure air which limits the effectiveness of MQL in minimizing the surface roughness. From the ANOVA of mean surface roughness presented in Table 3, it is observed none of the factors significantly influenced the mean surface roughness.

Table 3. ANOVA for Mean surface Roughness (Ra)

Factors	DOF	Adj SS	Adj MS	F-Value	P-Value
Nozzle Distance (mm)	2	0.52289	0.26145	0.88	0.532
Nozzle angle (Deg)	2	0.05625	0.02812	0.09	0.913
Air pressure (Bar)	2	0.08198	0.04099	0.14	0.879
Error	2	0.59343	0.29671		
Total	8	1.25455			

3.2 Multiobjective optimisation of turning responses under MQL conditions

Response surface methodology was adopted for obtaining the optimal conditions of MQL parameters in order to improve the cutting performance of Al 6082 alloy. From the response optimization plot as shown in Fig. 5, it was observed the optimal solution for the multiple responses were obtained when the nozzle distance was set at 40 mm, nozzle angle was set at -5º and air pressure was set at 4.5 bar. The overall composite desirability of 0.8170 indicated that the achieved optimal responses are under acceptable limits.

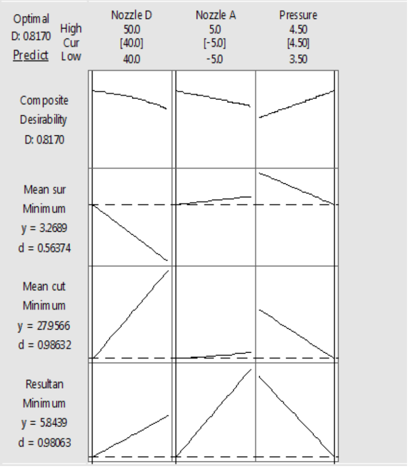

Fig. 5. Response Surface Methodology plot of the MQL parameters

4.0 Conclusions

The influence of MQL parameters such as nozzle angle, nozzle distance and air pressure on turning performance of Al 6082 alloy was reported. Response surface methodology was adopted for obtaining the optimal conditions of MQL parameters in order to improve the turning performance of Al 6082 alloy. The performance characteristics included cutting force, cutting temperature and surface roughness. While nozzle angle influenced the cutting force, nozzle distance was the influencing factor for cutting temperature. Surface roughness was not influenced by the range of the MQL parameters considered. The optimal solution for the multiple responses were obtained at nozzle distance of 40 mm, nozzle angle of -5^{o} and air pressure of 4.5 bar. The overall composite desirability of 0.8170 indicated that the achieved optimal responses are under acceptable limits.

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