EXPERIMENTAL STUDY IN USING AIR JET ASSISTED COOLING APPROACH FOR MILLING MACHINING

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ABSTRACT
In machining, cutting fluid plays a very important role. However, the usage of cutting fluid has been addressing the issues of environmental intrusiveness and occupational hazards especially the cutting fluid used in conventional wet machining. Therefore, pure dry machining has become a reliable choice in machining for some materials. Yet, the pure dry machining process has significant effect on cutting temperature due to no lubrication and cooling effect during the metal cutting process. Hence, the machining assisted with air pressure has arisen as an important alternative technique to increase the production efficiency and to minimise the usage of traditional cutting fluid such as water, oil-based cooling agents that contained harmful ingredients. In this study, a new lubrication method called air jet assisted cooling system was fabricated and applied for improving the cooling effect during the pure dry machining. The result from the cutting experiments showed that the air jet assisted cooling system has brought a great improvement on the cutting performance with reducing the cutting temperature and having a better surface finishing on the workpiece.

Keywords:
Air jet assisted cooling, Dry machining, Cutting temperature, Surface finishing, Aluminium alloy, Up-milling process

INTRODUCTION

Machining is the process in which a tool removes material from the surface of a less resistant body, through relative movement and application of force. In recent time, cutting fluid plays a very important role in machining. It is a type of coolant and lubricant designed specifically for metalworking and machining processes. There are various kinds of cutting fluids, which include oils, oil-water emulsions, pastes, gels, aerosols (mists) and air or other gases. They may be made from petroleum distillates, animal fats, plant oils, water and air, or other raw ingredients. Yet, the usage of cutting fluid has brought a lot of detrimental effects such as health hazards and environmental pollutions when it is handled improperly (Dhar, N *et al.*, 2006). In addition to the lately issue of cutting fluids increase the machining cost as its cost frequently higher than the cost of cutting tools, dry machining becomes one of the solutions to solve this problem and the trend towards dry machining is growing rapidly (Dudzinski *et al.*, 2004).

In pure dry cutting operations, the friction and adhesion between chip and tool tend to be higher, which causes higher temperatures, higher wear rates and, consequently shorter tool lives. Therefore, completely dry operation is not suitable for all processes and all materials especially hard materials. In end milling operation, there are parameters that could affect the surface roughness of the work piece, such as depth of cut, feed rate, cutting speed, operating temperature and material used (Goindi & Sarkar, 2017). Thus, the machining assisted with air pressure has become an important alternative technique to increase the production efficiency. A similar study of using cooling liquid mist together with air jet assisted cooling had been carried out by Obikawa, 2015. In this paper, the cooling technique was referred and modified to using only air jet assisted cooling system (AJACS) on dry milling process to define its efficiency of function.

LITERATURE REVIEW

A new lubrication method called air jet assisted (AJA) machining was reported as a solution of high-speed finish-machining of many materials. In this machining method the jet of compressed air was applied to the tool tip in addition to cutting fluid in conventional wet machining. Preliminary experiments showed that AJA machining had a favorable effect on the tool life extension. In AJA machining, not only cutting fluid but a jet of compressed air as well is applied to the tool tip from an air nozzle at the flank face of a tool holder (Obikawa *et al.*, 2011). In the air jet assisted cooling system (AJACS), air pressure is the main role as an alternative way to provide cooling effect during the dry milling process (Habrat et al, 2016).

A similar research project had been carried out by Obikawa *et al.* in year 2012. Their experiment setup had adopted an air nozzle with size of 0.95 mm^2 cross section and 1.1 mm inner diameter. Figure 1 showed the schematic design of AJA machining method adopted by Obikawa, 2012. The distance from the air nozzle to the tool tip was 12.0 mm. The pressure of compressed air for generating the air jet was fixed at 0.54 MPa in gauge pressure. Its flow rate was measured to be 61.7 l/min (NTP) using an area flowmeter. Its mean velocity was calculated to be 175 m/s on the assumption that its pressure was kept at 0.54 MPa at the exit of the nozzle. It was found that AJA machining improved tool life by 20 – 30% in comparison with conventional wet machining. It was proved that the cutting speed could be increased by 12% without decrease in tool life length by changing conventional wet machining to AJA machining (Obikawa *et al.*, 2012).

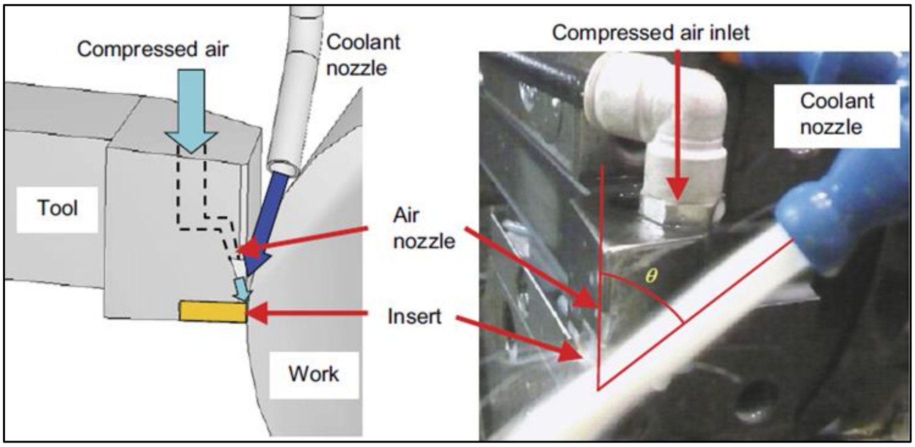


Figure 1: A Schematic Design of AJA Machining Method (Obikawa *et al.*, 2012)

EXPERIMENTAL METHOD

The development of AJACS was set up according to the diagram illustrated in Figure 2. It is supported by air compressor sub-assembly unit which consists of air compressor, air pressure water separator and air compressor hose pipe, while the AJACS (see Figure 3) is fabricated by using air pressure regulator gauge, air ejector line and an air nozzle. The air pressure regulator gauge is important to measure the air pressure output at the end of the air hose pipe and set the desirable air pressure range throughout the air ejector line and lastly to the air nozzle. The air ejector line is adjustable for any desirable direction and it comes with a control valve to control the air pressure flow. It is durable to eject high pressure air without any air leakage throughout the experiments.

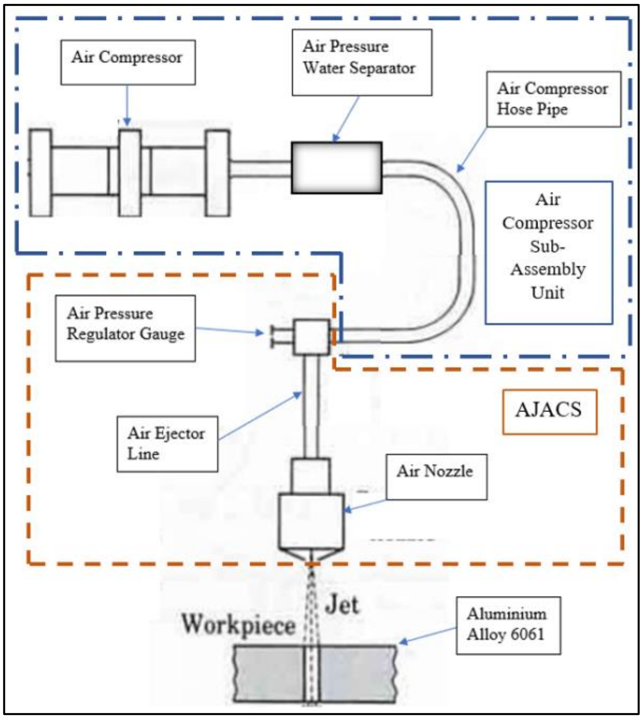


Figure 2: A Schematic Diagram of Components Used in the Air Jet Assisted Cooling System

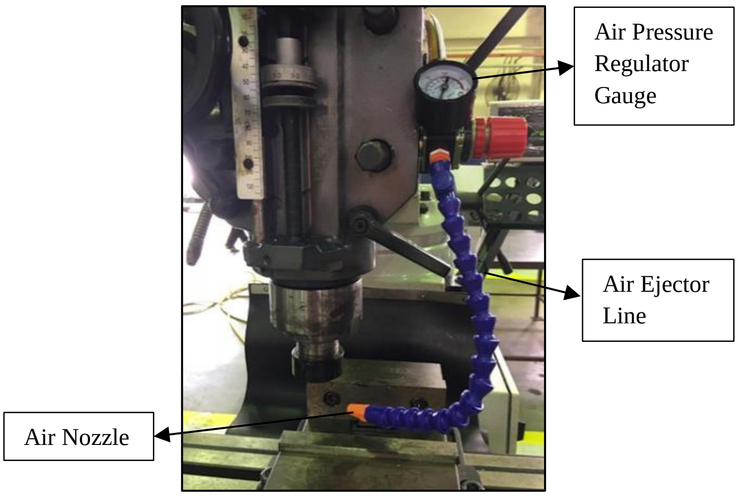


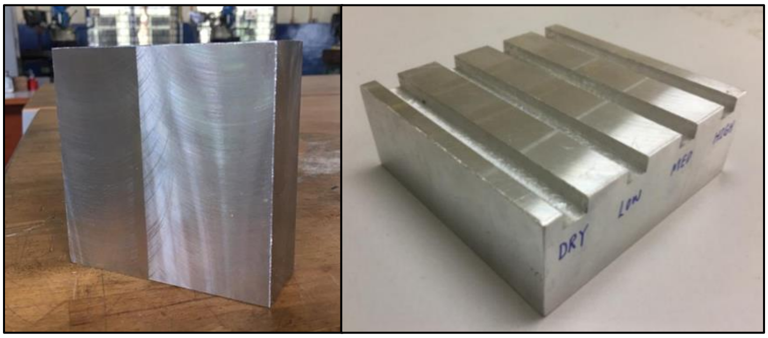
Figure 3: Air Jet Assisted Cooling System (AJACS)

The overall experimental parameter controls and machine settings during the experiment are as listed in Table 1.

Table 1: Experimental Parameter Settings and Controls

Experiment Mode	Dry Machining	i) Pure Dry ii) Air Pressure Assisted - Low Pressure (2 Bar) - Medium Pressure (4 Bar) - High Pressure (6 Bar)
Machine Control	Spindle Speed	3600 RPM (Fixed)
	Feed Rate	104.24 mm/min (Fixed)
Workpiece Control	Depth of Cut	5 mm (Fixed)

The workpiece selection is one of the important factors during an experiment. The selection of workpiece for this experiment is Aluminium Alloy 6061. The reason of choosing Aluminium Alloy 6061 is because of the alloy series is the most common material availability and economical. Before running the experiment, the workpiece shown in Figure 4 was after squaring process and pre-slotted with 4 slots in 5mm depth for a better up-milling process later. Each of the slots was labelled with 3 points in order to get the average data for every mode of experiment as shown in Figure 5.



a) Workpiece after squaring   b) Workpiece after slotting process

Figure 4: Preliminary Process

The experiment was conducted in two conditions of dry end milling process, one was without any coolant and another was with the air jet assisted cooling system (AJACS). The experiment of AJACS was further compared to 3 levels of air pressure, that are low, medium and high pressure with 2 Bar, 4 Bar and 6 Bar respectively.

The cutting tool selection is a 6mm HSS endmill bit. The cutting method used in the experiments was half immersion up-milling method. The experiments were taking place in a sunny day with ambient temperature 30˚C. The machine employed throughout the experiments was a ram-type milling machine that is a brand of Lagun FTV-2.

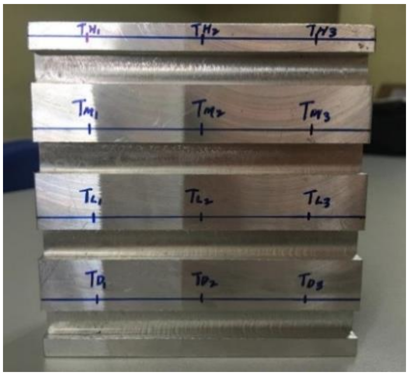
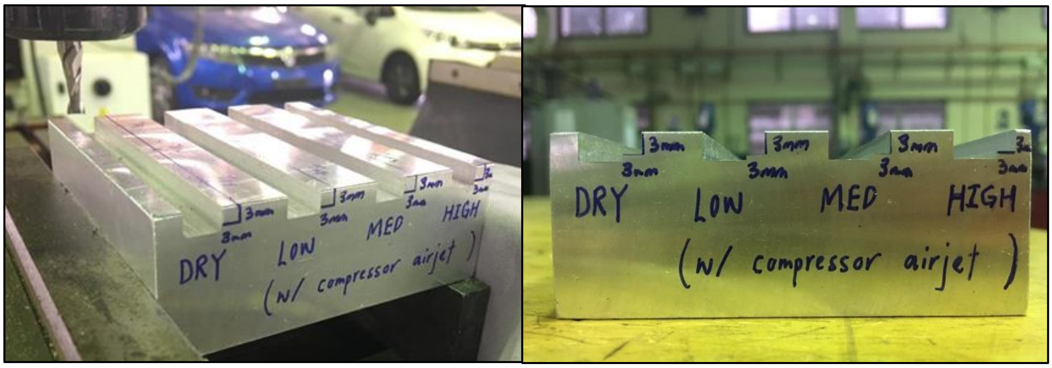
	T_{H1}, T_{H2}, T_{H3}	AJACS High Pressure = 6 Bar
	T_{M1}, T_{M2}, T_{M3}	AJACS Medium Pressure = 4 Bar
	T_{L1}, T_{L2}, T_{L3}	AJACS Low Pressure = 2 Bar
	T_{D1}, T_{D2}, T_{D3}	Pure Dry Machining

Figure 5: Workpiece before Experiment and the Points of Data Collection

Experimental Milling Process

The cutting region of workpiece was marked in 3mm x 3mm from the slot edge as shown in Figure 6(a). FLIR Thermal Imaging Camera (TIC) E50 model was used to measure the cutting temperature during the milling process for all the 3 points in each row to get the average data (see Figure 7). FLIR E50 is a good and high sensitivity device for capturing accurate thermal data. It is capable of distinguishing differences of 0.05 degrees Celsius.

The experiment was first started with pure dry condition without using any coolant and then continues testing in 3 different levels of air pressure of 2-bar, 4-bar and 6-bar. After completion of the milling process, the workpiece in Figure 6(b) was sent to surface roughness test.



a) Cutting Region Marked on the Workpiece

b) Workpiece after Half Immersion Up - Milling Process

Figure 6: Workpiece Used in Experiment

Figure 7: Capturing Cutting Temperature with Thermal Imaging Camera

Surface Roughness Testing

The apparatus used for the surface roughness test was called Mahr Perthometer S2 as shown in Figure 8(a). After the calibration, the workpiece was attached at the Perthometer PGK where the diamond stylus is located. Figure 8(b) shows the workpiece's set up at the Perthometer PGK. The surface roughness readings were taken 3 times per slot to get an average data. The steps were repeated for all of the 4 slots indicated dry, low, medium and high.

a) Mahr Perthometer S2 b) Workpiece set up at the Perthometer PGK

Figure 8: Surface Roughness Test

The result appeared on the screen are Mean Roughness (R_a), Roughness Depth (R_z), Maximum Roughness Depth (R_{max}) values as shown in Figure 9. R_a is the most common result among all three data. However, to get a more accurate surface roughness result, R_a and R_z have been recorded for this project.

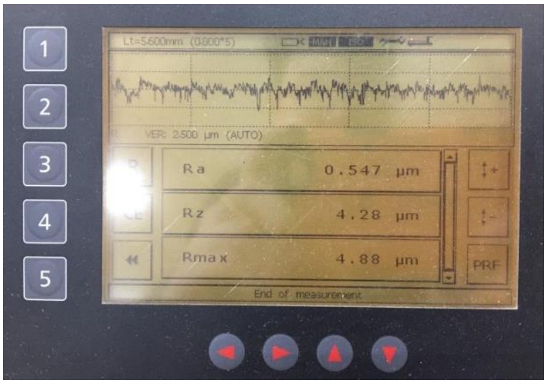


Figure 9: Screen Result of R_a, R_z & R_{max} Values

RESULTS AND DISCUSSION

From the experiment conducted, two main output parameters were collected; they are cutting temperature, T_c (˚C) and surface roughness, R_a and R_z (µm).

Data Collection and Data Analysis for Cutting Temperature, T_c (˚C)

Table 3 shows the cutting temperature, T_c (˚C) obtained from the Thermal Imaging Camera which is supported by software FLIR Tools.

Table 3 Data Collection for Cutting Temperature, T_c (˚C)

Experiment Output / Experiment Mode	Cutting Temperature, T_c (˚C)			
	1	2	3	Average
Dry Machining (without AJACS)	T_{D1} = 60.3	T_{D2} = 64.4	T_{D3} = 66.6	T_{Davg} = 63.8
Low Pressure 2-bar (with AJACS)	T_{L1} = 40.0	T_{L2} = 48.2	T_{L3} = 43.6	T_{Lavg} = 43.9
Medium Pressure 4-bar (with AJACS)	T_{M1} = 35.8	T_{M2} = 37.0	T_{M3} = 39.7	T_{Mavg} = 37.5
High Pressure 6-bar (with AJACS)	T_{H1} = 34.9	T_{H2} = 35.0	T_{H3} = 37.3	T_{Havg} = 35.7

The graph in Figure 10 shows that the cutting temperature for pure dry machining (without using AJACS) has the highest temperature of 63.76°C, followed by experiment mode using AJACS with Low Pressure (2-Bar) of 43.93°C, then 37.5°C for the Medium Pressure (4-Bar) and the lowest of 35.73°C for the High Pressure (6-Bar). This defined that air pressure and the cutting temperature has an inverse proportion relation. By increasing the air pressure in AJACS will result in decreasing the cutting temperature.

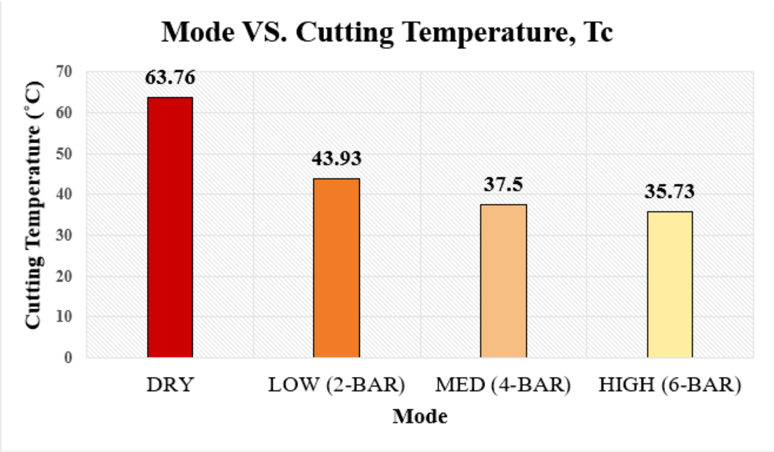


Figure 10: Experiment Mode vs. Cutting Temperature, T_c

Data Collection and Data Analysis for Surface Roughness, R_a and R_z (µm)

Table 4 indicates the data output of the surface roughness, R_a and R_z (µm) captured for all the modes of experiment.

Table 4 Data Collection for Surface Roughness, R_a & R_z, (µm)

Experiment Control / Mode	Surface Roughness, R_a & R_z (µm)							
	1		2		3		Average	
	R_a	R_z	R_a	R_z	R_a	R_z	R_a	R_z
Dry Machining (without AJACS)	0.919	7.59	0.987	8.79	1.030	7.59	0.979	8.00
Low Pressure 2-bar (with AJACS)	0.859	7.10	0.887	8.52	0.817	7.33	0.854	7.65
Medium Pressure 4-bar (with AJACS)	0.787	7.44	0.792	7.34	0.667	5.17	0.749	6.65
High Pressure 6-bar (with AJACS)	0.662	5.48	0.547	4.28	0.650	6.16	0.619	5.31

From Figure 11, it is noticed that both lines in the graph show a linear decreasing for Mean Roughness, R_a and Roughness Depth, R_z. The slot from the pure dry machining (without AJACS) has given the highest value of R_a = 0.979 µm, while mode AJACS with Low Pressure (2-Bar) decreased to 0.854 µm, and followed by 0.749 µm for the Medium Pressure (4-Bar) and the lowest of 0.619 µm for the High Pressure (6-Bar). Similarly to the data output of Roughness Depth R_z, the pure dry machining (without AJACS) has shown the highest value of 8.00 µm, while the High Pressure (6-Bar) has shown the lowest value of 5.31 µm. This also defined that air pressure and the surface roughness has an inverse proportion relation. By increasing the air pressure in AJACS will result in decreasing the value of mean roughness.

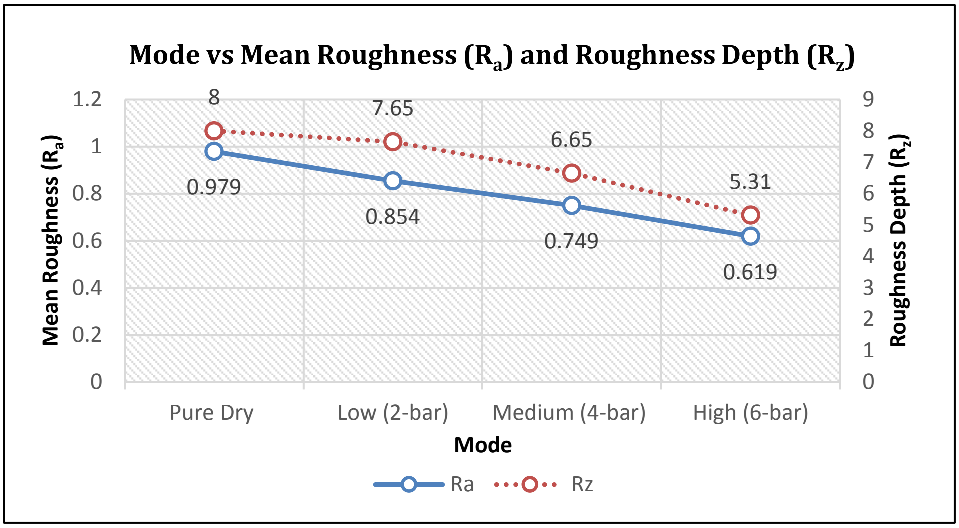


Figure 11: Mode vs. Surface Roughness

The lower the value of the mean roughness is, the finer the surface finishing on the workpiece. From the experiments, it shows that a lower cutting temperature during the milling process does providing a better surface finishing on the workpiece.

EFFECTIVENESS OF THE AIR JET ASSISTED COOLING SYSTEM

The dry machining without air jet assisted cooling system has been set as a benchmark of comparison with the dry machining with AJACS. The comparison data indicated in Table 5 shows that when the air pressure level used was increased, the % reduction in cutting temperature and mean roughness were increased as well. AJACS with High Pressure (6-Bar) has given the highest % reduction of 43.96% in cutting temperature, T_c and the highest % reduction of 36.77% in mean roughness, R_a.

Table 5 Comparison of AJACS with Pure Dry Machining

Benchmark	Pure Dry Machining = 63.76 ˚C		Pure Dry Machining = 0.979 µm	
Experiment Parameter / AJACS Mode	Cutting Temperature, T_c	% Reduction	Mean Roughness, R_a	% Reduction
Low Pressure 2-bar	43.93 ˚C	31.1%	0.854 µm	12.77 %
Medium Pressure 4-bar	37.5 ˚C	41.19%	0.749 µm	23.49 %
High Pressure 6-bar	35.73 ˚C	43.96%	0.619 µm	36.77 %

The result proved that the air jet assisted cooling is an effective approach of cooling process during dry milling. With the air pressure applied to the workpiece during the milling machining, this will give a better cooling efficiency and also provide a better surface finishing to the workpiece.

CONCLUSION

As a conclusion, this project has proved that the cutting performance has been improved effectively by using the AJACS during the dry milling process. The cutting temperature has been greatly reduced to 43.96% with using the AJACS High Pressure (6-Bar) comparing to the pure dry milling. The surface finishing on the workpiece also has been greatly improved by 36.77% due to the better cooling effect of the AJACS as well. In a nutshell, the higher the air pressure used during the dry machining process, the lower the cutting temperature. Additionally, the surface roughness has a inverse correlation to the cutting temperature. The lower the cutting temperature is the better the surface finishing.

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