iJET EXPLORE International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 8, August, 2012

Surface Roughness and Tool Wear Study on Milling of AISI 304 Stainless Steel Using Different Cooling Conditions

P. Chockalingam, Lee Hong Wee
Faculty of Engineering and Technology,
Multimedia University, Melaka, Malaysia

ABSTRACT

This research deals with the effect of different coolant conditions on milling of AISI 304 stainless steel. Cooling methods used in this investigation were flooding of synthetic oil, water-based emulsion, and compressed cold air. Cutting forces and the surface roughness were studied and tool flank wears observed. In this study, the comparison between different coolants' effect to the milling of AISI 304 stainless steel is done and the results from the study can provide very useful information in manufacturing field. The experiment results showed that water-based emulsion gave better surface finish and lower cutting force followed by synthetic oil and compressed cold air. Different cooling condition required different parameters in order to obtain lower surface roughness and cutting force. Chipping was the initial wear mode in the milling of AISI 304 stainless steel.

Keywords: *Surface roughness, cutting force, milling, stainless steel*

I. INTRODUCTION

Machining plays important role in producing products. Milling is the most widespread metal removal process in metalworking industry. Manufactured products qualities are determined by their surface quality. The high friction between tool and work piece leads to high temperatures, tool wear, and poor surface quality. In order to decrease the friction, cutting fluids are necessary to be applied during machining. However, the application of conventional cutting fluids becomes a source of environmental pollution and creates biological problems to the operators [1]. In recent years, pollution issues due to industrial waste have caught attention from public authorities. All these factors have attracted many researches to research on the use of biodegradable coolants and dry machining or coolant free machining.

M. Rahman et al. [2] found that in milling, the cutting force is reduced and surface finish is better with the use of high pressure coolant compare to conventional coolant and dry cutting. According to W.Y.H. Liew [3], mist lubrication gives a better surface finish than flooding technique in the low-speed milling of modified AISI 420 stainless steel with the use of coated and uncoated carbide end mills.

However, applying cutting fluids during machining has caused problems like high cost, pollution and hazards to operator's health [4]. Therefore, there are many researchers start to search other cooling method to reduce the use of cutting fluids in machining. Refrigerated cooling gas and high pressure water jet are the alternatives. Y. Su et al. [5] investigated the effect of cooling air cutting in turning of Inconel 718 and high-speed milling of AISI D2 cold work tool steel, and the experiments were conducted under dry cutting, MQL, cooling air and cooling air and minimal quantity lubrication (CAMQL). The results of the research showed that tool wear and surface roughness were reduced with the application of cooling air in turning of Inconel 718 and the cooling air cutting in the high-speed milling of AISI D2 provided longer tool life and slightly higher surface roughness than MQL and dry cutting. AISI 304 stainless steel is wide use in commercial industry. The applications of AISI 304 stainless steel are food processing equipment, kitchen equipment and appliances, architectural panelling, railings, chemical containers, heat exchangers, and many others.

II. EXPERIMENTAL SETUP AND PROCEDURES

The end milling of the AISI 304 stainless steel workpieces is performed by using Master CNC 10HVA milling machine with Garryson uncoated solid carbide end mill of 4 flute, 5 mm diameter with 16 mm flute length and 50 mm overall length. Table 1 shows the properties of AISI 304 stainless steel. The milling is carried out on 150 mm x 76 mm x 12 mm material. Figure 1 illustrate the schematic diagram of the experimental setup.

Table 1: Mechanical Properties of AISI 304 Stainless Steel

Tensile Strength (MPa)	627
Yield Strength, (MPa)	312
Hardness, (HV)	251.57
Elongation, A5 %	57

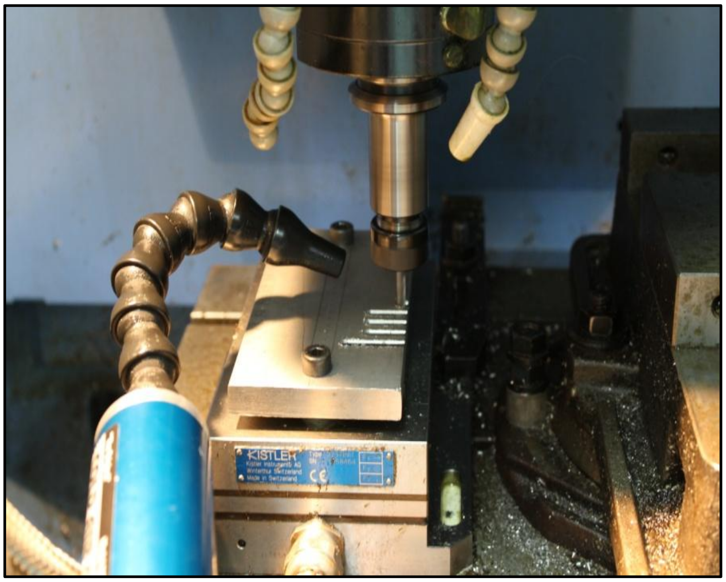


Figure 1: Milling Process Setup

The experiments are carried out in dry and wet environments. Three cooling systems used in the experiments are flooding of synthetic oil (YUSHIROKEN SC95), water-based emulsion, and compressed cooling air. In current work, the controllable parameters are spindle speed (N) and feed rate (f), while the depth of cut is kept constant at 0.5mm. The spindle speed (N) and the feed rate (f) are varied as 1500 rpm $\leq$ N $\leq$ 2500 rpm and 40 mm/min $\leq$ f $\leq$ 60 mm/min. The spindle speeds and feed rates are ranging as recommended by the lab technician and the machinery workers. The machining conditions are stated in Table 2.

Table 2: Machining Conditions

Cutting tools	Solid carbide end mill cutters (Garryson)
Spindle speed, N (rpm)	1500, 2000, 2500
Feed rate, f (mm/min)	40, 50, 60
Depth of cut, d (mm)	0.5

Cutting fluid

Synthetic oil (YUSHIROKEN SC95)

Synthetic oils contain neither petroleum nor mineral oil. YUSHIROKEN SC95 is a water miscible metalworking fluid (MWF), which is containing neither nitrites nor phosphates. It has high cooling capacity, highly resistant against bacteria, and low foam characteristics. Its highly resistant against bacteria characteristic ensures a longer coolant life.

Water-based emulsion (Koolcut C-300)

Water-based emulsion is also called as soluble oil. Generally, it contains about 60-90 percents of petroleum or mineral oil, emulsifiers, and some other substances. By mixing with water, it forms metalworking fluid with a milky and opaque appearance. In this project, AEROIL cutting oil (Koolcut C-300) is used to mix with water to form a milky white emulsion. It is recommended to mix with water in certain proportion of three parts or more of water to one part of oil.

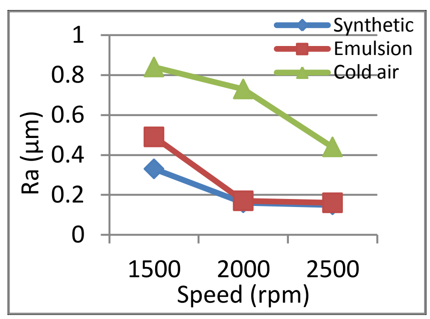
Compressed Cold Air

In order to perform the end milling under compressed cold air stream, an adjustable cold air gun Model 610 is used. This is the most popular and famous model for a wide range of industrial spot cooling and dry machining applications. This cold air gun converts filtered, 100 PSIG (6.9 Bar) compressed air into a cold air stream by using vortex tube technology. It is able to produce a cold air stream with temperature as low as -30 ̊F (-34.4 ̊C).

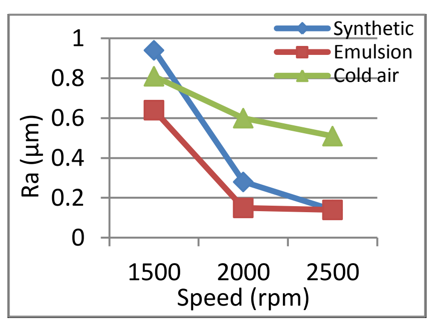
III. RESULTS AND DISCUSSION

Effect of different coolant conditions on surface roughness

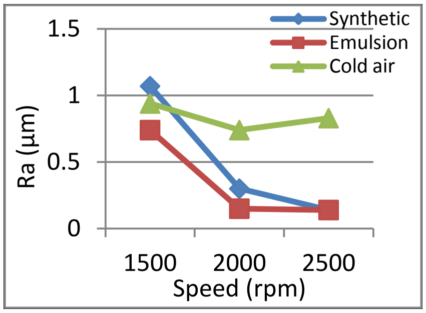
Surface finish is an important factor to indicate the effectiveness of the machining process. In order to explore the effect of different coolants to the surface finish, the surface roughness average values of machined surfaces at three different cooling conditions were recorded and analyzed. Figure 2 shows the plot of surface roughness, Ra, versus spindle speed for different cooling conditions at different feed rates (40, 50, 60 mm/min). A significant difference in variation of surface roughness under each cooling condition was observed. It is obviously seen the surface roughness value decreases as the spindle speed increases.



(a)



(b)



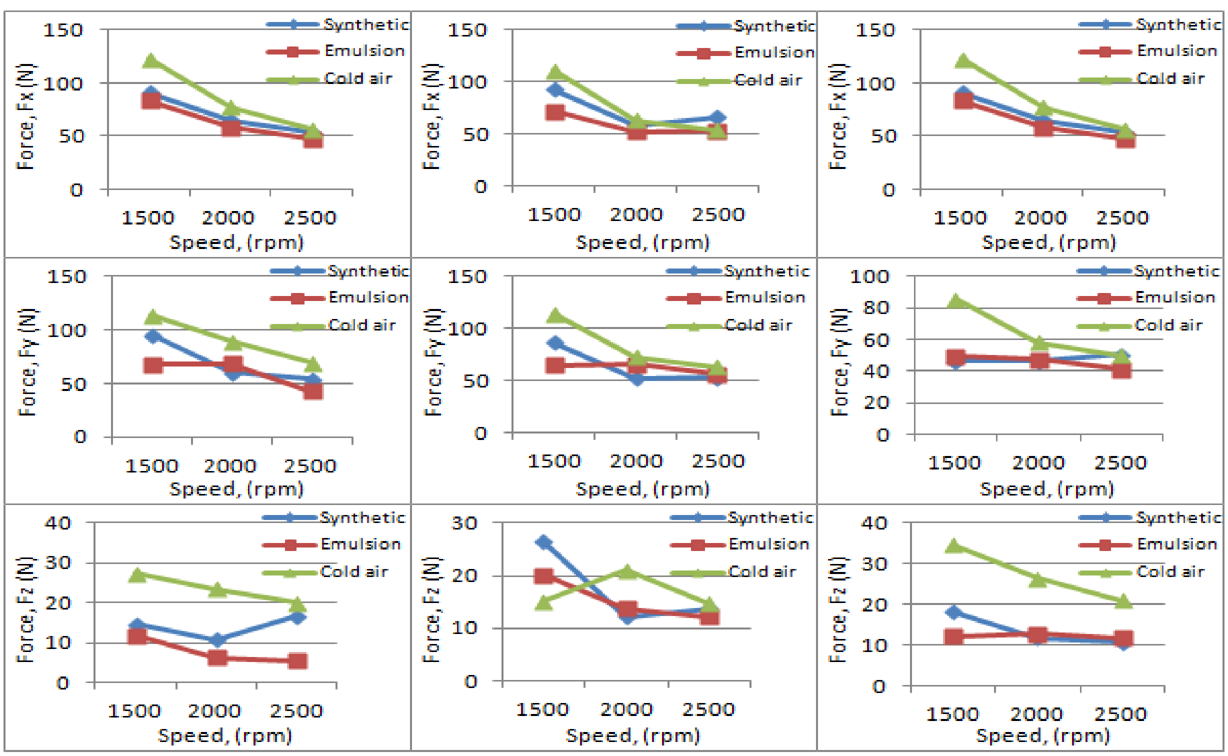
(c)

Figure 2: Variation of Surface Roughness with Spindle Speed at Various Levels of Feed Rate: (a) 40 mm/min, (b) 50 mm/min, (c) 60 mm/min

It can be seen that the best surface finish is obtained with the water-based emulsion and synthetic oil, followed by the compressed cold air. It is clearly shown that both conventional coolants gave the close surface roughness to each other at 2000 and 2500 rpm under three feed rates, the surface roughness values were ranging from 0.14 to 0.30 µm. Although both the applications of water-based emulsion and synthetic oil gave the lowest surface roughness, there was still slightly different in the variation of both. Water-based emulsion was still acting as a better coolant compared to the synthetic oil. This could be due to the additive of the water-based emulsion, emulsifier, reduced the friction between tool tips and work surface during end milling.

Compared with flooding of synthetic oil and water-based emulsion, compressed cold air produced slightly higher surface roughness. The surface finish obtained with compressed cold air was slightly worse than that with the conventional coolants because milling with compressed cold air is considered as dry cutting process. Compressed cold air did not have lubrication effect like conventional coolants. Although the cooling air could reduce the cutting temperature and blow away the chip fragments and wear particles, it did not have a lubricant to decrease the friction between tool and work piece. Besides, shearing of the hardened material and chip formation became more difficult due to the decrease of cutting temperature caused by cooling air and thus higher surface roughness values were obtained.

In general, an increase in the spindle speed leads to an improvement of surface finish. As the spindle speed increased up to 2500 rpm, the surface roughness values of machined surface at all types of cooling conditions were found to be decreasing. This could be due to the reduction of cutting forces at higher speed. The surface roughness at all cooling conditions was increased as the feed rate was increased. Theoretically, surface roughness is primarily a function of feed and the concavity angle on end cutting edges [29]. Thus, this result is expected. Based on the observation, optimal parameters for both conventional coolants to obtain the best surface finish were 2500 rpm and 60 mm/min, and the surface roughness values were 0.14 µm. Yet, the optimal parameters for compressed cold air condition to get a better surface finish were 2500 rpm with small feed rate, 40 mm/min, and the obtained surface roughness was 0.44 µm.



(a)40 mm/min (b) 50 mm/min (c) 60 mm/min

Figure 3 Variation of cutting forces with spindle speed at various level of feed rate: (a) 40 mm/min, (b) 50 mm/min, (c) 60 mm/min. (c) 60 mm/min

Effect of Different Coolant Conditions on Cutting Forces

Cutting forces are one of the important criteria that are used to evaluate the performance of the machining process. Figure 3 presents the variation of cutting forces (X, Y, Z) for different cooling conditions with varying spindle speed at various levels of feed rate (40, 50, 60 mm/min). Compared to compressed cold air, the application of synthetic oil and water-based emulsion gave lower cutting force. The lowest cutting force was obtained with the application of water-based emulsion followed by synthetic oil and compressed cold air. This could be due to the lubrication ability of the conventional coolants. The cooling air did not have any lubricant that could reduce the friction between tool and chip. Therefore, abrasion of tool and chipping tend to increase the material adhesion resulting in higher force level.

It has been observed that the cutting force decreases as the spindle speed increases. The spindle speed increases and the heat generated in the shear zone is unable to be conducted away in very short time. Hence, the material is softened by the risen temperature assisting the dislocation of grain boundary and thus the cutting forces are reduced. However, there were some graph lines showed the cutting forces fluctuating between high and low values. This could be due to the tool wear.

Based on the graph shown in Figure 3, increase in feed rate tends to increase the cutting force components as expected. This is because as the feed rate increases, the material removal volume per revolution increases. So, more energy is needed and thus increasing the cutting force. It is observed that the increasing in feed rate show significant influence on cutting force components for compressed cold air. In order to obtain lower cutting forces, the optimal parameters for all cooling conditions are spindle speed of 2500 rpm with feed rate of 40 mm/min.

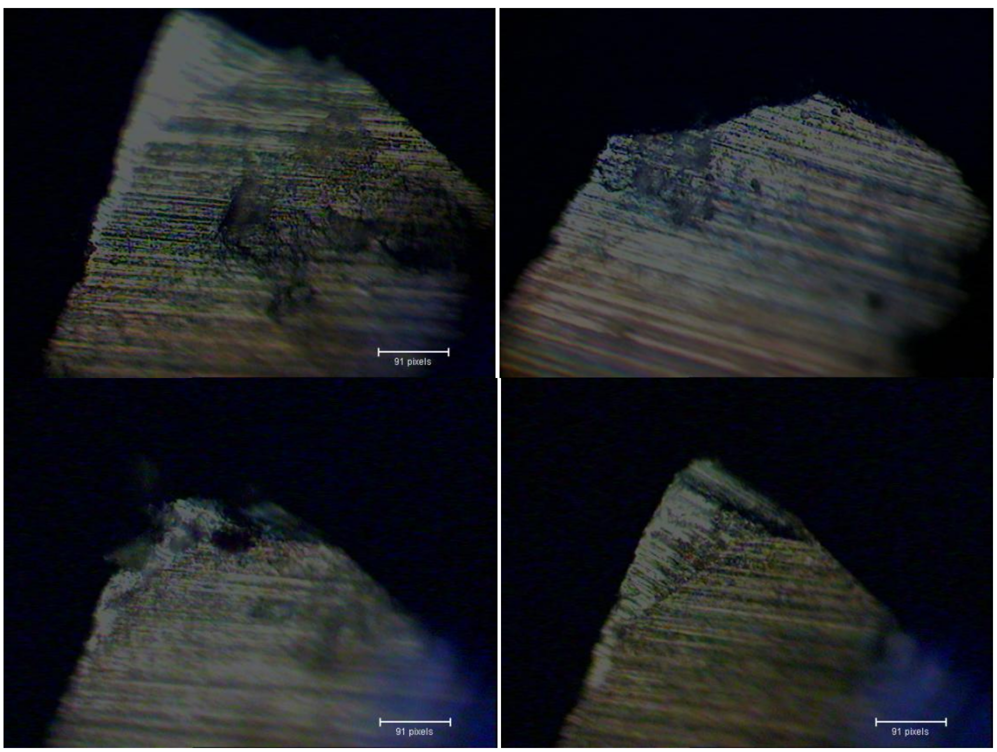


Figure 4: Microscopic views of flank wear under 40x magnification milling with synthetic oil

Effect of Different Coolant Conditions on Tool Wear

End mill cutter was used to perform the milling experiments under three different cooling conditions. Microscopic technique is employed to observe the flank wear of the cutting tool after experiment in each cooling condition. Figure 4 to Figure 6 show the microscopic views of flank wear under 40x magnification after milling with three different cooling conditions.

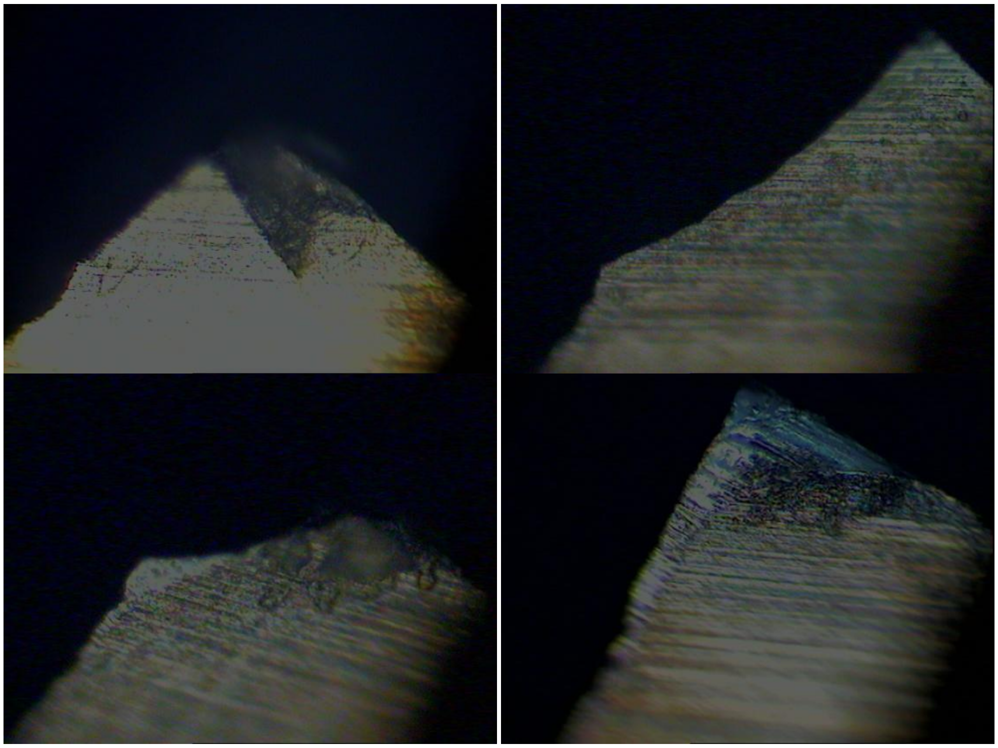


Figure 5: Microscopic views of flank wear under 40x magnification milling with emulsion

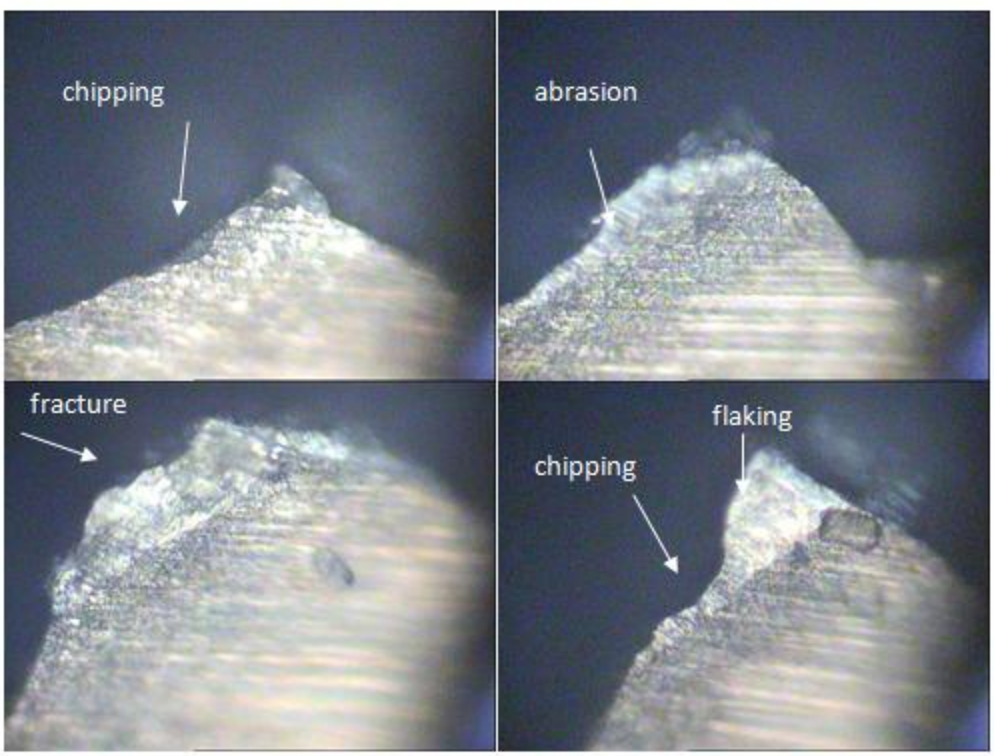


Figure 6: Microscopic views of flank wear under 40x magnification milling with cold air

The appearance of cavities and grooves on the tool surfaces proved the occurrence of abrasive wear. From Figures 4-6, chipping, fracture, and abrasion were more likely to take place when machining hardened steel with uncoated tool. Chipping was the initial wear mode. It could be seen that smaller chippings and fractures occurred in the initial stage of machining with synthetic oil as shown in Figure 4.

At the later stage of machining with water-based emulsion, the chippings, fractures, and abrasions continued to take place at the flank faces but with a slightly bigger scale which were illustrated in Figure 6. There was a crack occurred at one of the flutes which was shown in Figure. Compare to machining with flooding of synthetic oil and water-based emulsion, the tool was worn out intolerably after machining with compressed old air. From Figure 6, it could be obviously seen that more chippings, fractures, and abrasions were formed. Both conventional coolants are more effective in reducing flank wear compare to compressed cold air. This could be due to the cooling air did not have lubricant to reduce the friction between tool and work surface.

IV. CONCLUSION

The experiments were carried out in three cooling conditions which were flooding of synthetic oil, flooding of water-based emulsion, and compressed cold air to investigate the corresponding surface finish, cutting forces and tool wear.

From the results of the experiments, better surface finish was obtained with the application of water-based emulsion followed by synthetic oil. However, compressed cold air gave higher surface roughness compare to synthetic oil and water-based emulsion, and the surface roughness obtained with compressed cold air was ranging from 0.44 to 0.94. It is due to the cooling air does not have lubricant and thus the friction between tool and work surface is unable to be reduced. It had been found that higher spindle speed provided better surface finish. For both conventional coolants, higher feed rate is more sufficient in providing lower surface roughness while lower feed rate is more suitable for compressed cold air.

The experiment results showed that higher cutting forces were obtained with compressed cold air compare with synthetic oil and water-based emulsion. Besides, it had been found that the cutting force decreases as the spindle speed increases. It can be explained by the dislocation of grain boundary due to the heat generated. Higher spindle speed increases the heat generation at the shear zone and the heat generated is unable to be conducted away in very short time. The work material is softened by the risen cutting temperature and thus causing the dislocation of grain boundary. So, less energy is required to cut the material. In this context, the cooling air decreases the cutting temperature in a short time and hence strengthens the grain boundary. Therefore, more energy is required to cut the material. Besides, it can be concluded that higher feed rate will give higher cutting force. It is because more energy is required as the material removal volume per revolution is increased.

Microscopic analysis was done after each milling experiment. It can be seen that both the conventional coolants is more effective in reducing the tool wear compare with compressed cold air. From the microscopic views, chipping was the initial wear mode in the milling with solid carbide end mill cutter. More chippings and fractures were found after the milling with compressed cold air. The tool was worn out terribly after three experiments had been conducted. It can be concluded from the microscopic results that lubricant is important in reducing the tool wear.

The overall experiment result showed that the surface finish, cutting forces, and tool wear are related to the heat generated at the cutting zone and the friction between tool and work surface. Water-based emulsion is the best coolant compare with synthetic oil and compressed cold air. Conventional coolants can be applied in machining of hardened steel while compressed cold air can be used in machining of softer metal like aluminum, mild steel and etc. The effect of different coolants condition to the surface roughness, cutting force, and tool wear has been evaluated. A better coolant and optimal parameters have been figured out.

REFERENCES

[1] N. Suresh Kumar Reddy, and P. Venkateswara Rao. “Experimental investigation to study the effect of solid lubricants on cutting forces and surface quality in end milling”. International Journal of Machine Tools & Manufacture, vol. 46, pp. 189-198, 2006.

[2] R. Kovacevic, C. Cherukuthota, and M. Mazurkiewicz. “High Pressure Waterjet. Journal of Machine Tools & Manufacture. Vol. 35, No. 10, pp. 1459-1473, 1995.

[3] W.Y.H. Liew. “Low-Speed Milling of Stainless Steel wih TiAlN Single-layer and TiAlN/AlCrN Nano-multilayer Coated Carbide Tools Under Different Lubrication conditions”. Wear, vol. 269, pp. 617-631, 2010.

[4] Y. Su, N. He, L. Li, Iqbal, M.H. Xiao, S. Xu, B.G. Qiu. “Refrigerated cooling air cutting of difficult-to-cut materials”. International Journal of Machine Tools & Manufacture, vol. 47, pp. 927-933, Sep. 2006.

[5] Mike S. Lou, Dr. Joseph C. Chen & Dr. Caleb M. Li. “Surface Roughness Prediction Technique For CNC End-Milling”. Journal of Industrial Technology, vol. 15, No. 1, pp. 1-6, Nov. 1998-Jan. 1999.

