International Journal of the Korean Society of Precision Engineering Vol. 4, No. 1, January 2003.

Analysis of Cutting Fluid Atomization and Environmental Impact through Spin-Off Mechanism in Turning Operation for Environmentally Conscious Machining (I)

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ABSTRACT

This paper presents the experimental results to verify the environmental consciousness with economic balances due to cutting fluid behaviors and effectiveness in machining process. The cutting fluid improves the productivity through cooling, lubricating effects, however its environmental impact also increases according to the cutting fluid usage. The primary mechanism in this study is the spin-off motion of cutting fluids away from the rotating workpiece. In this study some machining parameters are adopted to analyze the productivity as well as environmental impact. This study provides the criteria for the resonable cutting fluid usage quantitatively to develop the environmentally conscious machining process.

Keywords : Cutting Fluid, Atomization, Environmental Conscious Machining, Spin-Off Mechanism

1. Introduction

The impact of industrial machining process on environment, human health and safety promotes global concerns for environmentally conscious machining process development.

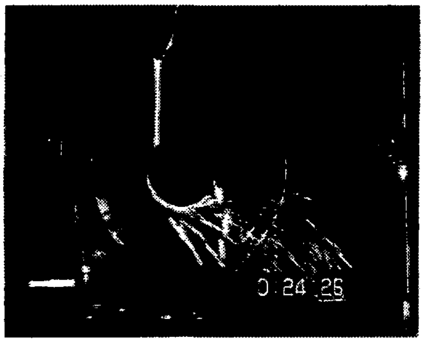
Cutting fluids are often used in manufacturing processes due to their cooling, lubricating, and chip removing capabilities. However, the use of cutting fluids has raised serious concerns with regard to environmental intrusiveness and occupational hazards. Cutting fluids often produce airborne mists, smoke, gases, and other particulate that cause hazard to the machine shop environment. Skin exposure to cutting fluid can cause folliculities due to follicular orifice blockage. Another form of health threat by cutting fluids is inhalation, which can be connected to emphysema, lung cancer and other respiratory problems[1)].

The aerosol size and concentration of airborne cutting fluid particulates in the machine shop environment are common attributes that quantify the environmental intrusiveness of cutting fluids. Aerosol size is a deciding factor for inhalation implications. OSHA (Occupational Safety and Health Administration) requirements for the metal cutting fluid concentration in a manufacturing environment is set to 5 mg/m^3 as a permissible exposure level for personnel (PEL). This PEL was consolidated to 0.5 mg/m^3 by the NIOSH(National Institute for Occupational Safety and Health)[2)] in 1998.

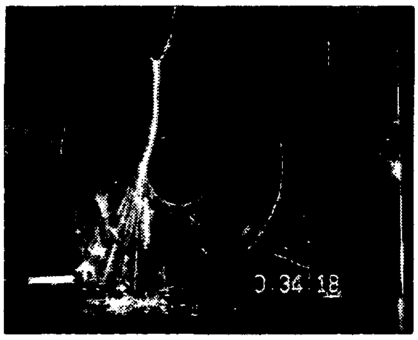
To reduce cutting fluid aerosol generation, common control strategies include enclosing the machine tool, using air filters or mist collectors, and adding anti-misting agents to the cutting fluid. However, these methods represent an added cost to the process and are not so effective. An alternative strategy is to modify the machining process itself to reduce the amount of cutting fluid usage. Such a strategy requires a fundamental understanding of the basic process conditions affecting aerosol generation. This paper presents the details and experimental investigation of the dominant operating conditions affecting cutting fluid aerosol formation and theoretical models to describe the aerosol generation phenomenon.

2. Aerosol Generation Mechanism

To understand the cutting fluid aerosol generation process, this paper provides the physical mechanism based on fluid atomization theory in coupling with flow field governing principles and experimental measurements to quantify the aerosol characteristics resulting from the use of cutting fluid in a turning process as shown in Fig. 1.



(a) 270 rpm



(b) 1850 rpm

Fig. 1 Photo of cutting fluids atomization via spin-off mechanism in turning operation

The primary mechanism considered in this study is the spin-off motion of fluids away from a rotating workpiece. The splash is a form of momentum transfer due to the impact of fluid particles on a solid tool or workpiece. The evaporation stems from the high temperature at the cutting zone that brings the contacting fluid to a vapor state. The spin-off is a result of the centrifugal force at the surface of the part in rotational motion. It is a dominant mechanism for over 80% of the total cutting fluid aerosol generation in machining process.

Cutting fluid application configuration is shown in Fig. 2. The center part (Part B) of cutting fluid jet stream has a larger flow rate than part A. The process of rotary disk atomization can be used to simulate the atomization of this part.

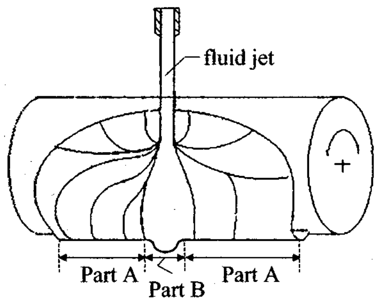


Fig. 2 Typical cutting fluid behavior in machining process

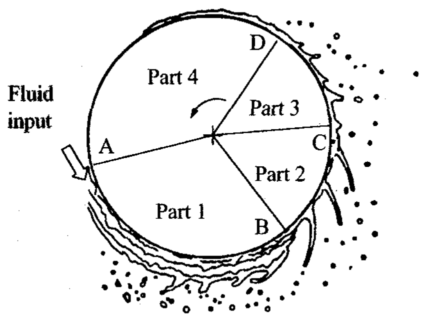


Fig. 3 Rotary disk atomization process and three formation modes

Figure 3 shows the cutting fluid entering into contact with the workpiece at point A and moving around the cylindrical surface in the form of a thick film. When this film disintegrates, it does so in an irregular manner, which results in an appreciable variation in the droplet size. This process through a certain point B, ligaments form along the periphery and disintegrate into drops. This process taking place in Part 2 is termed atomization by ligament formation. There exists a critical point C at which the liquid spreads out at a low flow rate and is centrifuged off in the form of drops. This phenomenon is generally known as drop formation atomization, as shown in Part 3.

3. Measurement of Cutting Fluid Aerosol

A few experiments were performed to understand the quantitative characteristics of cutting fluid aerosol. The experiments were performed on a CNC engine lathe (TSL-6, Hwacheon). The quantity of suspended cutting fluid aerosol within the closed control volume was measured by Dual PDA (Particle Dynamics Analyzer, Dantec/Invent) during the machining operation under various cutting speeds and cutting fluid flow rates.

Dual PDA system can measure the average velocity, size, concentration of the cutting fluid aerosol effectively. This system is operated with Ar-Ion laser source and can be used to measure the particles under a range of 0.5mm~13mm diameter moving at a maximum speed of 470m/s. It is consists of 57X80 Dual PDA probe for optical devices and 58N80 MultiPDA process for signal processing. Measuring outputs were stored in a digital storage oscilloscope (LeCroy 9310A) or Personal Computer to analyze the results.

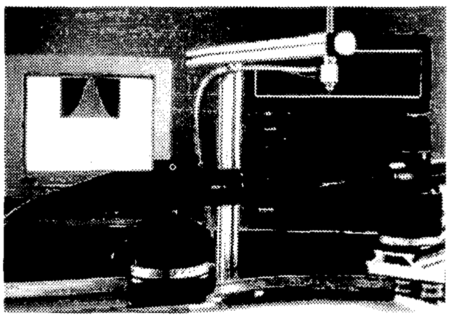


Fig. 4 Photo of PDA system for aerosol particle measurement of cutting fluid

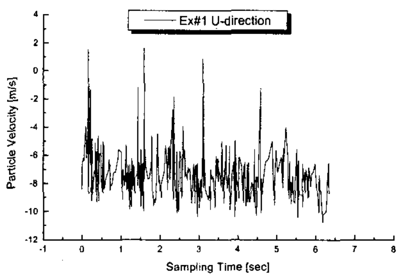
Cutting fluid was applied via a nozzle centered above the workpiece at a distance of approximately 250mm and positioned at upper, center, and lower location with respect to the workpiece. To analyze the Productivity & Economy Index (PEI), flank wear of the cutting tool and surface roughness were measured with tool microscope (TM-101, Mitutoyo) and roughness tester (Surftester-501, Mitutoyo). The measured quantities of cutting fluid aerosol were used to decide the Environmental Consciousness Index (ECI).

Throughout the experiments, the workpiece diameter was set to 50.0 mm, workpiece material was SM20C, maximum workpiece rotational speed was set to 2500 rpm with engine lathe and circular fluid nozzle had a diameter of 5mm with maximum supply rate of 4 *l*/min.

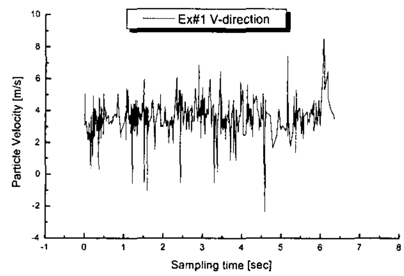
4. Experimental Results and Discussions

4.1 Characteristics of Cutting Fluid Aerosol

The variation of average velocity of the fluid aerosol with respect to the operation time is shown in Figs. 5 and 6. The average velocities in u and v directions were measured above the workpiece at a distance of approximately 16mm~22mm and positioned orthogonal to the workpiece.



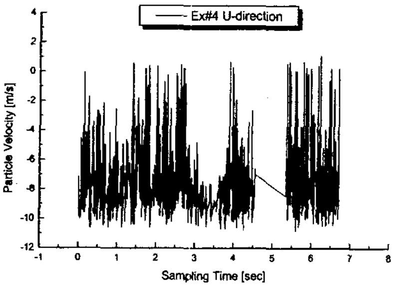
(a) u-velocity



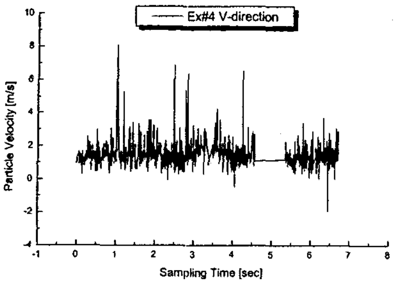
(b) v-velocity

Fig. 5 Cutting fluid's aerosol particle velocity with respect to arrival time (EX#1)

The average velocities of u and v directions of the cutting fluid aerosol measured by PDA system under 2000 rpm are shown in Fig.5. The measured velocities at 16mm (EX#1) from the workpiece were 6~8[m/s] in the u-direction and 3~5[m/s] in the v-direction. As shown in Fig.6, the variation of u-direction average velocity at 22mm position (EX#4) was changed largely and v-direction velocity was decreased to 1~2[m/s] compared with the Fig.4 results. Because the kinetic energy of aerosol was decreased as the aerosol flying time increased, the v-direction velocity was reduced and finally fell down on the shop floor ground.



(a) u-velocity

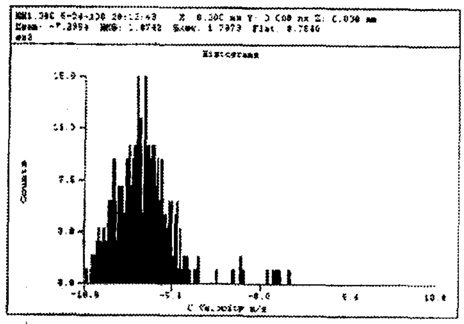


(b) v-velocity

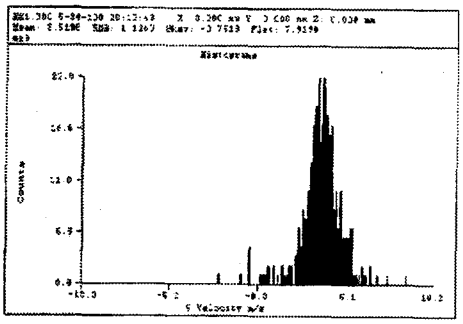
Fig. 6 Cutting fluid's aerosol particle velocity with respect to arrival time (EX#4)

In Figs.7 and 8, the average velocity distribution of the cutting fluid aerosol due to spin-off mechanism is shown. In EX#1 test, the average velocity in u and v directions were measured above the workpiece at 16mm and in EX#4 test, 22mm. In EX#1, the u-direction velocity of atomized aerosol was 7.29[m/s] and the v-direction velocity was 3.52[m/s].

In EX#4, the u-direction velocity was 7.39[m/s], and the v-direction velocity was 1.42[m/s]. According to the distance of the workpiece, the velocity of the cutting fluid aerosol in the u-direction was changed rapidly and spread widely whereas the v-direction velocity was reduced.



(a) u-velocity



(b) v-velocity

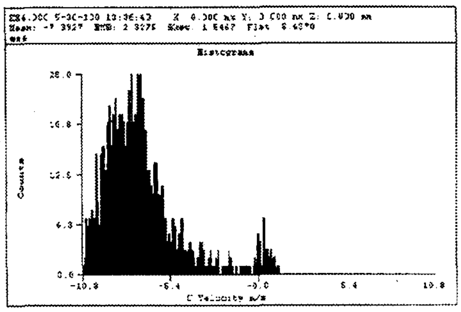
Fig. 7 Distribution of cutting fluid aerosol velocity due to spin-off mechanism (EX#1)

4.2 Characteristics of Tool Wear and Surface Roughness by Cutting Fluid Usage

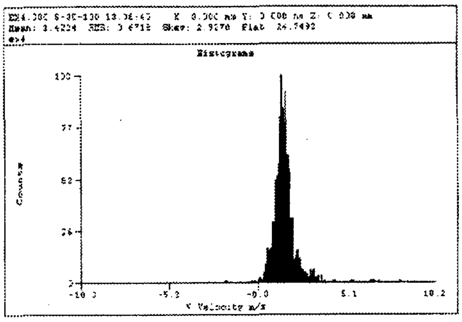
A few experiments were performed to understand the effectiveness of the cutting fluid application in view of productivity and environmental consciousness. Cutting condition was set to 300~2500 rpm as the rotational speed of workpiece, dry cutting and 0.5 l/min~4 l/min as the cutting fluid flow rate.

Figure 9 shows the variation of flank wear of the cutting tool increments with respect to cutting time at 1500 rpm rotational speed of the workpiece. The flank wear shows a tendency to increase as a function of cutting time and cutting fluid flow rate because of cooling and lubricating effects of the cutting fluid.

Figure 10 shows the variation of flank wear of the cutting tool with respect to cutting fluid flow rate and



(a) u-velocity



(b) v-velocity

Fig. 8 Distribution of cutting fluid aerosol velocity due to spin-off mechanism (EX#4)

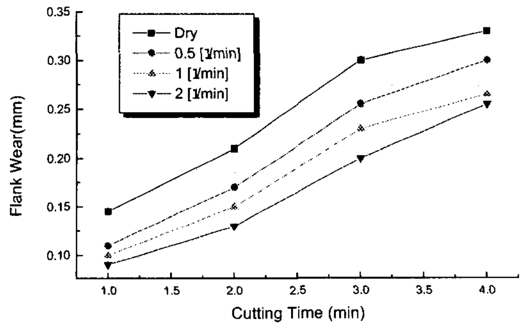


Fig. 9 Tool wear increments with respect to cutting time (1500 rpm)

workpiece rotational speed. This result shows that the cutting fluid effect was significant in reducing flank wear compared with dry cutting condition. Even though the fluid flow rate is increased, improvement of flank wear has a limitation at the high speed range and the cutting fluid has virtually no effect on lubrication because there is insufficient time for the fluid to penetrate the contact area and form a lubricating layer between the tool-chip asperities.

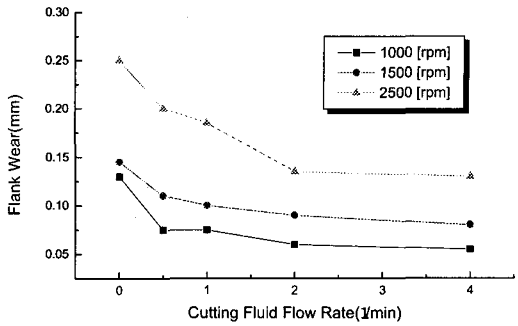
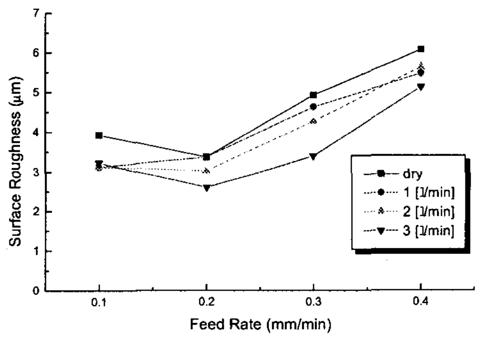
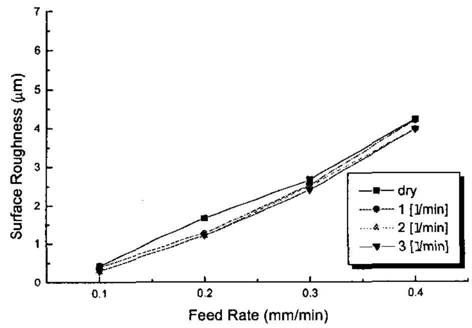


Fig. 10 Variation of tool wear with respect to cutting fluid flow rate & cutting speed



(a) 300 rpm



(b) 1300 rpm

Fig. 11 Variation of surface roughness with respect to cutting fluid flow rate and cutting conditions

The variation of surface roughness with respect to the cutting fluid flow rate, rotational speed of workpiece and feed rate is shown in Fig. 11. The surface roughness is a very important deciding parameter for productivity and economy in a machining process. The surface roughness is affected by the lubricating effectiveness of cutting fluid. Surface roughness is reduced considerably by the application of cutting fluid at the low rotational speed of the workpiece. However, at higher speed range the cutting fluid as lubricant has no effect and this indicates that the lubricant could not penetrate to this speed before the chip had moved up the tool face.

4.3 Characteristics of Cutting Fluid Aerosol Diffusion

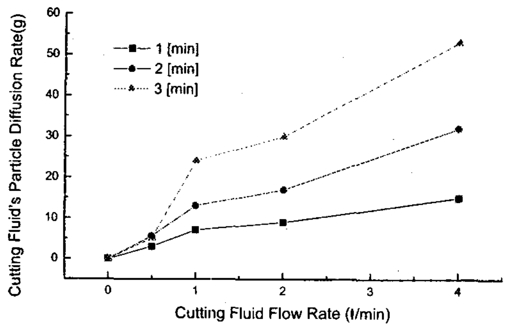


Fig. 12 Variation of diffusion rate of cutting fluid in the air with respect to cutting fluid flow rate and operation time (2500 rpm, middle position)

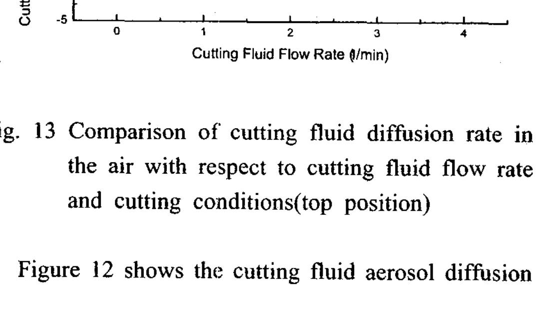


Fig. 13 Comparison of cutting fluid diffusion rate in the air with respect to cutting fluid flow rate and cutting conditions(top position)

Figure 12 shows the cutting fluid aerosol diffusion rate with respect to fluid flow rate and operation conditions. The cutting fluid aerosol diffusion rate increases with respect to fluid flow rate and cutting time increment. It indicates that the rotational speed of the workpiece and the fluid flow rate have great influence on the aerosol diffusion rate. Variation of cutting fluid aerosol diffusion rate with respect to cutting conditions and operation time is shown in Fig. 13. Diffusion rate of the cutting fluid aerosol is affected by the cutting conditions (combination of cutting speed and fluid flow rate). It appears that the critical cutting speed and the fluid flow rate exists in view of atmospheric environmental intrusiveness in a real machining process. From the experimental results of this study the aerosol diffusion of cutting fluid in air can be increased over 20 times and this amount is sufficient to contaminate the shop floor environment and the air.

4.4 Critical Flow Rate of Cutting Fluid Usage

The measured quantity of the cutting fluid aerosol is a critical point to decide the environmental consciousness in a machining process. It has influence on inhalation implications. The cutting fluid aerosol diffusion rate is increased as a function of cutting fluid flow rate and rotational speed of the workpiece. From the result of this investigation the following cutting conditions are recommended for turning process without deteriorating productivity or machinability less than 1500 rpm rotational speed and maximum cutting fluid flow rate of 2 *l*/min.

5. Conclusions

The objective of this study is to achieve the scientific understanding of cutting fluid usage to address the timely issue of cutting fluid control for environmentally conscious manufacturing process. To understand the characteristics of cutting fluid aerosol generation, several experiments were performed to measure the cutting fluid effectiveness under various cutting conditions. This paper is a basic study with the aim to quantify the environmental influences of the cutting fluid. The obtained results can be further applied to control the environmental impact in manufacturing processes.

Acknowledgement

This work supported by grant No.2001-1-30400 -026 -2 from the Basic Research Program of the Korea Science & Engineering Foundation.

References

1. Preifer, T., Evershein, W., Keonig, W., Manufacturing Excellence, Chapman & Hall, pp. 517-521, 1994.
2. U.S. Department of Health and Human Services, Occupational Exposure to Metalworking Fluids, NIOSH Publication, 1998.
3. Bell, D. D., Chou, J., Liang, S. Y., "Modeling of Cutting Fluid Effect on Shop Floor Environment," Tribology Transactions of STLE, Vol. 42, No. 1, pp. 168-173, 1999.
4. Matsumoto, S., Takashima, Y., "Atomization Characteristics of Power Law Fluids by Rotating Disk," ICLAS-78, pp. 145-150, 1978.
5. Hwang, J., Chung, E. S., "Optimization of Cutting Fluids for Environmentally Conscious Machining," Proc. Annual Conference on Korean Society of Precision Engineering, Vol. 2, pp. 948-951, 2000.