Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2013, 5(9):472-477

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Exploration about the cutting force reducing of low-temperature MQL cutting technology

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ABSTRACT

With the development of green cutting technology, the low-temperature MQL technology emerged. In order to solve the problem that caused by cutting heat, it adds the low-temperature air on the foundation of MQL. In the view of low-temperature MQL studies which could reduce the cutting force, we have done a lot of experiments and theoretical pushovers. The experimental results show that the most important reason why the low-temperature MQL can reduce the cutting force effectively is a reliable lubricant film that between tool and chip. It describes the forming process of the oil film and derives the friction coefficient relationship between dry cutting and oil film cutting.

Keywords: Low-temperature MQL, Cutting Forces, Film formation

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INTRODUCTION

In the traditional mechanical manufacturing industry, in order to reduce cutting force, cutting heat, and therefore, water-based or oil-based cutting fluid are extensive use, to improve the cutting conditions but in the same time a lot of problems left behind. Cutting fluid contaminated environment of the plant, the factory floor, everywhere is oil. After contact with hot surfaces cutting fluid will evaporate a lot of water droplets and droplet splashing, detrimental to health workers after inhalation. As human environmental awareness as well as various countries launched a cutting fluid restriction policy, "green manufacturing technology", "environmentally sound technologies "[5]etc., which can meet the production needs and the rational use of resources, the technology is increasingly attracted attention.

Based on the requirements of environmental protection, people began to study green cutting technology, began the study of the dry cutting technology, later found that the tool material performance requirements are too high, making it difficult to find out the right tool to solve the dried friction material brought wear problems. Subsequently, it proposed compromise-MQL technique, that small amount of lubricating fluid (5~20ml/h) sprayed onto the cutting edge of dried friction problem solving. In this way, it becomes a boundary friction of dried friction, while not as an excess of cutting fluid and cause environmental pollution. Technicians found through the use of common metals, such as: aluminum, magnesium alloy, 45#steel, can meet the cutting requirements, but for a number of difficult to machine materials, such as: stainless steel, titanium, etc, which can’t solve the MQL technology generated during cutting a large number of cutting heat and shortening tool life issue. So researchers also proposed new technical solution- low-temperature MQL cutting technology.

Low-temperature MQL cutting technology and its characteristics

Low-temperature MQL cutting technology are MQL technology and low-temperature cold cutting technology combine to a new cutting technology. Application of this technology not only temperature of the machining pointed to ease, but also the lubricity of the tool has also been guaranteed. This technique takes advantage of a strong cutting

MQL lubricity and composed air cooling, results far beyond the using of two effects when used it alone. Figure 1 shows the schematic cryogenic cool air system.

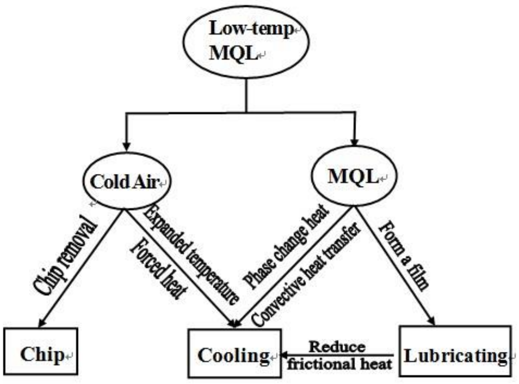

Fig.1: Cold cryogenic system schematic

Small amount of lubricating oil by high-pressure high-speed air in the processing area lubricant film formed on the surface. The film can effectively reduce the friction between the tool and the chip, thus reducing the cutting force; the main function of the compressed gas temperature is cooling and chip, reducing the temperature of the cutting oil while helping to enhance the lubricating effect. Cooling effect is mainly caused by the high flow of mist generated intense heat convection. By reducing the temperature of the compressed gas, on the one hand, to improve the cutting zone of intense heat intensity, improve the effect of heat transfer. On the other hand, the improvement effect of heat transfer and can make lubricating film lubricant droplets further maintain the lubrication ability to reduce tool wear and increased durability of the tool.

Low-temperature MQL system interactions by many factors, different processes, different tools, different workpiece materials and different processes system settings (including the nature and amount of lubricating oil, compressed gas pressure and temperature, etc.), which demonstrated significantly cutting performance difference. Low-temperature MQL system is the greatest impact on the cutting performance and followed by the processing conditions, such as workpiece materials, cutting tool and cutting parameters.

For the low-temperature MQL system requirements of specific parameters, the industry does not have a clear conclusion, only from the actual production and the criteria used by researchers at home and abroad to a rough definition. The temperature ranges under-10～－40℃. MQL fluid usage: 30～200ml/8h. The cold pressure is about 0.2 ~ 0.8 Mpa.

MQL can effectively reduce the cutting force

As everyone knows the cutting force from three aspects: (1) It's overcome the material to be processed on resistance of deformation; (2) It's overcome the processed material to plastic deformation resistance; (3) It's overcome the cutting face transition surface and the machined surface of friction between the rake face and flank friction force. Among the literature on low-temperature MQL, many of them will be referred to that the MQL technology can effectively reduce the cutting force, but reduces cutting forces cause is unclear. So we redo the cryogenic experiments to explore the impact of MQL cutting force.

Experimental system: Air Compressor, Chongqing Chengtian CTL-40/1.5 type cold jet machine(It provides cold air at -40℃), Accu-Lube MQL system (It provides a diameter of 4 μm to 20 μm oil droplet), CNC lathes CY-e6150Bi,Dynamometer; Infrared Thermometer. As figure 2 shows a schematic composition of low-temperature MQL system. The cutting material selection 45# steel and titanium TC4, respectively, in dry, emulsion and low MQL conditions, cutting parameters f=0.2mm/r, a_p =0.5mm, n=320r/mm for cutting force measurements.

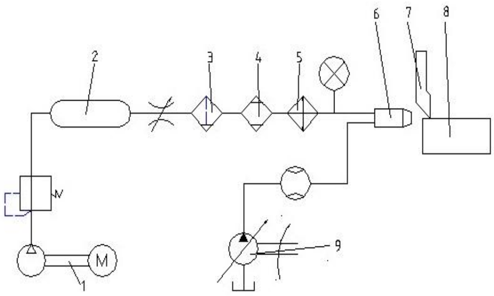

Fig. 2: low-temperature MQL system

1-Compressor 2- Cylinders 3- Air filter 4- Air Dryer 5- Coolers 6- Nozzle 7- Tool 8- Workpiece 9- Adjustable oil supply pump

Fig. 3: Experimental site maps

The experimental results: In the three environments contrast; the main cutting force can find that MQL cutting force is smaller than the mastic's and dried cuttings. At the same time, it dried cutting force is slightly larger than the mastic. In the same cutting parameters, the cutting force generated when cutting titanium just bigger than 45 steel. It can be seen that low-temperature MQL on the cutting force has more advantages than the other two categories. It compared the mechanical properties of titanium and 45 that-figure 4-can be found in the material strength, the higher the hardness, the greater resistance to overcome, So it needs greater cutting force.

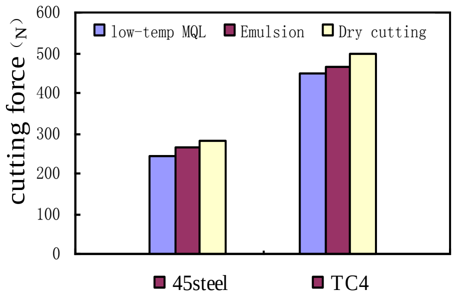

Fig. 4: Titanium and 45 steel main cutting force comparison charts

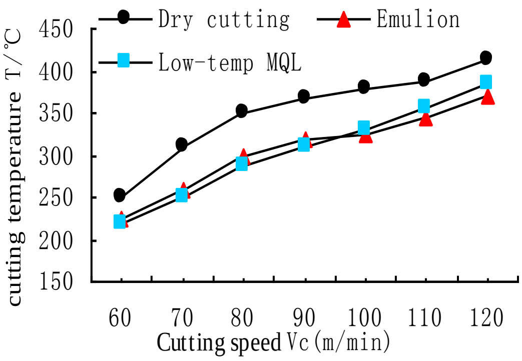

Fig. 5: Titanium alloy cutting temperature under different conditions

As we can see from the figure 5 that the temperature of dry cutting is always higher than those with cooling measures. In contrast to emulsion and low-temperature MQL can be seen that when the temperature is relatively low, the knife body temperature difference is small. However, when the cutting speed increases, to a certain extent, is also produced more cutting heat, due to the heat capacity of water is larger, it can take away a lot of heat, the cooling effect is better than that of low temperature air.

The reason of low-temperature MQL decrease cutting force

From Chen Ding's[1] study can be seen, titanium and titanium alloys as the temperature decreases, the intensity greatly improved performance, elongation, impact toughness and fracture toughness decreases, titanium alloys at low and ultra-low temperatures, can still maintain its mechanical properties. And in the above experimental conditions, cold air cannot quickly reduce the temperature of the alloy. The low temperature is not a main reason of lower cutting force.

In contrast to the above experiments, the dry cutting and emulsion lubrication, they are all buried cutting the tip from being able to provide continuous and reliable lubrication. The use of high-pressured gas carrying subtle oil drops into the bottom surface on the rake face and chip sliding action of rubbing and plowing blade - chip contact region forming a large number of capillaries (Fig. 7) through the siphon and the combined effects of pressure gas, so that the fluid penetration into the area and the blade lubricating film formed on the surface [2]. Lubricant reduces workpiece and tool friction, thereby reducing the cutting forces.

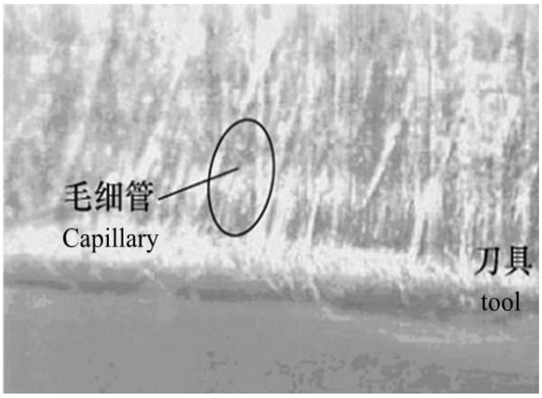

Fig. 6: Formed between the knife and the chip capillary network

Film formation

Domestic scholars Yan L.T.[4] on the MQL infiltration mechanism made a thorough research. Liu L.Q. [3] and his colleagues who established that the boundary lubrication cutting fluid dynamics model. Based on their research, we concluded that MQL oil film forming process as figure 7 shows, in the cutting process the cutting zone friction interface, the workpiece due to strong tension and compression and shear stress, will produce small hard particles.

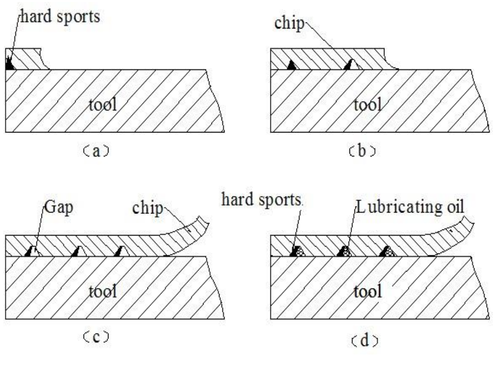

Fig. 7: Film formation

Since the tough particles embedded in compression within the chip (Figure 7a), at the same time the tool and the chip relative motion that the chip contact surface of the tough particles will form a space (Figure 7b). Hard particles in the workpiece under the action of the friction gradually expanded to form capillary (Figure 7c). From the process point of view, a vacuum inside of the capillary, one end of the atmosphere when the outside air and the fine oil quickly fill in the continuing relative movement, have external MQL fluid pressure in the capillary continues to add lubricating fluid, thereby forming a kind of boundary lubrication oil wedge model (7d).

The above film formation process is directed at the rake face, flank the main role is then machined surface is formed, its lubricant film formation process: strong tension and compression and shear stress, the tear of the metal, the leaving extremely smooth surface roughness between the workpiece and the tool, there are many gaps, fine oil particles in the gas under high pressure, injected into the gap, thus formed between the tool and the workpiece uniform film layer.

Carrying the high-pressure cold, the oil particles, and the gap into the metal adsorbed on the metal surface. Meanwhile, the cold away, most of the heat generated by cutting, but also reduces the temperature as the oil itself, lubricating oil at low temperatures, the viscosity will increase, will be formed in the cutter body better compression performance film.

Low-temperature MQL reduce cutting forces mathematical proof

As shown in Figure 7, when the two friction load bearing surfaces after a portion of the asperity contact pressure are greater because of the boundary rupture. Tool and chip will have direct contact (Area expressed by S_m), while the other part to the state will be film lubrication. Assuming to lubricate the contact area between the surface S for real, the friction force F can be expressed as:

$$F = S[s_W \tau_S + (1 - a_W)\tau_L] + F_f \tag{1}$$

In this formula: s_W is a solid contact area of S_m in the percentage of real contact area in S. τ_S is a solid surface shear strength; τ_L is a fluid surface shear strength; F_P is a furrow effect produces resistance.

Total load can be written as:

$$W = S[s_W P_0 + (1 - s_W)P_L] \tag{2}$$

In this formula: P_0 is lower hardness metal shaping flow pressure; P_L is the pressure of the lubricating film. If we take the average pressure $\overline{P}$ of the formula (2) becomes:

$$W = S \cdot \overline{P} \tag{3}$$

If we divided by (1) formula with (3) formula that could obtain boundary lubrication friction factors f_B.

$$f_B = \frac{F}{W} = s_W(\frac{\tau_S}{\overline{P}}) + (1 - s_W)\frac{\tau_L}{\overline{P}} + f_P \tag{4}$$

In this formula, $f_P = \frac{F_P}{\overline{P}A}$. In boundary lubrication, the formula (4) in the third term is relatively small and can be ignored. Dry friction condition known load W and friction force F is:

$$W = S \cdot P_0 \tag{5}$$

$$F = S\tau_S + F_P \tag{6}$$

Here $P_0 = \overline{P}$ and F_P can be ignored, so that the dry friction state of the friction coefficient *f* is:

$$f_m = \tau_S / \overline{P} \tag{7}$$

Compare (4) and (7) and ignore f_p, we get the formula(8).

$$f_B / f_m = s_W + (1 - s_W)\frac{\tau_L}{\tau_S} \quad (8)$$

Since $\tau_L \langle\langle \tau_S$, so that the second term can be ignored. We can get $f_B / f_m = s_W$. For the general case, $s_W \langle\langle 1$, so we can conclude mixed lubrication friction coefficient smaller than dry friction.

It is because of the oil film lubrication and mixed trace formation, to improve the friction condition between the cutting tool and the machined material, so the friction coefficient is reduced, thereby reducing the cutting force.

CONCLUSION

(1) Through experiments and theoretical models proved low-temperature MQL can reduce cutting forces.
(2) Fine particles of lubricating oil can enter the gap torn metal on the outside of the gas carrying the oil supplement, the tool and the workpiece is formed between the boundary lubrication film.
(3) Mixed lubrication and friction coefficient and the ratio of solid dry friction contact surface on the contact surface with the real, the solid contact surface is smaller, the smaller the friction coefficient mixed lubrication, cutting force is smaller.
(4) When cutting heat generated relatively large, the air specific heat capacity is small, so that it is difficult to take a lot of heat away, the cooling effect is not as good as emulsion.

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