



Comparing Cooling and Lubricating Effects of Different Cutting Fluid Applications in Micromilling Process

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ABSTRACT: Micromilling is one of the main manufacturing processes of creating miniaturized parts which are highly demanded in many industries nowadays. Like any other machining processes, cutting fluids are used for cooling and lubricating during micromilling while it can be challenging due to small cutting zone. In this study, the effects of different cooling and lubricating systems such as dry cutting, wet condition and minimum quantity lubrication systems are investigated on such characteristics as surface quality and wear of the micro tool. In case of the minimum quantity lubrication, two methods of single-nozzle and bi-nozzle spraying systems are applied and their effects on such characteristics are compared to each other. Machining tests are carried out using a two-flute micro cutter with diameter of 0.8 mm on a titanium alloy Ti6Al4V. Results show that the minimum quantity lubrication is significantly effective on the both cooling and lubricating whereas wet application has no effect on the cooling. Finally, using minimum quantity lubrication applications results in lower tool wear and better surface finish compared to those of the dry and wet conditions hence the one with two-nozzle is more advantageous in micro end-milling of this alloy.

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1- Introduction

Micromilling is one of the main manufacturing processes of miniaturized parts where cutting tools less than 1 mm are generally used. Down-scaling from macro- to micro-scale result in rising size effect and differentiate it from conventional milling [1]. Many factors like the vibrations, tool run-out, deflection, microstructure, etc. which can be ignored in macro-scale are of great importance in micro-scale and cause large burr formation, rapid tool wear and an unpredictable tool breakage. These can be more important when talking about difficult-to-cut materials like titanium alloys. However, applying appropriate cutting fluids as well as selecting optimum cutting parameters can strongly help to minimize these problems [2]. Using proper cutting fluids by reducing the friction and better act of cooling will provide longer tool life, lower cutting forces and better surface quality [3]. Cutting fluids are generally used to reduce the friction, to cool the workpiece and the tool and to wash away chips from cutting area [4]. There are different types of cooling/lubricating techniques including dry, wet, Minimum Quantity Lubrication (MQL) and cryogenic methods. Performance of each technique depends on the type and the way how they are applied during process.

Comparing to conventional milling, cutting fluids have great importance in micromilling. Because of smaller tool diameter and so lower bending module, the tool may deflect easily due to the fluid pressure or cutting forces. On the other hand, removing chip from small cutting area is more difficult

for the cutting fluids during micro scale machining. With these in mind, the aim of this study is to investigate the effect of different cutting fluid applications in micromilling of Ti6Al4V. cooling and lubricating effect of each condition as well as using one or two nozzles are analyzed and compared considering output characteristics as roughness, burr size, accuracy, tool wear, cutting force and temperatures.

2- Methodology

The material used in this study was Ti6Al4V titanium alloy with a hardness of 400 Hv. A block rectangular shape workpiece with dimension of 65×65×4 mm was used in the experiments. Tests were carried out on an ultra high precision CNC milling machine Kern-evo with a maximum 50000 rpm and equipped with two nozzle MQL system (Fig. 1).



Fig. 1. Experimental set-up

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Two-flutes micro cutter made of NS-tool Co. with diameter of 0.8 mm were used. Separate tools were used for each milling condition in order to prevent tool wear effects on the results. Three different lubricating systems such as dry, wet and MQL were investigated. For the MQL, two ways of spraying with one-nozzle in feed direction, and two-nozzles in both feed and against feed direction were used. Experiments were conducted at constant cutting parameters of $v_c=60$ m/min, $ap=150$ μm , and $f_z=6$ $\mu\text{m}/\text{tooth}$. Output parameters are included as surface roughness, burr width, and accuracy of micro channels. For better analysis and comparison, cutting forces, temperatures and tool wear were also measured.

3- Results and Discussion

Tool wears at different milling conditions were measured. Diameter loss tool and average flank wear land were used for measurements (Fig. 2). As it can be seen, dry cutting caused largest tool wear while minimum wear was achieved when using MQL particularly in two-nozzle method. Build-up edge formation and adhesion to the tool were observed in dry cutting and to some extent in wet condition; however sharp cutting edge with no build-up edge were observed in MQLs application. Fig. 3 shows the build-up edge formed when dry cutting.

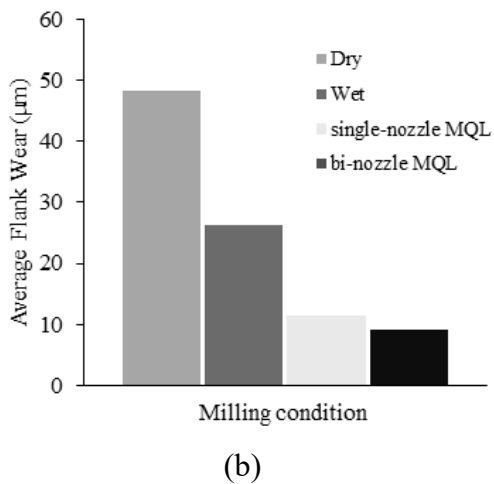
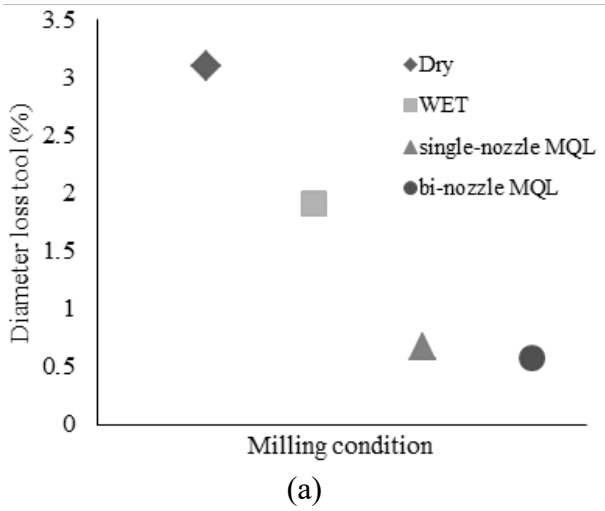


Fig. 2. (a) Diameter loss tool percentage and (b) Variation of average flank wear length

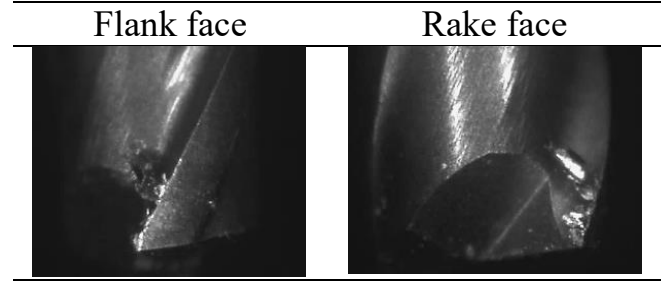


Fig. 3. Build-up edge formation observed at dry cutting

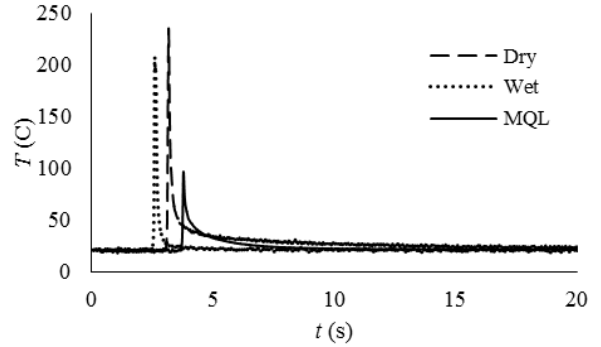


Fig. 4. Temperature rise against time for various cooling systems

To compare the cooling effect of different cutting fluids applications, cutting temperatures were measured (Fig. 4). It is clear that comparing to the dry cutting, wet condition had no great effect on cooling (about 11%) whereas MQL was effective with 58% reduction of cutting temperatures.

To compare the lubricating effect of different conditions, cutting force were measured. Obtained results are summarized in Table 1. Maximum cutting forces were produced in dry cutting while minimum forces were achieved using MQL applications particularly with two-nozzle method. From the result it can be said that MQL techniques have great influence on lubricating during micromilling while lower forces and thereby lower friction were produced.

Surface roughness measurements were done using a 3D profiler. Results are given in Table 2.

Figs. 5 show the burr formed at different milling conditions. Largest burr were formed in dry cutting while minimum burr was achieved using MQL applications. Wider burr was formed in up milling sides.

The accuracy of micro channel shapes produced at different

Table 1. Main cutting force values attained with various lubricating conditions

Two-nozzle MQL	One-nozzle MQL	Wet	Dry
2.736 N	3.002 N	4.028 N	6.077 N

Table 2. Ra surface roughness values, μm

Two-nozzle MQL	One-nozzle MQL	Wet	Dry
0.311	0.326	0.350	0.361

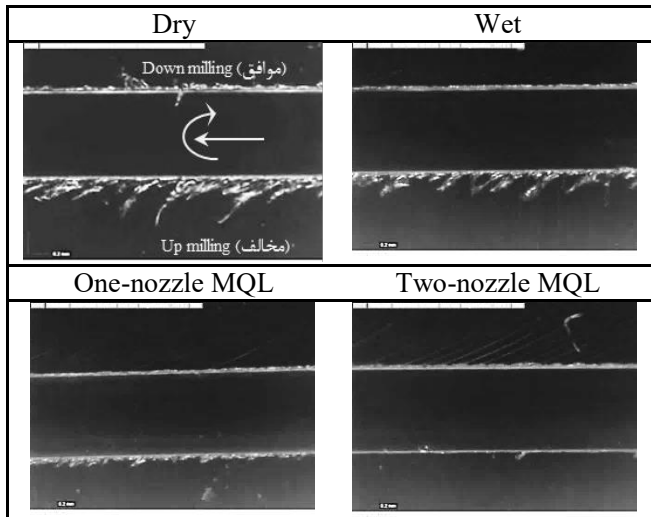


Fig. 5. Burr formation at different conditions

conditions was compared. Best result was obtained using two-nozzle MQL system. In contrary, in wet condition, the micro channels exhibit a trapezoidal shape with larger corner radius.

4- Conclusions

MQL applications had significant effect on both cooling and lubricating during micromilling of Ti6Al4V. Lowest tool wear and best surface quality was achieved using MQLs. In case of MQL systems, two-nozzle application was more advantageous.

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