CUTTING FORCES AND CHIP SHAPE IN MQL MACHINING OF ALUMINIUM BRONZE

Sabahudin Ekinović, Edin Begović, Elma Ekinović, Belma Fakić
University of Zenica
Fakultetska 3, Zenica
Bosnia and Herzegovina

ABSTRACT
Minimum Quantity Lubrication (MQL) machining involves the application of a minute amount of oil-based lubricant to the machining process in an attempt to replace the conventional flood coolant system. The use of a large amount of cutting fluid can impact the environment and increase manufacturing costs, and possibly lead to ground contamination, excess energy consumption, the need for wet chip disposal and potential health and safety issues. This paper presents a short classification of advanced MQL methods, and the results of measurements of cutting forces and chip shape and segmentation frequency when machining one type of aluminum bronze using MQL. As a medium for cooling and lubricating a system of oil-on-water was used.
Keywords: MQL machining, Oil-on-water droplet, Aluminium bronze, Cutting forces, Chip shape, Segmentation frequency

1. INTRODUCTION
During machining, a metal working fluid may significantly affect the tribological conditions at these interfaces by changing the contact temperature, normal and shear stresses and their distributions along the interfaces, the type and/or mechanism of tool wear, machined surface integrity and machining residual stresses induced in the machined parts, etc. [1,2,5]. Also, the use of coolant and lubrication significantly affects the chip shape and frequency segmentation [1],[3]. On the other hand, according to the manufacturing statistics shown in Fig. 1, the total cost for acquiring, maintaining and disposing of coolants represents between 8% to 20% (approximately 15%) of total production cost depending on the work piece, the production structure and the production location [4]. In contrast, tooling cost is within single digits (usually about 4%). Cost, as well as health and environmental issues, mandate manufacturing enterprises to drastically reduce coolant consumption and, if possible, eliminate it altogether. As a result, these trends tend to two more economically and

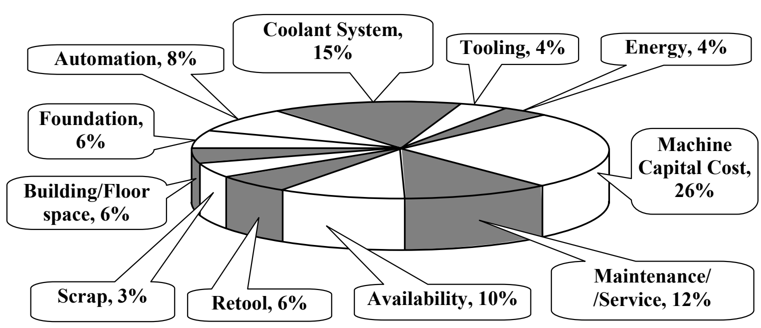

Figure 1. Distribution of manufacturing costs for wet machining [2]

environmentally fri-endly conceptions of machining, termed, dry machining and MQL machining or near-dry machining.

There are several principal ways to reduce ecological, economical and health impacts of metal working fluids:

- Balanced selection of metal working fluids,
- Proper application of metal working fluids,
- Meticulous management of metal working fluids, and
- Gradual reduction of metal working fluids usage by increasing the use of MQL machining (or near-dry) and dry machining. At present, many efforts are being undertaken to develop advanced machining processes using less or no metal working fluids.

2. ADVANCED MQL MACHINING

Minimal quantity lubrication (MQL) machining was developed as an alternative to flood and internal high-pressure coolant supply to reduce metal working fluids consumption. This technique also known as near-dry machining (NDM), supplies very small quantities of lubricant to the machining zone. In MQL machining, the cooling media is supplied as a mixture of air and an oil in the form of an aerosol (often referred to as the mist). An aerosol is a gaseous suspension (hanging) into air of solid or liquid particles. In literature and in practice, there are no accepted classifications of MQL machining so it is very difficult for a practical engineer or plant manager to make the proper choice about the regimes of MQL machining and equipment needed.

The first level of MQL classification includes a way by which aerosol is supplied into the machining zone: a) MQL with external aerosol supply (the aerosol is supplied by an external nozzle placed in the machine similar to a nozzle for flood metal working fluid supply), and b) MQL with internal (through-tool) aerosol supply (the aerosol is supplied through the tool similar to the high-pressure method of internal metal working fluids supply).

Second level of MQL classification includes an aerosol composition. Generally speaking, there are two groups of MQL machining with respect of this classification. First group represents the aerosol as an air–oil mixture. The discharge of the oil in this mixture is selected to be in the range 30–600 ml/h depending upon the design of the MQL system, the nature of the machining operation, the work material and many other factors. Second group represents so called advanced MQL system uses aerosol that includes not only oil but also some other components. There are two examples of advanced MQL systems: oil on water droplet and advanced minimum quantity cooling lubrication machining (MQCL machining).

MQL based on the concept of oil on water droplet is shown in Fig. 2, which shows ideal oil on water droplet moving towards a hot surface. When the droplet reaches the tool or hot work piece surface, the lubricant oil spreads over the surface in advance of water spreading. The water droplets are expected to perform three tasks: carrying the lubricant, spreading the lubricant effectively over the surface due to inertia and cooling the surface due to its high specific heat and evaporation. To make this concept practical, i.e., to generate oil on water droplets, a specially designed discharge nozzle is needed.

Results of experimental studies are presented in the following section of this paper is related specifically to the use of this MQL system.

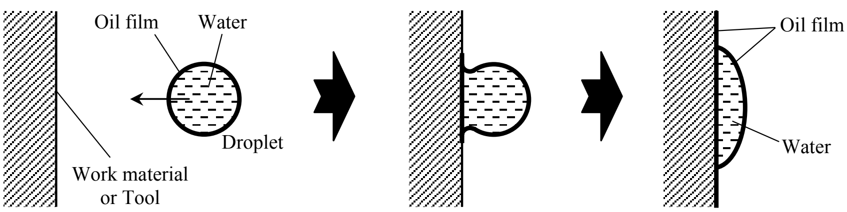

Figure 2. The concept of the oil on water MQL machining

3. EXPERIMENTAL WORK

The experiments, which results are presented in this paper were conducted at the Laboratory for metal cutting and machine tools (LORAM) at Faculty of Mechanical Engineering University of Zenica, and at the Metallographic laboratory MI "Kemal Kapetanovic" University of Zenica. Machining tests were carried out on a lathe. Work piece material is a kind of aluminum bronze tags Cu85.5Al10Fe2.5Mn2, hardness of 150 HB. Machining tests were carried out by turning in two ways: without the use of metal working fluid, and by use of advanced MQL machining (oil on water droplet). Turning conditions were: cutting speed v=130 mpmin, depth of cut d=1.5 mm, and feed f=0.16 mmprev. Cutting tool was uncoated cemented carbide K10, with standard cutting geometry. Experimental setup is shown in Fig. 3. MQL machining conditions were as follows: the amount of oil 50 mlph, the amount of water 50 mlph, and the pressure of compressed air p=2 bar. Vegetable (biodegradable) rapeseed oil is used. By using appropriate measuring equipment (dynamometer KISTLER 5070), cutting forces are measured and chip shape, segmentation frequency and microhardness were analyzed.

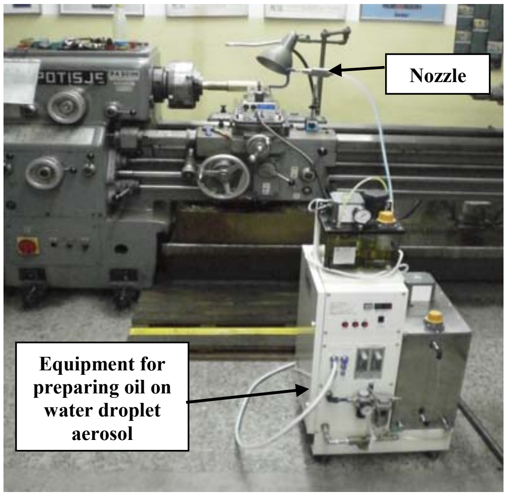

Figure 3. Experimental setup

4. ANALYSIS OF RESULTS AND CONCLUSIONS

Experimental results are presented in Fig.4, and Fig 5. During the machining components of cutting force Fx, Fy, and Fz were measured (Fig.4.a, and Fig.5.a). Chips were observed by metallographic method, and Vickers microhardness of the chip is measured, too (Fig.4.b, and Fig.5.b).

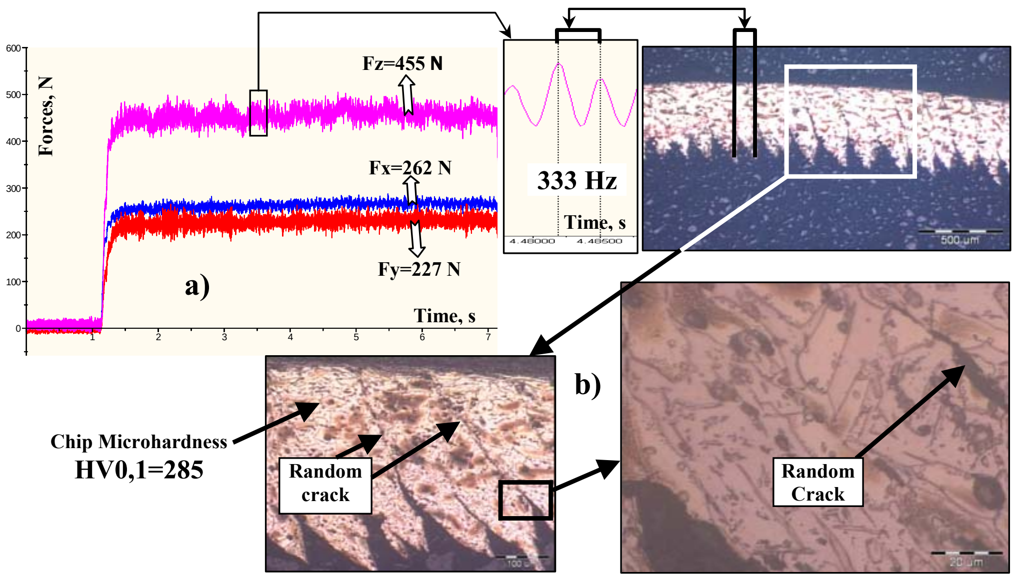

Figure 4. Cutting forces measuring results and chip shape exploration (machining without the use of metalworking fluid)

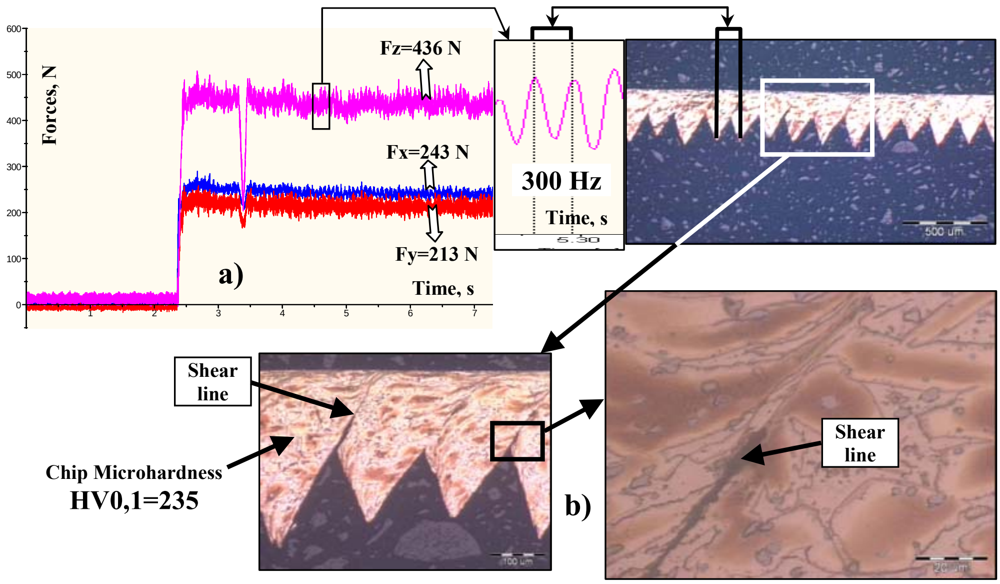

Figure 5. Cutting forces measuring results and chip shape exploration (MQL machining)

On the basis of results (See Fig.4, and Fig.5), following conclusions can be made:

- The average thickness of the chip in machining without the use of metalworking fluid (0.6 mm) is greater than the same in MQL machining (0.4 mm). This can be explained by the reduced force of friction between chip and tool in MQL machining.
- Less cutting force by 16% for MQL machining actually mean less power consumption which is very important in terms of energy savings (sustainability).
- In machining without the use of metalworking fluid, segments of the chip occur randomly and do not depend on the processing parameters, while chip's segments in MQL machining are uniform and the same geometrical parameters, with a clear shear line between the segments.
- Frequency segmentation of the chips is almost the same: 333 Hz in machining without the use of metalworking fluid, and 300 Hz in MQL machining.
- A smaller degree of strain hardening happens during MQL machining (compare: HV=285 and HV=235).
- Based on the above it can be concluded that the MQL machining gain less cutting force, the less strain hardening and the chip formation process is a favorable.

5. REFERENCES

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