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A STUDY ON THE MQL COOLING SYSTEMS OPTIMIZATION FOR MACHINING

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Abstract: An efficient MQL system (Minimal Quantity Lubrification) ensures the proper cooling of the various moving parts, resulting in the cutting process on the machine tools. The introduction of MQL systems responds to the growing demand in the industry with a whole host of real benefits. The geometry of the nozzle influences the flow parameters of the coolant; these parameters can also be influenced by the nature of the fluid or liquids used. The nozzle of the cooling system has a convergent-divergent geometry, the dispersion of the fluid in the areas to be processed being better. A high temperature in the working area above a certain critical value can be harmful to the quality of the surface and can have some negative influences on the life of the cutting tool. MQL-type cooling systems combine different cooling fluids to achieve better cooling and lubrication of the cutting area. Following the simulations performed, the coolant speeds depend on the length of the analyzed nozzle, we can see that the speed has a lower value in the initial section of the nozzle which increases at the nozzle outlet. After exiting the convergence-divergence nozzle, the fluid jet velocity decreases in proportion to the fluid jet length, the simulation of these phenomena can optimize the geometry for the chosen purpose. The present paper aims to analyze the types of coolants and their correct choice, temperature control resulting from the cutting process is achieved due to the correct distribution of cooling fluids in the processing area, optimization can be achieved through computer simulation.
Key words: MQL, cooling system, optimization, cutting process.

1. INTRODUCTION

The literature shows that various specialized studies deal with reducing the amount of liquid used in the cooling system, without diminishing the cooling and lubrication effect in the work area. Cooling systems in general are particularly important because these have a good influence on the cutting operation and on the resulting surface quality. The selection of coolants is made depending on the type of material to be processed, the cutting regime and the chosen processing method, [1].

It is known that a dry machining environment quickly leads to rapid wear of cutting tools and therefore their costs while flooded lubrication systems often lead to problems specific to this method: high lubricant consumption, high costs, heavy cleaning and greening and last but not least, the release into the atmosphere of the various substances harmful to the environment and the health of the service personnel, [2].

A small amount of coolant is economically important as it is less expensive and also has a better impact on the environment and the health of the operator, extensive hours of cleaning and maintenance are often saved for the installation and operation of an MQL system.

Thus, it is necessary to design the optimal geometry of the nozzle for the development of high-performance MQL (minimum quantity lubrication) systems is closely related to the optimization of the coolant distribution in the work area. Correlation of the fluid or perhaps of the cooling fluids if several are used is very important in the design of cooling systems [3].

In other words, excessively used cooling fluids generally contain harmful chemical constituents and thus, the prolonged contact of the operator with the aerosols resulting from the cooling system during its operation can lead to various ailments: asthma, some respiratory irritations, the beginning of pneumonia, spots on the skin, possibly cancer and others. In general, it is preferable to use vegetable oils as much as possible in coolant emulsions instead of using oils of petroleum origin, [4-6].

By optimizing the cooling-lubrication systems, by choosing the right fluids and how they are dispersed in the system, an ecological manufacturing process can be achieved. At the same time, the inefficiency of a cooling system can lead to the rapid deterioration of the cutting tool, this leads to its replacement much more often leading to unjustified additional costs brought to the cutting process, [7].

Research in this field leads to the development of new coolants, they lead to the development of efficient cooling systems and their integration on machine

tools, together with the optimization of the processing process, the development of ecological materials is reached, [8].

2. PARAMETERS OF THE CUTTING PROCESS

A method of reducing the amount of lubricant that acts as a coolant can be found experimentally using various practical comparisons in the case of the established cutting process.

The parameters that must be taken into account are: the cutting force generated by the machine tool, the surface roughness is given by the nature of the machining and the tools used and the temperature in the cutting area that affects the dimensional accuracy and tool life.

These studies can predict the amount of coolant used, reaching the control of surface fineness by optimizing the cutting. This is in addition to improving the surface quality by using a cooling system, using a smaller amount of coolant. At the same time, special attention is paid to the environmental aspects and fluid economy that are achieved with such cooling systems, through the MQL cooling system and if the working fluids are chosen correctly.

For the MQL cooling system, aerosols are used which are in fact oil droplets driven by a jet of pressurized air, they are dispersed directly in the working area of the cutting tool, providing the entire area with better cooling and at the same time lubrication.

Through the appropriate design of the convergent-divergent nozzle of the chosen cooling system, an optimal dispersion of it is achieved, the jet starts to break up into a conical spray at a certain angle once it leaves the nozzle hole, as we move away from the hole the jet becomes more and more diluted towards the cutting area. We will find by studying the formed jet that most of the mass of oil sprayed in drops is concentrated towards the spray axis, and outside the jet there is a smaller amount of oil and thus much smaller drops. Figure 1 shows schematically such an MQL system, [9].

This concentration of lubricant drops decreases in amount in the radial direction due to the interaction with the ambient air. We can observe on this occasion that the efficiency of the fluid jet is higher when an angle of 10-15° of the spray cone is recorded relative to the angle of the spray axis, most of the oil droplets agglomerate in the MQL cooling jet.

The flow rate of the coolant is about 100 ml/h at an air pressure of 5 bar. There are several parameters that must be taken into account when choosing the angle of action of the coolant dispersion nozzle in relation to the workpiece, this also depends on the chosen processing process. All this analysis of the fluid jet flow as well as the optimal angle of entry into the cutting area can be done experimentally and by computer simulation.

If we analyze the cooling fluids we find that they are of several types: aqueous solutions of electrolytes, hydrophilic soaps, corrosion inhibitors that use trisodium phosphate and soluble glass, oil-water emulsions, activated emulsions formed from water, active capillary substances and mineral oil emulsify, [10].

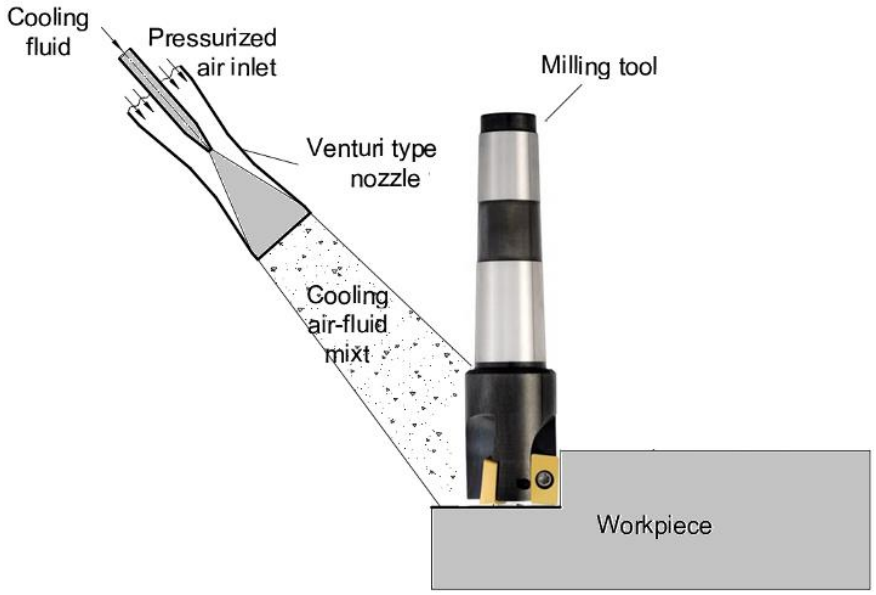


Fig. 1. Minimum Quantity Lubrication System

When preparing water-based emulsions, a softened water is used, the preparation is done by mechanically stirring the oil-water mixture by introducing the oil into the water. Also for a better emulsification, hot water is preferred, if emulsions with bactericidal

additives are used, it can reach half a year, however, it is not recommended to use them in machine tool tanks. The choice of the profile and the position of the nozzle is made according to three main parameters of the working fluid: the jet speed which is synchronized according to the speed of the cutting process, in the cutting process the nozzle is positioned as close as possible to the thermal action area. The construction of the system ensures that the fluid jet enters the tangential direction at the cutting area, the angle being chosen after studying several factors of the cutting process.

The pressurized air together with the lubricant are mixed inside the nozzle with the help of a mixing device of studied geometry, as shown in Figure 2.

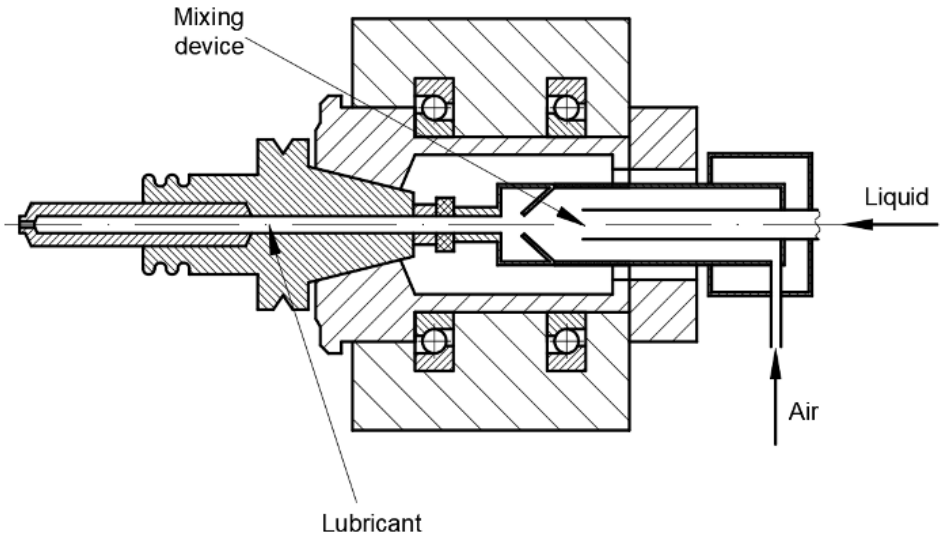


Fig. 2. MQL type cooling device

Lubrication is obtained by using oil, the pressurized air ensures a minimum cooling, it is used to direct the lubricant that reaches the cutting surface.

3. RESULTS AND DISCUSSION

The simulations are based on the following parameters: cutting depth, feed rate, cutting speed, tool type and geometry, angle of attack, size of the workpiece, type of material and last but not least the type of lubricant used.

The depth of cutting will determine the removal rate of the material, this will be observed by the roughness of the surface, because it directly affects the friction between the tool and the part, wear is avoided by lubricating the contact bodies. The life of the cutting tool is essential to reduce timely replacement and reduce costs in order to achieve improved machining productivity.

An optimal combination of cutting process parameters that simultaneously improve surface quality, material removal rate and tool life cannot be easily determined. If they are kept at high values, high heat will be produced at the cutting area and, as a result, it will affect the surface roughness, dimensional accuracy and significantly reduce the tool life.

For this reason, these coolants are used to reduce the heat between the cutting tool and the workpiece, due to their lubricating effect, and they are also used to wash the chips away from the cutting area. This process not only improves the quality of the product, but also extends the life of the tool.

There are numerous research studies to optimize the parameters of the metal cutting process with the help of MQL systems compared to wet machining and dry machining for parametric purposes such as dimensional accuracy and surface quality.

As expected, the experiments showed that the use of the MQL system significantly improves the output parameters compared to dry and drowned processing. The fluid supply system is developed according to the parameters of the jet flow: the pressure, the flow and the distance between the nozzle and the cutting area are controllable.

The flow passes through a nozzle and mixes with air as another component, therefore, it has different constituents in different locations in the case of processing aluminum alloys 6026-T9 at different cutting depths, in Table 1 is shown its chemical composition.

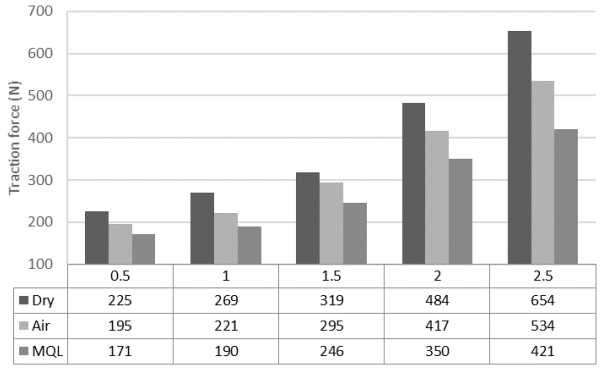
Table 1. Chemical composition (%) of aluminum alloy, type 6026-T9

Mg	Si	Fe	Cu	Cr	Sn	Mn	Zn	Others	Al
0.6-1.4	0.6-1.4	0.7	0.2-0.5	0.3	0.3	0.20-1	0.30	0.05	Balanced

The experiments were performed in different settings of shaft speed, feed rate, cooling technique and cutting tool material. Conventional cooling by liquid drowning, dry processing and the use of an MQL system were used as the cooling technique.

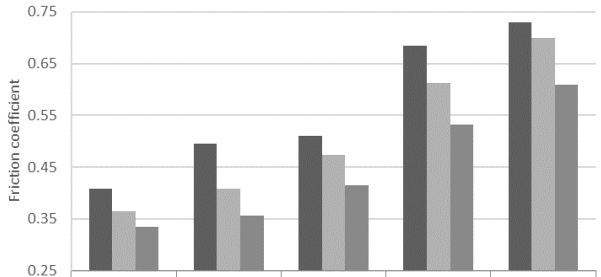
In the case of the MQL system it was applied at an oil flow rate of 5 ml/min at an air flow rate of 1,000 ml/min. A solution containing oil and water (oil/water ratio = 1/10) was used for MQL and water as a coolant for the flooded technique.

The MQL cutting fluid was sprayed under pressure with a 5 bar air compressor and sent with the nozzle to the active area of the cutting tool and the workpiece. The study was performed on a head milling cutter with a diameter of 10 mm as a cutting tool and 6026-T9 aluminum alloy with a thickness of 10 mm as a material for the workpiece.



	0.5	1	1.5	2	2.5
Dry	225	269	319	484	654
Air	195	221	295	417	534
MQL	171	190	246	350	421

Fig. 3. Traction force in depth of cutting for dry, flooded and MQL systems

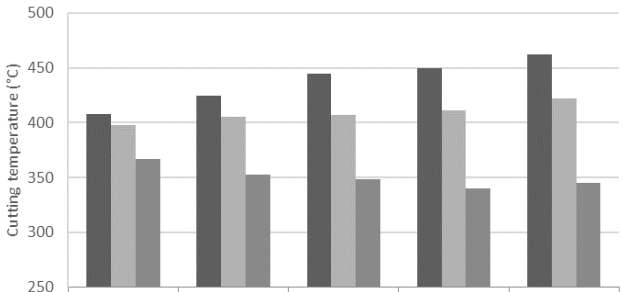


	0.5	1	1.5	2	2.5
Dry	0.41	0.50	0.51	0.69	0.73
Air	0.36	0.41	0.47	0.61	0.70
MQL	0.34	0.36	0.42	0.53	0.61

Fig. 4. Friction coefficient in depth of cutting for dry, flooded and MQL systems

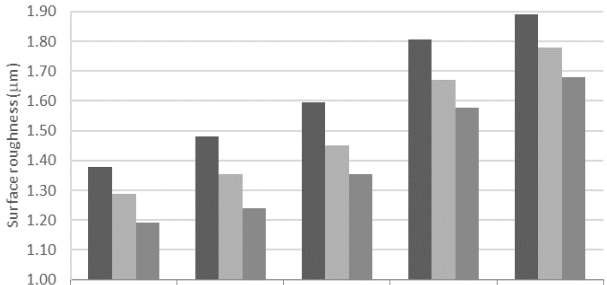
If we observe the graphical representations of the traction force in depth of cutting and friction coefficient in depth of cutting for dry, flooded and MQL systems we will notice that the MQL system is located halfway between dry and flooded processing, figure 3 and 4.

Similarly, we can say that for the graph of the temperature gradient relative to the surface roughness as a function of the depth of cut, the use of the MQL system implies as in the previous case an intermediate classification between the graph for dry processing and the process flooded with coolant. 5 and 6.



	0,5	1	1,5	2	2,5
Dry	408	424	445	449	462
Air	398	406	407	411	422
MQL	366	353	348	340	345

Fig. 5. Cutting temperature in depth of cutting for dry, flooded and MQL systems



	0.5	1	1.5	2	2.5
Dry	1.38	1.48	1.60	1.81	1.89
Air	1.29	1.35	1.45	1.67	1.78
MQL	1.19	1.24	1.35	1.58	1.68

Fig. 6. Surface roughness in depth of cutting for dry, flooded and MQL systems

If we look at the fluid flow as a whole, we see that a significant improvement over the dry method is cooling in the cold air cutting area, however the MQL system based on a mixture of coolants improves the tool life better reaching a much lower degree of wear compared to other cooling methods. This can be explained by a proper choice of cooling method as well as the fluid used. Fluid jet speed has a direct influence on the effect of lubrication and cooling.

We can say that, observing the simulations made, the coolant speeds depend on the length of the nozzle analysis, we can see that the speed has a value of about 200 m/s in the first 15 mm of the nozzle section, which increases at the outlet of the nozzle. nozzle at 450 m/s for the MQL system used. After exiting the convergence-divergence nozzle, the fluid jet velocity decreases in proportion to the fluid jet length.

The study indicated an efficient optimization of the surface roughness in the milling operation with the MQL system for the multiple demands of the cutting process.

4. CONCLUSIONS

As it appears from this study, the use of an MQL system is often much more advantageous. After analyzing the simulations made for the type of nozzle chosen, it can be seen that this fluid jet system allows a better lubrication and cooling of the cutting area compared to dry cooling and specially to flooded cooling.

The use of as little fluid as possible is important from an economic point of view, as well as the advantages brought by the MQL system on the chipping process. Due to the launch speed, the fluid jet can effectively remove the chips resulting from the machining process.

From the comparative analysis between the different graphical cutting methods, a lower tensile force and a lower coefficient of friction can be observed when using a mixture of emulsion-based fluids compared to different cutting depths for MQL systems, higher values are recorded of the coefficient of traction and friction, it better controls the temperature in the cutting area, being able to use it for different cutting depths and the resulting surface to be better after processing.

The MQL process uses the cooling fluids for a shorter period of time, being three or four times less than the period required for a flooded cooling, so we can conclude that the MQL system is more efficient in a final processing process.

As previously discussed, using a minimal amount of lubricant in the machining process can have a better impact on the environment as well as the operator's health. Coolants that come into contact with the overheated cuting surface can develop a significant amount of aerosols which, depending on the chemical composition, are not always healthy.

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