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A study on fluid flow simulation in the cooling systems of machine tools

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Abstract. This paper aims analysing the type of coolants and the correct choice of that as well as the dispensation in the processing area to control the temperature resulted from the cutting operation and the choose of the cutting operating modes. A high temperature in the working area over a certain amount can be harmful in terms of the quality of resulting surface and that could have some influences on the life of the cutting tool. The coolant chosen can be a combination of different cooling fluids in order to achieve a better cooling of the cutting area at the same time for carrying out the proper lubrication of that area. The fluid flow parameters of coolant can be influenced by the nature of the fluid or fluids used, the geometry of the nozzle used which generally has a convergent-divergent geometry in order to achieve a better dispersion of the coolant / lubricant on the area to be processed. A smaller amount of fluid is important in terms of the economy lubricant, because they are quite expensive. A minimal amount of lubricant may have a better impact on the environment and the health of the operator because the coolants in contact with overheated machined surface may develop a substantial amount of these gases that are not always beneficial to health.

1. Introduction

Cutting fluids are used in machining operations in order to improve the tribological processes, that occur between those two surfaces in contact with the cutting tool. It is known that the fluid cutting improves the cutting tool life, improve the surface resulting from the cutting and the cutting process in assemble. It also helps to reduce processing temperatures and removal of the chips produced during the processing of the cutting area [1].

Cutting fluids have many negative effects, due to their composition because of chemical constituents used to lubricate the processing area can harm the environment. These fluids are difficult to remove, so coolants recycling is costly and this can cause irritation of the skin and also pulmonary disease to operators due to the air pollution [2].

Due to the negative effects associated with cutting fluids combined with strict environmental laws and policies, it has developed a line of research in order to minimize the use of cutting fluids where they cannot be avoided completely. In literature it has estimated costs related to the use of cutting fluids as often greater than the costs of labor and overhead costs [3].

Even if in the economic studies the dry machining without coolant it's most advantageous in terms of production costs and the environmental impact, the friction forces and the heat generated in the manufacturing process can cause dimensional errors into the workpiece and accelerated wear of the cutting tool [4].

Therefore, to compensate the disadvantages associated with the dry processing we have found that one method by way would be to use a minimum quantity lubrication (MQL). Cutting fluid for an MQL system should be selected not only based on the primary characteristics related of the cooling performance in the cutting process, but also according to its secondary properties such as biodegradability, stability to oxidation and storage possibilities. The cutting processes in which the friction and adhesion phenomena have a dominant role, in general, require the use of minimum quantities of liquid [5].

MQL process relates to the use of cooling liquids for a minimum period of time, which are generally three or four times lower than that used in flooded lubrication conditions.

There are papers which indicates that the MQL process is more efficient in a final cutting process. This is considered to be the cause through the lubricant can reach the cutting zone easier in milling operations compared to other cutting methods. MQL with rapeseed oil has only a smaller effect of lubrication in processing condition with small forces. This is because the film formed on the surface instrument limit is not strong enough to support the low friction and avoid sticking to the work; but by the process MQL with water drops showed good lubrication performance during the same cutting conditions [6-8].

2. MQL cooling systems of machine tools

Minimal quantity lubrication is a recent technique which was introduced in machining processes to obtain safe, environmental and economic benefits, by reducing the use of coolant or lubricant fluids in metal cutting. As we can found in literature the metal-working fluids cost ranges from 7 to 17 % of the total machining cost, while the tool cost ranges from 2 to 4 % [9].

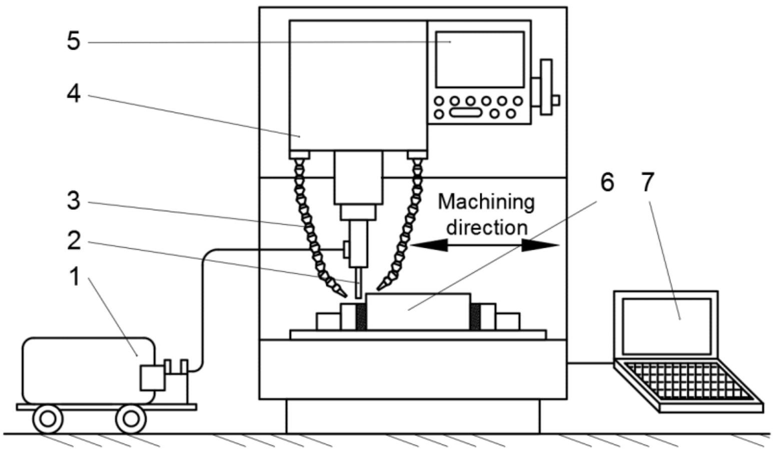


Figure 1. Machine tools cooling system
1. compressor; 2. cutting tool; 3. cooling system; 4. machine tools;
5. control board; 6. workpiece; computer.

MQL technique presented in figure 1, have a remarkable reduction of machining costs which can be obtained only by reducing of the quantity of lubricant used in machining. In MQL, is used a very small lubricant flow system (ml/h instead of l/min). It’s necessary in MQL systems to mix air and lubricant to obtain the mixture to be spread on the cutting surface. Thereby may be used two different mixing methods: mixing inside nozzle and mixing outside nozzle.

Using the mixing inside nozzle equipment, the pressurized air and the lubricant are mixed into the nozzle through a mixing device, as shown in figure 2. The lubrication is obtained by the use of lubricant, while a minimal cooling action is achieved with the pressurized air that reaches the cutting surface [9].

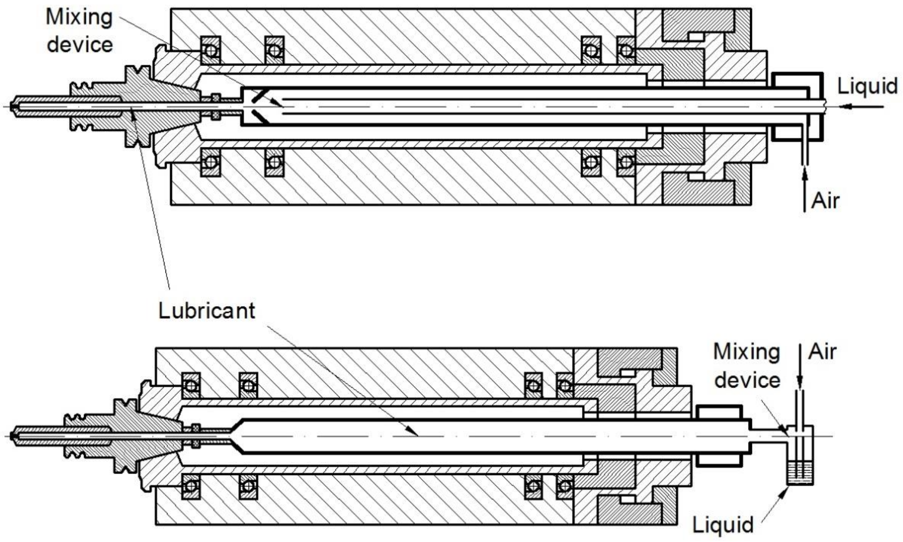


Figure 2. MQL type cooling device.

Several advantages derive applying this method, first of all the dangerous vapors are reduced and the mixture setting is very easily to control. With the method by mixing fluids outside of the nozzle (figure 3) the mixture is obtained in a mixing device positioned in a specific tank, in this case lubrication between workpiece and tools can be achieved.

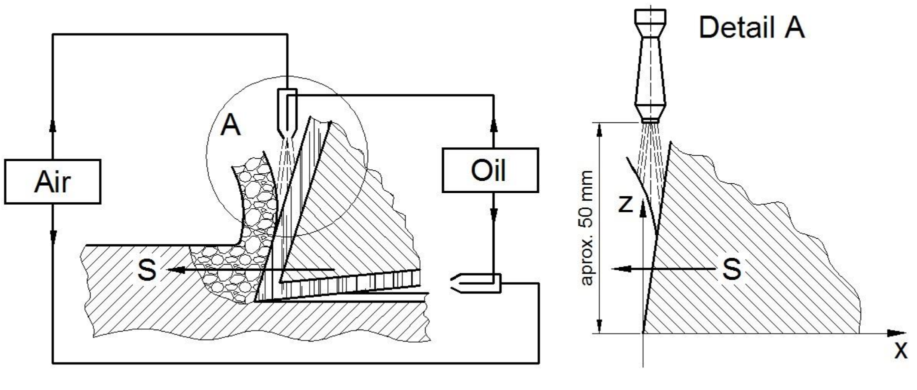
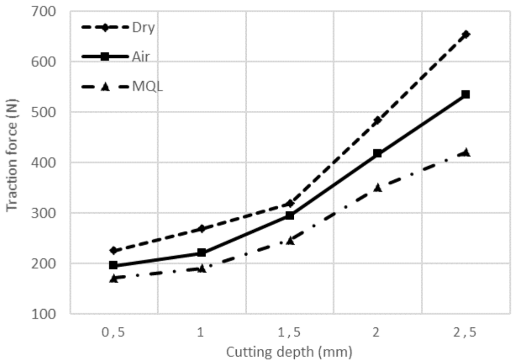


Figure 3. Cooling systems of machine tools.

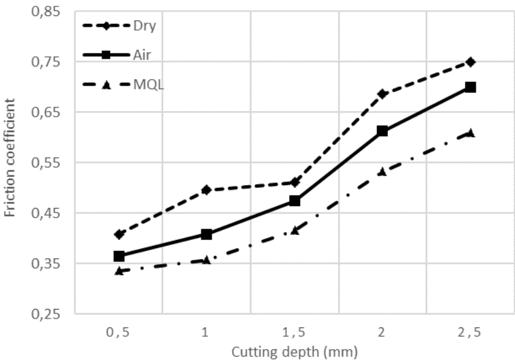
It's generally used in a system complex of cooling. A nozzle device is located before the flank of the cutting nozzle and another after that device in areas where is observed a high friction between tool and workpiece. For how can be lubricate this processed area depends on the correctness of the system used and the resulting processed surface. Height adjustable nozzles are used to be the best possible coverage area for further processing workpiece geometries.

3. Results and discussion

The flow generator and fluid feeding system are developed depending of jet flow parameters: pressure, flow rate and cooling distance (it is the distance between nozzle and cutting zone) are controllable. The flow goes through a nozzle and mixes with air as another one-component, hence, it has different constituents at different locations in case of machining 6061 aluminum alloys at different cutting depths.



a.



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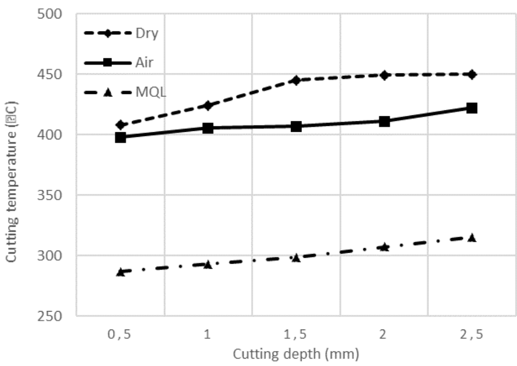

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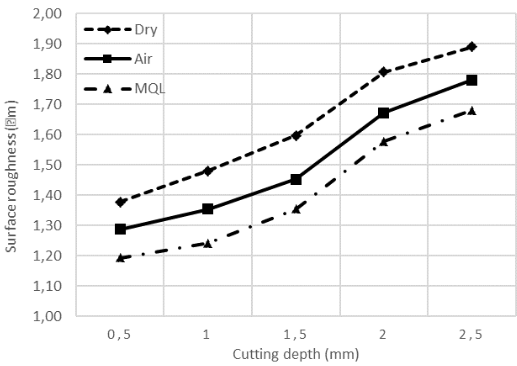

d.

Figure 4. Comparison between different cutting methods (dry cutting, oil emulsions and compressed air - MQL): a. traction force; b. friction coefficient; c. cutting temperature; d. surface roughness.

From the analysis of these graphs from figure 4 we can see that when are use a cooling system MQL type composed from emulsion of two fluids that oil and air is a noticeable improvement of all graphics processing analysis. Can be observe a lower traction force and lower friction coefficient in the case of using an emulsion based mixture of fluids reported at the various cutting depths. Are recorded lower values of tensile and friction coefficient this leads to diminished of the temperatures from the cutting area for cutting depths and a better surface of the workpiece.

Figure 5 shows how it improves the wear of the cutting tool to the three cases studied, it can be seen easily as dry method has the greatest impact on cutting tool and thus the resulting surface after processing. The cutting temperature was measured using thermocouple and it was found to increase with an increase in the depth of cut, the cutting fluid mainly depends on heat convection to reduce the cutting temperature.

A significant improvement compared to the dry method is the cooling in cutting zone with the cold air, however the MQL system based on a mix of coolants improves the better life of the tool reaching a degree of wear much lower compared to other methods cooling. This can be explained by a suitable choice of the method for cooling as well as the fluid used.

The velocity of the jet flow has a directly influences for the lubricating and cooling effect. Through measuring velocity of nozzle in different locations in the cooling distance, the distribution of velocity is modeled in a specialized software SolidWorks by means of Flow Simulation module with different colors standing for different values of velocity.

In figure 6 is presented the nozzle geometric parameters for cooling system chosen [10].

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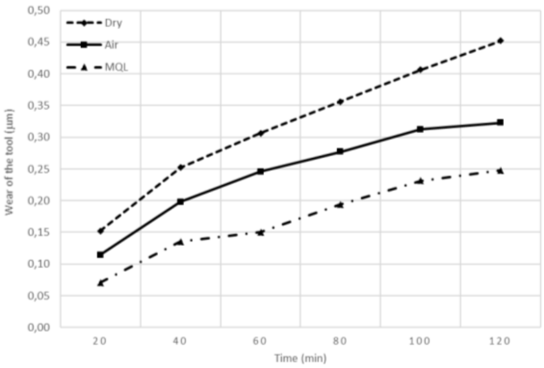

Figure 5. Wear of the tool for different cutting methods

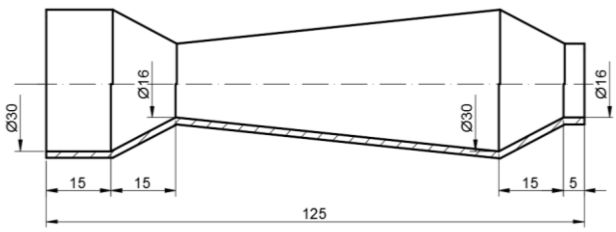

Figure 6. Nozzle system geometrical parameters

Using this type of convergent divergent nozzle can be achieved by the computer simulation to analyze speed within this system. In figure 7 represents the distribution of velocities in the cooling system. To achieve the simulation were used as working fluids such as air and analysis of fluid mixed one.

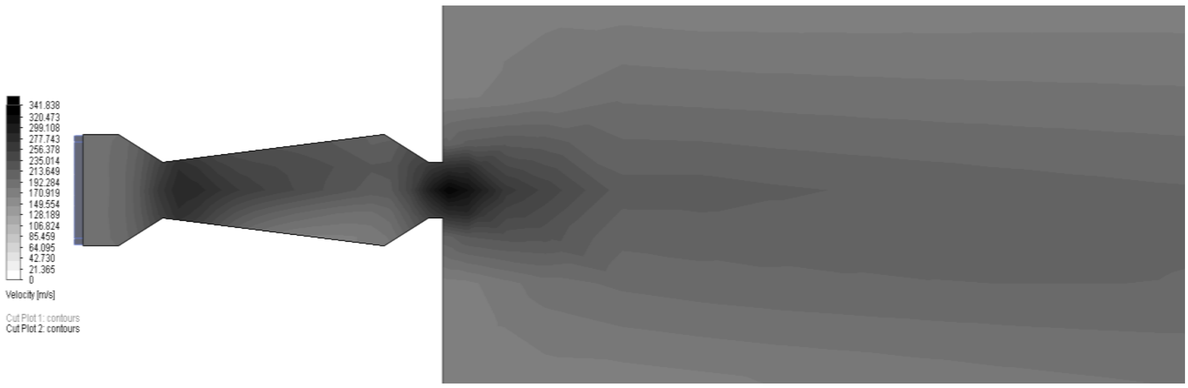

Figure 7. Flow parameters in nozzle system

By using of this simulation program the speed distribution can be extracted from the entry to the exit nozzle cooling fluid and analyzed, working pressure for these liquids was chosen as around 3 bar, figure 8.

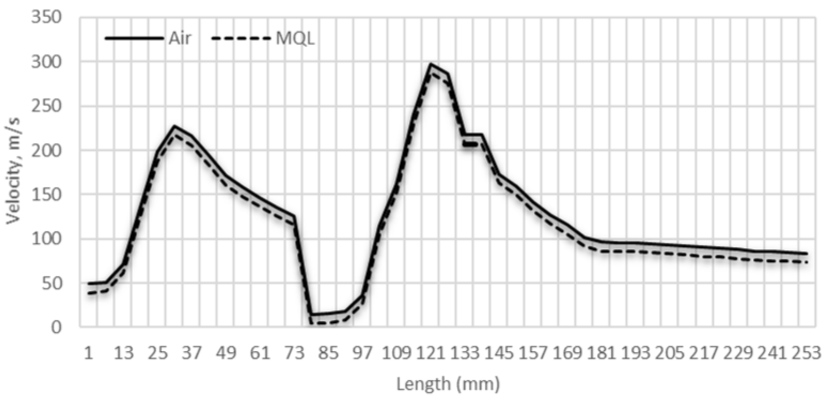

Figure 8. Fluid velocities distribution in length of the cooling system

After the chart speeds depending on the length of the nozzle analysis, it can be seen that the speed has a value of approximately 230 m/s in the first 16 mm diameter section of nozzle, this increasing in the outlet of the nozzle at 125 mm on graph to 300 m/s for both case we use air and MQL system as a working fluid. After exiting from the convergence-divergence nozzle, velocity of the fluid jet decreases proportionally for both coolants studied.

4. Conclusions

As can be seen from the study has been demonstrated that the use of an MQL system is advantageous in several ways. Analyzing the chart simulations for this type of nozzle can be seen as the jet speeds are quite high the fluid jet allows a proper lubrication and cooling of the cutting area.

A smaller amount of fluid is important in terms of the economy lubricant, however using MQL system can be advantageous in milling processes. Due to launch velocity fluid jet can remove the resulted chips from machining process.

From analysis of comparison between different cutting methods graphs may be observed a lower traction force and lower friction coefficient in the case of using an emulsion based mixture of fluids reported at the various cutting depths for MQL systems, are recorded lower values of tensile and friction coefficient this leads to diminished of the temperatures from the cutting area for cutting depths and a better surface of the workpiece.

A minimal amount of lubricant may have a better impact on the environment and the health of the operator because the coolants in contact with overheated machined surface may develop a substantial amount of these gases that are not always beneficial to health.

References

[1] Kurnosov N E and Tarnopolskii A V 2007 *Air–Liquid Lubricant and Coolant Aerosols in Machining*, Russian Engineering Research **10** 689–691
[2] Yang S H, Lee Y M, Kim, Y S 2004 *Analysis of Cutting Properties with Reference to Amount of Coolant used in an Environment-Conscious Turning Process*, KSME International Journal **12** 2182-89
[3] Ryzhkin A, Shuchev K G, Aliev M M, and Gusev V V 2008 *Dissipative Properties of Lubricant and Coolant Fluid in Cutting and Friction*, Russian Engineering Research **12** 1243-47
[4] Kirillov K. 2007 *Ecologically Sound Dry-Cutting Technology with Lubricant and Coolant Functions, Russian Engineering Research* **12** 855-61
[5] Itoigawa F, Childs T H C, Nakamura T, Belluco W 2006 *Effects and mechanisms in minimal quantity lubrication machining of an aluminum alloy*, Wear **260** 339-44
[6] Sayuti M A, Sarhan A D, Fadzil M, Hamdi M 2011 *Enhancement and verification of a machined surface quality for glass milling operation using CBN grinding tool-Taguchi approach*, International Journal of Advanced Manufacturing Technology 1-12
[7] Shetty et al. 2008 *Steam as coolant and lubricant in turning of metal matrix composites*, Journal of Zhejiang University Science **A 9** 1245-50
[8] Liu J et al. 2007 *Study on lubricating characteristic and tool wear with water vapour as coolant and lubricant in green cutting*, Wear **262** 442–52
[9] Attanasio A, Gelfi M, Giardini C and Remino C 2006 *Minimal quantity lubrication in turning: Effect on tool wear* Wear **260** 333–38
[10] Olaru I and Nedelcu D I 2015 *Study on Minimum Quantity Lubrication Systems in Cooling of Machining Processes*, Applied Mechanics and Materials, Trans Tech Publications, Switzerland **809-810** 1022-27