21st International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2018, Karlovy Vary, Czech Republic, 18th – 22nd September, 2018

THE APPLICATION OF MINIMUM QUANTITY LUBRICATION (MQL) DURING MACHINING PROCESS

Sabahudin Ekinović, Edin Begović
Univesity of Zenica
Faculty of Mechanical Engineering
Fakultetska 1., 72 000 Zenica
Bosnia and Herzegovina

Mario Dragičević
University of Mostar
Faculty of Mechanical Engineering,
Computing and Electrical Engineering
Matice hrvatske b.b., 88 000 Mostar
Bosnia and Herzegovina

ABSTRACT
In this paper recent state of art and application of minimum quantity lubrication (MQL) in machining processes is presented. Machining with the MQL system presents huge potential for sustainability of global manufacturing industry. Companies are constrained by different legal frameworks and regulations and they are forced to use new techniques for cooling, flushing and lubrication to be economically, socially and environmentally friendly. Because of this, it is interesting for scientists and manufacturers to adopt new technologies to improve the quality of the finished product and to increase the tool life with the least impact on all sustainability segments of machining process. This can be achieved by employing alternative techniques of cooling like MQL system as a substitute for traditional emulsion flood cooling.
Keywords: MQL machining, sustainability, alternative techniques of cooling

1. INTRODUCTION
The main goal of any machining process besides better productivity and lower costs is to get a high quality products. In addition to input cutting parameters a major contribution to the quality of final products and tool life have cutting fluids (CFs). The first studies of CFs in machining processes began in the 18th century and focus were to analyze of their impact on reducing friction and temperatures in the cutting zone [1]. Historical development of CFs Byers has described in the book "Metalworking Fluids" [2]. The most commonly used CFs in machining processes still are conventional or traditional oil emulsions. Conventional utilization of CFs have a negative impact on the sustainability of machining process. In recent years special attention in manufacturing industry was paid to use of conventional CFs. A significant component in technological planning of machining process represents proper choice of type and quantity of CFs and its delivery to the cutting zone as well as proper choice of appropriate combination of cutting parameters, cutting tool and workpiece. The implementation of sustainable development in machining process involves changes in type and quantity of used resources as well as proper storage and disposal of industrial waste [3]. Today manufacturing industry use more than 2.4 million liters of different CFs [4]. The United States utilization of CFs is estimated at 100 million gallons annually and the current worldwide consumption is about 640 million gallons annually. It is estimated that 52% is used for machining processes and 31% is applied to shaping processes [5]. Rabiei et al. [6] estimated annual usage of CFs by European Union is around 320,000 tones, out of which 66% is disposed after usage. Many scientific research data indicate an increase in production costs about 17% by using conventional CFs [7]. Particularly in technologically advanced countries where it is possible to determine the extent of the negative impact of CFs on environmental, human and economic segments of sustainable machining [8, 9, 10]. Due to the reduction of negative impacts and enforcement of environmental and human protection laws, the manufacturing industry seeks to reduce the use of conventional CFs and to have alternative and sustainable approach in manufacturing. Alternative techniques represent a challenge for many scientists and researchers because they have to fulfill all technical and economic requirements placed for achieving of main

machining goals. Different alternative types for cooling, flushing and lubrication like minimum quantity lubrication (MQL) machining can help to build a sustainable manufacturing strategy and to reduce costs related with the use of conventional CFs.

2. MINIMUM QUANTITY LUBRICATION MACHINING

Compared to conventional CFs the MQL technique includes to apply mixture of minimum amount of lubricant and air or water in form of aerosol to the cutting zone [11]. Application of MQL aerosol mixture to the cutting zone can be possible in two different ways. The first one is external in the case when the lubricant is applied from outside and another possibility is internal through the rotating machine tool spindle and the inner channels of the tool [12]. Machining processes like milling, turning and grinding can be easily implemented with external MQL systems. The internal MQL systems enables successful aerosol delivery to the cutting zone through the cutting tool. This makes it possible to drill very deep holes and use very high cutting speeds [12]. These systems can be with an external atomizer with single channel or with an internal atomizer with two or multiple channels. Astakhov [13] states that the lack of internal systems can be the influence of spindle speed and current state of the internal channels on continuous delivery of aerosol. To ensure smooth flow of aerosol to the cutting zone by multiple system it is desirable that the system is fixed. Very important parameters during MQL machining is type and ratio of cutting fluids and lubricant, pressure (2-6 bars), flow rate (5-500 ml/h), number (1-2), distance (5-30 mm) and angle (30^0 -60^0) of nozzles and so on [14, 15, 16]. Upadhyay et al. [17] in their paper gave a detailed view of the most influence MQL parameters on the efficiency of these technique. Depending on the machining process, material and geometry of the cutting tool and workpiece, lubricant types and input parameters, scientists and researchers give a different understanding about implementation of MQL technique in machining process. Bashir et al. [18] are analyzed the influence of cutting parameters and delivery of different amounts of oil (from 50 ml/h to 200 ml/h) using MQL techniques on the output values of surface roughness, cutting forces and tool wear during milling of hardened steel AISI 4140 (40 HRC). Due to the favorable penetration and interaction of aerosols between cutting tool and chips during delivery of 150 ml/h effect of built up edge - BUE is reduced. As a result minimum value of surface roughness and cutting force are achieved. Khan et al. [19] confirmed that the effects of MQL during turning of AISI 9310 alloy steel by using vegetable oil were very successful to reduce the cutting temperature compared to conventional emulsion cooling. Chetan et al. [20] performed turning of Nimonic 90 and compared dry machining, cryogenic machining and MQL machining. The authors pointed out that indicators of the tool wear, surface roughness and morphology of chips due to the corresponding combination of cooling and lubrication of cutting zone give a favor to the application of the MQL technique. Ekinović et al. [21] compared the results of the cutting force and temperatures in the cutting zone during MQL (type: OoW: Oil on Water) and dry turning of construction steel St52-3 and nickel based super alloy Nimonic 263. Results confirmed that difference between MQL and dry machining goes up to 25% in favor of MQL machining. Nouioua et al. [22] during turning of X210Cr12 steel with multi layer coated cutting tool concluded that MQL technique has a positive effect on reducing friction between cutting tool and workpiece. The temperature in the cutting zone is reduced and consequently the tool wear is lower about 23.34% compared with conventional and about 40% with dry machining. Liao et al. [23] reported about experiments carried out using the MQL technique during milling of Inconel 718. The authors used different combinations of oil and water ratio in the MQL system (10:90, 40:60, 60:40 and 100: 0) and oils with different viscosities. For all experiments the pressure was 5 bar, nozzles were 20 mm away from the cutting zone at an angle of 45. Oil flow for all combinations of oil and water ratios is 20 ml/h, 60 ml/h and 100 ml/h. The authors pointed out that with lower ratio of oil and water (with lower viscosity oils) during high milling with higher flow can allow more efficient aerosol penetration into the cutting zone. In this research, the optimum water and oil ratio and the flow rate which the best output performance values are obtained during milling Inconel 718 alloys are 60:40 and 60 ml/hr. Agrawal and Patil [24] compared results of the surface roughness and tool wear during turning of high speed steel using MQL technique with biodegradable oil. Experimental results indicated that surface roughness with MQL technique is lower about 6.7%, and the tool wear about 0.14% compared to conventional machining. Liao et al. [25] claimed that the MQL technique provides better results of the surface roughness at higher cutting speeds by oils with lower viscosity compared to conventional and dry machining during milling of increased hardness steel. On the other hand Calgan and Buldum [26] state that studies about influence of the MQL system during machining of softer materials is of great scientific importance. Based on the current state of art it can be concluded that the MQL technique can be an alternative to the conventional CFs application, especially during high speed machining. Also it can be concluded that using high pressure for delivery of aerosol in the cutting zone allows better penetration into the contact zone between tool/worpiece and tool/chips compared to conventional cooling. Through literature review it is evident that there are a lot of space to explor the influence of MQL system parameters on output values of different machining processes with different types of cutting tool and workpiece material in combination with different machining parameters. MQL techniques are rarely represented in industrial practice, and therefore relatively unexplored areas and it is resulting in an insufficient utilization in view of the opportunities what it provides.

3. CONCLUSION

In this paper, the application of MQL technique during the machining process is presented. It may be concluded that MQL machining process represents acceptable solution in the terms sustainability of machining process. Advantages of this technique is possibility of the application of vegetable biodegradable oils, which are desirable in the machining process. Also small amount of aerosol mixture during machining enables temperature reduction in the cutting zone what have a positive impact to reduce cutting forces, tool wear and surface roughness during machining. The costs of implementing and maintaining of MQL are highlighted as disadvantages of this technique. Success in the application of MQL systems is mainly related to boundary conditions such as type of machining process, material and tool geometry, the type of coolant as well as the selection of appropriate input cutting parameters and parameters of MQL system. The influence of the above mentioned parameters on the output values of the machining process using the MQL system is different and variable considering the wide range of possible variance of each parameter individually. During recent research in literature specific and uniform recommendations of the best comibantion of MQL paramaters have not been obtained. From the viewpoint of the lack of recommendations and concrete indicators related to concrete selection of MQL parameters there is possible to provide a significant contribution to different machining processes with combinaition of different types of cutting tool and workpieces. It would be useful to give concreate results for further improvement of the MQL technique in order to meet requirements of sustainable machining and provide clear guidelines that will encourage greater application of this technique in practice.

4. REFERENCES

[1] Brinksmeier, E., Meyer, D., Huesmann-Cordes, A. G., Herrmann, C.: Metalworking fluids - Mechanisms and performance, CIRP Annals - Manufacturing Technology, vol. 64, no. 2, pp. 605–628, 2015.

[2] Byres, J. P.: Metalworking fluids (second edition), CRC Press/Taylor & Francis Group, pp. 2-15, 2006.

[3] Veleva, V., Hart, M., Greiner, T., Crumbley, C.: Indicators of sustainable production", Journal of Cleaner Production, vol. 9, no. 5, pp. 447–452, 2001.

[4] Glenn, F. T., Van, A.: Opportunities and Market Trend in Metalworking Fluids. // Journal of the Society of Tribologists and Lubrication Engineers, 54,p.p. 31-34, 2004.

[5] Brockhoff, T., Walter, A.: Fluid minimization in cutting and grinding abrasive, Journal Abrasive Engineering Society, pp. 38–42, 1998.

[6] Rabiei, F., Rahimi, A. R., Hadad, M. J., Ashrafijou, M.: Performance improvement of minimum quantity lubrication (MQL) technique in surface grinding by modeling and optimization, Journal of Cleaner Production, vol. 86, pp. 447–460, 2015.

[7] Lawal, S.A., Choudhury, I.A., Nukman, Y.: A critical assessment of lubrication techniques in machining processes: a case for minimum quantity lubrication using vegetable oil-based lubricant. Journal of Cleaner Production 41, 210-221, 2013.

[8] Koné, F., Czarnota, C., Haddag, B., Nouari, M.: Modeling of velocity-dependent chip flow angle and experimental analysis when machining 304L austenitic stainless steel with groove coated-carbide tools, Journal of Materials Processing Technology, vol. 213, no. 7, pp. 1166–1178, 2013.

[9] Pusavec, F., Kramar, D., Krajnik, P., Kopac, J.: Transitioning to sustainable production-Part II: Evaluation of sustainable machining technologies, Journal of Cleaner Production, vol. 18, no. 12, pp. 1211–1221, 2010.

[10] Veleva, V., Hart, M., Greiner, T., Crumbley, C.: Indicators of sustainable production, Journal of Cleaner Production, vol. 9, no. 5, pp. 447–452, 2001.
[11] Autret, R., Liang, S. Y.: Minimum quantity lubrication in finish hard turning. // Proc. International Conference on Humanoid, pp. 1-9, 2003.
[12] Deutsche Gesetzliche Unfallversicherung DGUV. Minimum quantity lubrication for machining operations, Berlin, 2010.
[13] Astakhov, V. P.: Ecological Machining : Near-dry Machining - Machining Fundamentals and Recent Advances, University of Aveiro, Portugal, Department of Mechanical Engineering, Aveiro, Portugal, Book, 2007.
[14] Mozammel, M., Munish, K. G., Gurraj, S., Grzegorz, K., Danil, Y. P.: An Approach to Cleaner Production for Machining Hardened Steel Using Different Cooling-Lubrication Conditions., Journal of Cleaner Production, DOI: 10.1016/j.jclepro.2018.03.279, 2018.
[15] Senevirathne, S. W. M. A. I., Punchihewa, H. K. G.: Reducing surface roughness by varying aerosol temperature with minimum quantity lubrication in machining AISI P20 and D2 steels, The International Journal of Advanced Manufacturing Technology, 94:1009–1019, 2018.
[16] Gurraj, S., & Munish, K. G., Mozammel, M., Vishal S. S.: Modeling and optimization of tool wear in MQL-assisted milling of Inconel 718 superalloy using evolutionary techniques, The International Journal of Advanced Manufacturing Technology, https://doi.org/10.1007/s00170-018-1911-3, 2018.
[17] Upadhyay, V., Jain, P. K., & Mehta, N. K. Machining with minimum quantity lubrication: a step towards green manufacturing, International Journal of Machining and Machinability of Materials, 13(4), 349. https://doi.org/10.1504/IJMMM.2013.054277, 2013.
[18] Bashir, M., Mozammel, M., Nikhil R. D.: Investigations on Surface Milling of Hardened AISI 4140 Steel with Pulse Jet MQL Applicator, Journal of The Institution of Engineers (India): Series C – Springer, DOI 10.1007/s40032-016-0277-2, 2016.
[19] Khan M. M. A.; Mithu, M. A. H.; Dhar, N. R. Effects of minimum quantity lubrication on turning AISI 9310 alloy steel using vegetable oil-based cutting fluid. // Journal of Materials Processing Technology, 209, 5573– 5583. DOI: 10.1016/j.jmatprotec.2009.05.014, 2009.
[20] Chetana, S. G., Rao, P. V.: Environment Friendly Machining of Ni-Cr-Co Based Super Alloy Using Different Sustainable Techniques, Materials and Manufacturing Processes, DOI: 10.1080/10426914.2015.103791, 2015.
[21] Ekinović, E., Begović, E., Prcanović, H: MQL machining of difficult to cut materials, 17th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology", 17-20, 2013.
[22] Mourad, N., Mohamed A. Y., Riad, K., Salim, B., Tarek. M.: Comparative assessment of cooling conditions, including MQL technology on machining factors in an environmentally friendly approach, International Journal of Advanced Manufacturing Technology, DOI 10.1007/s00170-016-9958-5, 2017.
[23] Yunn, S. L., Chin, H. L., Hsien, M. L.: Study of Oil-Water Ratio and Flow Rate of MQL Fluid in High Speed Milling of Inconel 718, International Journal of Precision Engineering and Manufacturing, DOI: 10.1007/s12541-017-0033-4, Vol. 18, pp. 257-262, 2017.
[24] Agrawal, S. M., Patil, N. G.: Experimental study of non edible vegetable oil as a cutting fluid in machining of M2 Steel using MQL, Procedia Manufacturing, Vol. 20, 2018, pp. 207-212, 2018.
[25] Liao, Y. S., Lin, H. M.; Chen, Y. C.: Feasibility study of the minimum quantity lubrication in high-speed end milling of NAK80 hardened steel by coated carbide tool", International Journal of Machine Tools and Manufacture, vol. 47, no. 11, pp. 1667–1676, 2007.
[26] Cınar, C., Baris, B.: Investigation of the Effect of Minimum Quantity Lubrication (MQL) on the Machining of Titanium and its Alloys A Review", International Journal of Mechanical and Production Engineering Research and Development, Vol. 7, Issue 6, 2, 453-462, 2017.