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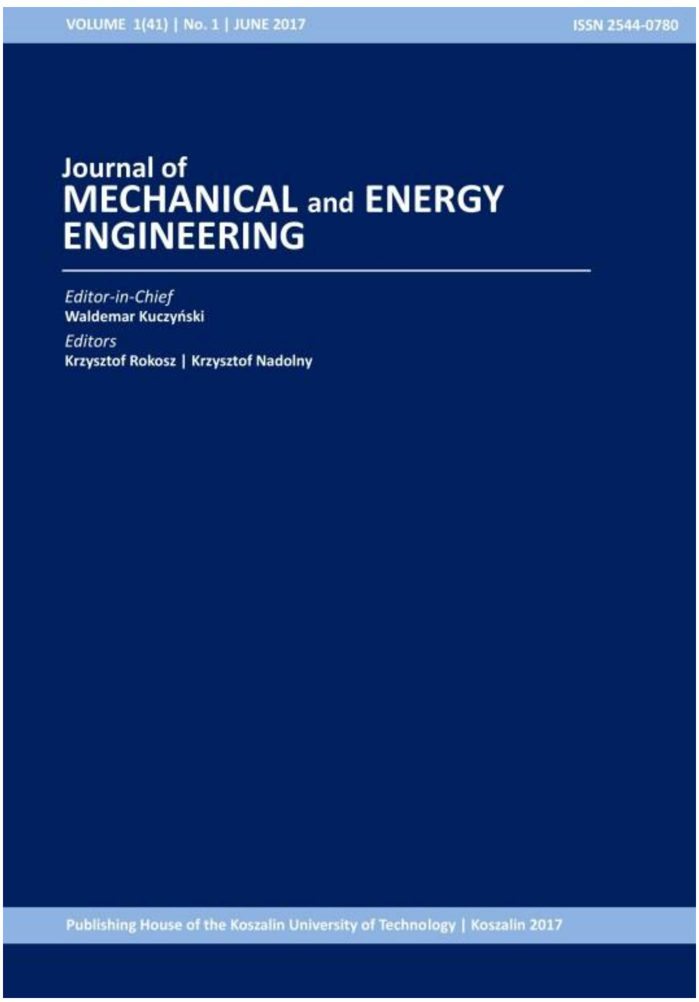

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INFLUENCE OF SUPPLYING THE VEGETABLE OIL WITH MINIMAL QUANTITY LUBRICATION ON WEAR OF THE HOB DURING HOBBING PROCESS OF THE GEARS

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Abstract: In the paper, the experimental investigations on hobbing cutting of the gears with the use of cooling fluids with minimal quantity lubrication (MQL) has been presented. The experiments were prepared during milling of 42CrMo4 alloy steel at of 32 ± 2 HRC hardness using high speed steel HS6-5-2 hobs without coating. Gears have been generated made in one single pass, to the full depth of the cut. As a cooling fluid in the MQL method, the vegetable oil and synthetic mineral oil MICRO 3000 was used. During the experiment, the size of the clamping was measured on the worm blade application surface, thus determining the direct VB_C wear indicator and the F_c cutting force value was recorded. Based on the obtained results, the influence of the type of used oil with MQL on the wear of the tool was assessed. The carried out analysis revealed that the use of vegetable oil in the field of assessed conditions gave better results than dry milling.

Keywords: hobbing, minimal quantity lubrication (MQL), cutting fluids, vegetable oil, wear of the hob, cutting force

1. INTRODUCTION

The primary goal of sustainable production is the cost-effective manufacture of the products, while minimizing its negative impact on the environment, saving energy and natural resources. In addition, the goal of sustainable production is to increase the safety of workers by eliminating the factors that threaten their health and life [1].

The above-mentioned goals also apply to the manufacturing processes utilizing the machining methods. In these methods one of the main factors affecting for conditions for sustainable production is using of cooling liquids [1].

The advantages of using conventional cooling liquids in the form of oils or aqueous oil emulsions are well known [2]. Their main task is to lower the temperature of the machining process and to remove chips from the cutting zone. As a result, the required quality of the workpiece and the tool life can be achieved [3]. However, from the standpoint of sustainable production, conventional cooling liquids delivered to the cutting zone by floodplain method is considered to be an undesirable [4]. It depend primarily due to economic reasons. Is commonly known fact, given in literature [2, 5], that the costs of using the cooling liquids are up to 17% of total manufacturing costs and are significantly higher than tool costs (2-4%) Another reason is ecological considerations and the need to adapt to increasingly stringent environmental regulations and to the safety and health of operators of the technological machines [6, 7].

Due to the above disadvantages, it trying to lead to the total removal or reduction of expense of colling liqids in the machining processes [2]. Total elimination of cooling liquids, which occurs in the case of dry machining (DM) often does not guarantee good results of the machining process. This is mainly due to the commonly used a high speed steel tools and conventional technological machines that do not provide the processing parameters required for dry cutting.

The use of DM in such cases increases machining costs as a result of reduced a cutting tools life. Often the temperatures during dry cutting exceed the permissible temperatures of the material for a given machining tool, which results in a reduction in the cutting parameters and a reduction in the machining capacity. In this situation it is possible to use alternative lubrication and cooling methods. One of them is the minimum quantity lubrication (MQL) method [3, 8]. The main advantages of the MQL method include:

- reducing direct production costs,
- no trouble with separating chips and machining fluid,
- supporting environmentally friendly production,
- avoiding the thermal shock affecting the cutting tool and object.

MQL is increasingly being used in industry and in research laboratories in the wide range of machining process. The studies widely described in the literature have shown that, under certain conditions, its application allows for results (cutting forces, tool life, surface roughness) much better than DM and comparable to machining in floodplain mode [2, 3, 5, 9]. One of the recent research issues, which is related to the MQL method is the replacement of used oils (mineral, synthetic, ester and fatty alcohols) by vegetable oils [1, 3, 10].

Hobbing is the most common method of producing gears in an uncured state, when using modern tooling materials, also in the hard state [11]. Available scientific publications and studies on the hobbing process indicate that the impact of used the MQL on process effectiveness has not yet been investigated or is limited in scope [12, 13]. Because during hobbing of the gears removing the machining allowance through many of teeth of the hob results in uneven load and also uneven clash of the cutting edges, experimental testing of efficiency of the MQL method in this application is fully justified.

In Institute of Machine Tools and Production Engineering at the Lodz University of Technology, researches related with using of the MQL during hobbing process are carried out since few years [14-16]. One of the important research problems is to determine the impact of the used cooling liquid (oil) on the wear of the hob. The research carried out so far was aimed at verifying that there is a rational possibility of replacing expensive oils dedicated to MQL applications by cheaper vegetable oils widely available on the market.

Efficiency evaluation of the supplying of various machining fluids was carried out by measuring the wear of hob during the entire tool life. The results obtained for the MQL method were compared with the results obtained during DM. The paper presents the results of the research and analysis and the evaluation.

2. MATERIALS AND METHODS

During the experimental investigations, machining with (MQL) and dry machining (DM) was used. The investigations were performed at constant cutting speed v_c and longitudinal feed rate f by hobbing the gears in one single machining passage, to the full depth of the cuts. During the experiment the tool wear was measured in the following way:

- direct, as the width of the wear on the flank face near the corner of the cutting edge – VB_C indicator,
- intermediate, as the value of the cutting force F_c acting along the axis of the gear.

As a criterion parameter for wear, a fixed milling length L = 400 mm was assumed.

During investigations, the cylindrical helical gears made for 42CrMo4 steel with a hardness of 32±2 HRC, were counterclockwise milled. The hobs NMFc-3/20°/B type with module m = 3 made for high speed steel HS6-5-2 without coating were used. Other cutting conditions are summarized in Table 1.

Tab. 1. Cutting conditions during experimental investigations

Process	Hobbing
Grinding machine	Conventional hobbing machine ZFC20 produced by CBKO Pruszków, Poland
Cutting parameters	v_s = 34.4 m/min, f = 0.5 mm/rev, a_p = 6.6 mm

In the MQL method, the MicroJet MKS-G100 system produced by Link (Germany) for external single-channel oil mist generation was used [9]. The machining liquid was delivered at flow rate of 15 ml/hr. During experiments the esterified mineral oil MICRO 3000 (MQL_1) supplied by the MKS-G100 system producer and the refined rapeseed oil (MQL_2) was used. The selected physical and chemical properties of the used oils are summarized in Table 2.

Tab. 2. The physical and chemical properties of the used oils

Property	Esterified mineral oil MICRO 3000 (MQL_1)	Refined rapeseed oil (MQL_2)
Kinematic viscosity (at 40°C), mm^2/s	48	36
Flash-point, °C	non-inflammable	332

The experimental stand for measurement of the cutting force F_c has been designed for the ZFC-20 conventional hobbing machine. The gears were mounted on a specially designed spindle. The spindle is used to mount the KISTLER Type 9321B piezoelectric dynamometer. The test signal from the dynamometer is directed to KISTLER Type 5011B single channel laboratory amplifier and converted to a voltage signal. Then from the amplifier the signal is sent to the KEITHLEY Type KPCMCIA-12AI-C measuring card located on the computer. The software for recording of the measurement data was designed and produced in Institute of Machine Tools and Production Engineering at the Lodz University of Technology [10].

Measurements of wear were carried out on the MWDc workshop light microscope produced by PZO (Poland) equipped with an electronic digital indicators EWC-3 , enabling readings with a resolution of 0.001 mm. The wear of the hob blades was on the flank surfaces and took the form of a clash near the cutting edge. The largest value of VB_{C-in} was found around the corner at the side of tooth contact zone. This value, for the most worn blade, was taken as a measure of wear when analyzing test results. In Figure 1, an image of the wear trace observed by the microscope eyepiece was presented. There was no significant wear on the analysed rake surfaces.

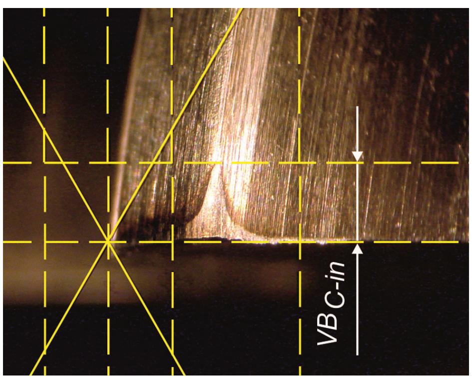


Fig. 1. Image of the wear on the rake face observed in the eyepiece of the workshop light microscope MWDc

3. RESULTS AND DISCUSSION

3.1. Wear of the rake face (VB_C)

In Figure 2 shows the distribution of VB_{C-in} values on all blades covered by measurable wear traces, during processing with MQL. The graph in Figure 2a refers to the use as cooling liquid supplied with minimal flow rate of synthetic oil MICRO 3000 designated MQL_1, whereas Figure 2b of refined rapeseed oil designated MQL_2. For comparison, the distribution of VBC-in wear on the blades during machining without cooling liquid is presented in Figure 2c.

Depending on the machining fluid used (MQL_1 and MQL_2), the number of blades that are affected by wear traces changed. For synthetic oil MQL_1, the wear occurred on a smaller number of the blades - 9, whereas for vegetable oil MQL_2, the number of blades with visible wear was significantly higher and was 13.

This indicates a lack of adequate lubrication in the case of vegetable oil, most likely due to the lack of suitable lubrication properties compared to the MICRO 3000 oil, which is dedicated by the producer to the wide range of the machining process. This leads to an excessive increase in the cutting temperature and increased thermal stresses on the individual blades, as is the case with DM. It is worth noting that for the DM machining, the number of blades with visible wear traces was greater only by one than for oil MQL_2.

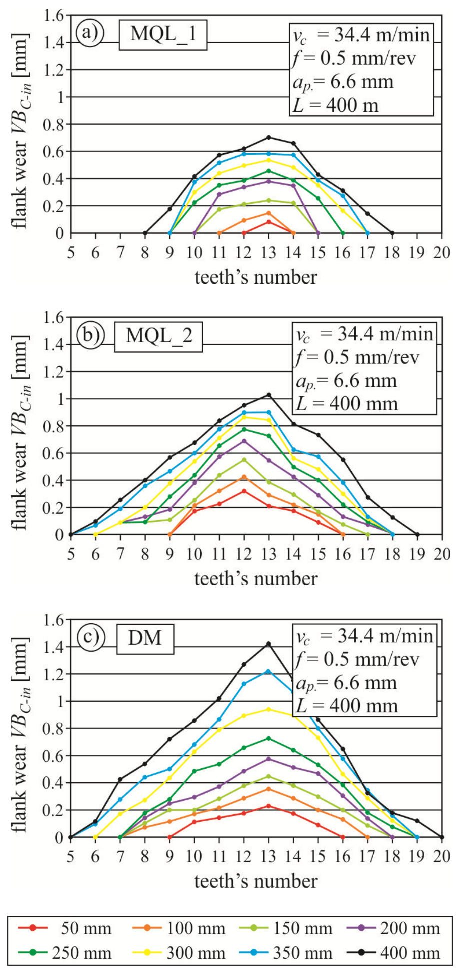


Fig. 2. Distribution of VB_{C-in} wear on the cutting edges of the hob as a function of time: a) synthetic oil -MQL_1, b) vegetable oil - MQL_2, c) without PCS - DM

In Figure 3 shows the change in VB_{C-in} flan wear in the most heavily loaded blade of the hob as a function of time t and milling length L during machining with minimal quantity lubrication (MQL) and without machined liquid (DM).

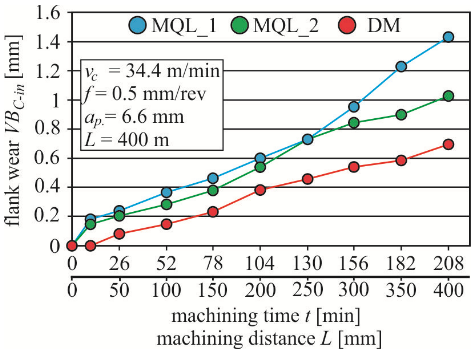


Fig. 3. Max. $VB_{C\text{-}in}$ flan wear as a function of time and milling length

As shown in Figure 3, the wear trace on the blades using MQL_2 vegetable oil and dry milling (DM) occurs at the earliest (~ 10 min). This indicates a lack of comparable, with MQL_1 synthetic oil, lubrication during the initial cutting period. In the case of MQL_1 and MQL_2 the wear curves show similar tendencies and their inclination is similar. However, differences in wear values are significant throughout the machining period. This indicates a significant difference in process temperature values. Finally, after 208 minutes of the machining, the $VB_{C\text{-}in}$ value for MQL_2 is 43% higher than for MQL_1.

In the case of hobbing without the share of machining fluid (DM), the wear curve shows a similar inclination compared to the other two methods up to 130 minutes of the machining. After this time, the curve rises rapidly, and $VB_{C\text{-}in}$ reaches a value of 1.4 mm after 208 minutes and is 100% greater than that obtained for MQL_1 oil and 40% greater than MQL_2 oil. This indi-cates for a better cutting conditions for machining with MQL than DM regardless of the type of fluid used.

3.2. Cutting force F_c

In Figure 4 shows the course of the cutting force Fc for MQL method depending on the machining fluid used (MQL_1 and MQL_2). For comparison, the course of cutting force during DM is also shown.

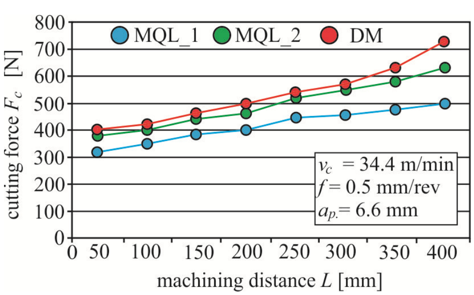


Fig. 4. Cutting force F_c as a function of time and milling length

The curves corresponding to the forces for MQL_1 and MQL_2 have a similar inclination, with the value of the cutting force during processing with vegetable oil MQL_2 being up to 30% greater than for synthetic oil MQL_1. It is worth noting that the significant difference between the force values for MQL_1 and MQL_2 indicates that there is insufficient lubrication when using vegetable oil during the entire machining period.

The F_c force curve for milling without the share of machined liquid (DM) shows similar tendencies to the other two curves to the milling length L = 300 mm which corresponds to approximately 130 minutes of machining. After this time, the DM values increase to 19% compared to the vegetable oil MQL_2 and up to 26% for the synthetic oil MQL_1.

4. CONCLUSIONS

On the basis of the results presented above, it can be stated that within the range of tested machining conditions:

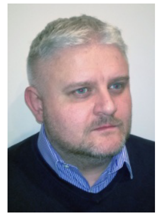
- for MQL_2 vegetable oil, the number of blades covered by the wear trace is 40% greater than that of MQL_2 synthetic oil, which indicates higher cutting temperatures and less lubrication during machining with refined rape oil;
- the wear curves for the most heavily loaded blade in the case of MQL_1 and MQL_2 are similar and their inclines are similar. However, in the case of vegetable oil MQL_2 the VBC-in consumption values are significantly, even 100%, higher than the synthetic oil MQL_1. This indicates a significant difference in process temperature values;
- for hobbing without the share of machining fluid (DM) after 208 minutes of the process, the VBC-in value is 100% greater than that obtained for MQL_1 and 40% greater than MQL_2. This indicates a better cutting condition in case, where the machining is carried out with minimal lubrication (MQL) regardless used type of machining fluid;
- the cutting forces by the use of MQL_1 and MQL_2 have similar tendencies, but the constant large difference in cutting force since beginning of the process (up to 30%) indicates a lack of sufficient lubrication when using vegetable oil;
- the use of the vegetable oil in the MQL method does not produce comparable effects to the MICRO 3000 synthetic oil but provides better machining conditions compared to machining without a DM;
- it is expedient to carried out further research on the use of vegetable oil supplying with minimal quantity during hobbing of the gears. Future research should include other types of vegetable oils, increased the oil flow supplying through

MQL method and other types of workpieces (uncured steel).

References

1. Pusavec F., Krajnik P., Kopac J. (2010). Transitioning to sustainable production – Part I: application on machining technologies. *Journal of Cleaner Production*, Vol. 18, No. 2, pp. 174-184.
2. Weinert K., Inasaki I., Sutherland J.W., Wakabayashi T. (2004). Dry machining and minimum quantity lubrication. *CIRP Annals – Manufacturing Technology*, Vol. 53, No. 2, pp. 511-537.
3. Sharma V.S., Singh G., Sørby K. (2015). A review on minimum quantity lubrication for machining processes. *Materials and Manufacturing Processes*, Vol. 30, No. 8, pp. 935-953.
4. Pusavec F., Krajnik P., Kopac J. (2010). Transitioning to sustainable production – Part II: evaluation of sustainable machining technologies. *Journal of Cleaner Production*, Vol. 18, No. 12, pp. 1211-1221.
5. Fratila D. (2010). Macro-level environmental comparison of near-dry machining and flood machining. *Journal of Cleaner Production*, Vol. 18, No. 10-11, pp. 1031-1039.
6. Sanchez J.A., Pombo I., Alberdi R., Izquierdo B., Ortega N., Plaza S., Martinez-Toledano J. (2010). Machining evaluation of hybrid MQL-CO2 grinding technology. *Journal of Cleaner Production*, Vol. 18, No. 18, pp. 1840-1849.
7. Silva L.R., Corrêa E.C.S., Brandão J.R., de Ávila R.F. (2013). Environmentally friendly manufacturing: Behavior analysis of minimum quantity of lubricant - MQL in grinding process. *Journal of Cleaner Production*. DOI: 10.1016/j.jclepro.2013.01.033
8. Boubekri N., Shaikh V. (2012). Machining using minimum quantity lubrication: A technology for sustainability. *International Journal of Applied Science and Technology*, Vol. 2, No. 1, pp. 111-115.
9. Byrne G., Dornfeld D., Denkena B. (2003). Advancing cutting technology. *CIRP Annals – Manufacturing Technology*, Vol. 52, No. 2, pp. 483-507.
10. Lawal S.A., Choudhury I.A., Nukman Y. (2012). Application of vegetable oil-based metalworking fluids in machining ferrous metals—A review. *International Journal of Machine Tools and Manufacture*, Vol. 52, No. 1, pp. 1-12.
11. Bouzakis K.-D., Lili E., Michailidis N., Friderikos O. (2008). Manufacturing of cylindrical gears by generating cutting processes: A critical synthesis of analysis methods. *CIRP Annals - Manufacturing Technology*, Vol. 57, No. 2, pp. 676-696.
12. Matsuoka H., Ryu T., Nakae T., Shutou S., Kodera T. (2013). Fundamental research on hobbing with minimal quantity lubrication of cutting oil. Comparison of cutting performance with dry cutting. *Advances in Materials Science and Applications*, Vol. 2, No. 3, pp. 88-100.
13. Matsuoka H., Ryu T., Nakae T., Shutou S., Kodera T. (2013). Fundamental research on hobbing with minimal quantity lubrication of cutting oil. Influence of hardness of work materials under several cutting conditions. *Advances in Materials Science and Applications*, Vol. 2, No. 4, pp. 154-167.
14. Stachurski W. (2012). Application of minimal quantity lubrication in gear hobbing. *Mechanics and Mechanical Engineering*, Vol. 16, No. 2, pp. 133-140.
15. Stachurski W. (2015). Influence of axial feed in hobbing with minimal quantity lubrication (MQL) on wear of the hob and cutting forces. *Scientific Journal of Silesian University of Technology*. Series Transport, Vol. 89, pp. 155-161 (in Polish).
16. Stachurski W., Midera S., Kruszyński B. (2016). Mathematical model describing the course of the process of wear of a hob cutter for various methods of cutting fluid supply. *Maintenance and Reliability*, Vo. 18, No.1, pp. 123-127.

Biographical note



Wojciech Stachurski received his M.Sc. degree in Production Engineering and Ph.D degree in Machinery Construction and Operation from Lodz University of Technology, in 2001 and 2008, respectively. Since 2003 he has been a researcher in the Institute of Machine Tools and Production Engineering at the Lodz University of Technology, where currently he works as an assistant professor. His scientific interests focus on abrasive processes, technological researches of the surface texture as well as wear and durability of cutting tools. He has participated in 3 national research projects as well as 5 international and 13 national conferences. He has published more than 50 scientific papers in various international and national journals. He is also the author of 2 national patents.