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THE USE OF EDIBLE VEGETABLE OILS APPLIED VIA MQL TECHNIQUE IN TURNING AISI 1045 STEEL

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Abstract. *The use of cutting fluids in machining processes is usually important to guarantee good surface integrity to the machined component, as well as to control temperature during cutting, maximize tool life, and reduce cutting forces. However, the use of cutting fluids, especially those containing mineral oil, can be harmful to the machining operator and the environment. In addition, the costs associated with the maintenance and disposal of cutting fluids are high. In this context, strategies to reduce the use of cutting fluid in machining processes such as the minimum quantity lubrication (MQL) technique are important, especially considering the use of environmentally friendly cutting fluids (e.g., vegetable oils). In this sense, this work aims to evaluate the use of edible vegetable oils as cutting fluids applied via the MQL technique in turning AISI 1045 steel. Soybean, corn, and sunflower oils were tested. A specific integral oil for MQL technique application and dry conditions (with no cutting fluid application) were also tested for comparison. Different cutting conditions in terms of feed rate were employed (0.23 mm/rot and 0.35 mm/rot). The output variables evaluated were surface finish (Ra and Rz parameters), the electric current of the machine tool, and the chips. The results showed that no significant variation in the surface finish (Ra and Rz parameters) was found for the different cooling-lubrication conditions tested. For the electric current of the machine tool, it was observed that cutting fluid application via the MQL technique increased this output parameter up to 10% in comparison to dry turning. Among the oils tested, the best result in terms of reducing the electric current during turning was found for soybean oil. The chips formed using the MQL technique presented a brown color irrespective of the oil, while those formed during dry turning presented a blue/violet color. For the higher feed rate tested, longer chips were observed during the turning using the MQL technique. The use of edible vegetable oils applied via the MQL technique in the turning of AISI 1045 steel can be a viable cooling-lubrication strategy, presenting better results in comparison to dry turning and comparative or even better results in comparison to the use of specific cutting fluid for MQL technique.*

Keywords: *Turning, Cutting fluids, Vegetable oils, MQL technique, Surface Roughness.*

1. INTRODUCTION

The high productivity in terms of machining processes is generally associated with high values of cutting speed, however, increasing this input variable can promote the development of high temperatures in the cutting zone that could lead to the workpiece surface integrity deterioration (Debnath et al., 2014). In this sense, due to better temperature control at the cutting zone, the application of cutting fluids is considered an important alternative to increase productivity, improve surface quality, and reduce costs in the machining process (Vieira et al., 2010). The cooling property of the cutting fluid contributes to reducing the temperature in the contact zone and minimizing distortions in the workpiece (Debnath et al., 2014). Kalpakijan and Schmid (2009) highlight the ability of the cutting fluid to reduce friction and tool wear, thereby increasing cutting tool life.

However, besides the improvements in terms of cooling and lubrication when using cutting fluids, it is important to mention that contact with cutting fluids can cause occupational diseases, especially mineral-based ones (Shashidhara and Jayaram, 2010). This occurs due to the composition of fluid that may be irritant or allergic (Debnath et al., 2014). In this context, to replace the mineral oils due to the risk for the operator and the environment, vegetable oils have been an attractive alternative, since they are biodegradable, more environmentally friendly, and less toxic in comparison to the mineral oils (Shashidhara and Jayaram, 2010). As stated by Lisboa et al (2013), cutting fluids must present, among their physical and chemical properties, a low viscosity so that the cutting fluid flows easily, and a high wettability establishing a good thermal contact. Additionally, cutting fluids must be able to withstand high pressures and high temperatures without vaporizing, as well as presenting a high specific heat coefficient and thermal conductivity. According to Shubrajit et al (2019), vegetable oils, as bio lubricants, can offer improved lubricity, lower volatility, and a high vitamin content. Additionally, they possess a long chain of fatty acids and polar groups in their structure, which makes them suitable for their utilization as lubricants.

In addition, the minimum quantity lubrication (MQL) technique is an environmentally friendly and economically method to apply the cutting fluid in the machining process (Debnath et al. 2014). In this technique, the cutting fluid flow rate is extremely low (about 50-500 mL/h), thereby reducing the costs associated with cutting fluids, and making the process less toxic to the operator and the environmental (Walker, 2015). This low quantity of cutting fluid, about ten thousand times less than the conventional technique (Chetan et al., 2015), is then directed to the cutting zone with the aid of compressed air, with pressures in the range of 0.6-0.8 MPa.

Since the cutting fluid applied via MQL technique forms an air-mixture, using cutting fluids less harmful to the human health and environment are preferable, such as the edible vegetable oils. Bedi et al. (2020) investigated the use of rice bran oil and coconut oil applied with MQL technique in the turning of the AISI 304 steel. The main results showed that, compared to dry conditions, applying rice bran oil and coconut oil contributed to reducing the cutting force in 31.43% and 29.2%, respectively. Surface finish with the MQL technique showed better results (lower surface roughness values) in comparison to the turning under dry conditions.

In a similar work, Revuru et al. (2020) evaluated the turning of AISI 4140 steel using vegetable cutting fluids applied via MQL and flood techniques under different cutting conditions. Dry turning was also performed, and the cutting fluid tested was the soyabean oil. The results showed that the feed rate was the most significant parameter that influenced the roughness of machined surface. The cutting fluid application presented minor influence in surface quality of the workpiece. In terms of tool wear, the use of the MQL technique contributed to reducing this output parameter in comparison to the other cooling-lubrication conditions.

Considering the importance of the MQL technique and the use of vegetable based cutting fluids, this work aims to evaluate the use of edible vegetable oils as cutting fluids applied via the MQL technique in turning AISI 1045 steel with carbide tool. The edible oils tested were soybean, corn, and sunflower oils. An industrial oil for MQL technique applications and dry conditions were also tested for comparison.

2. METHODOLOGY

2.1 Machine tool, cutting tool and workpiece material

The turning tests were conducted on a Veker TVK-1660ECO horizontal lathe, with a nominal power of 3.35 kW. The cutting tool employed was a HADSTO class P carbide insert, with designation of TNMG160408BR-M. The recommended cutting parameters for this tool include a cutting depth (a_p) ranging from 1 to 4 mm, and a feed rate (f) between 0.20 and 0.50 mm/rev.

For the workpiece, samples of the AISI 1045 steel with a diameter of 47 mm and a length of 100 mm were employed. The hardness of the material was determined through experimental measurements using the INSIZE ISH-BRV hardness tester. A total of six measurements were performed, resulting in an average hardness value of 210 ± 6 HB. The chemical composition of the specimens was determined in accordance with the NBR NM87:2000 standard and is presented in Table 1. Microstructural analysis was carried out using an optical microscope, revealing predominantly ferrite and pearlite phases, as depicted in the Figure 1.

2.2 Cooling-lubrication conditions and cutting parameters

Three different edible vegetable oils were tested in this work as cutting fluid: soybean, corn, and sunflower oils. The Vascomill MM FA 2 oil, from Blaser Swisslube, was also tested. All the cutting fluids were applied via MQL technique, using a flow rate and compressed air pressure of 60 mL/h and 0.6 MPa, respectively. Dry tests were also performed. Thus, a total of four different cooling-lubrication conditions were tested. The cutting speed and depth of cut employed were 173 m/min and 1.0 mm, both constant for all turning tests. Two different cutting conditions in terms of feed rate were tested: 0.23 mm/rev and 0.35 mm/rev. The design of experiments (DOE) is shown in Table 2.

For each turning test, 50 mm of the workpiece was machined in the feed direction, while keeping the cutting speed (v_c) and the depth of cut (a_p) constant. It is worth mentioning that, despite the importance of cutting speed to machining productivity and temperature, the influence of the feed rate in the machined surface's finishing is more significant considering conditions with no build-up edge formation, thus different conditions of feed rate were tested. The configuration for the experimental trials is shown in Figure 2.

Table 1. Chemical composition of SAE/AISI 1045 steel according to NBR NM87:2000

Carbon (C) %	**Manganese (Mn) %**	**Phosphorus (P) % maximum**	**Sulfur (S) % maximum**
0.43-0.50	0.60-0.90	0.040	0.050

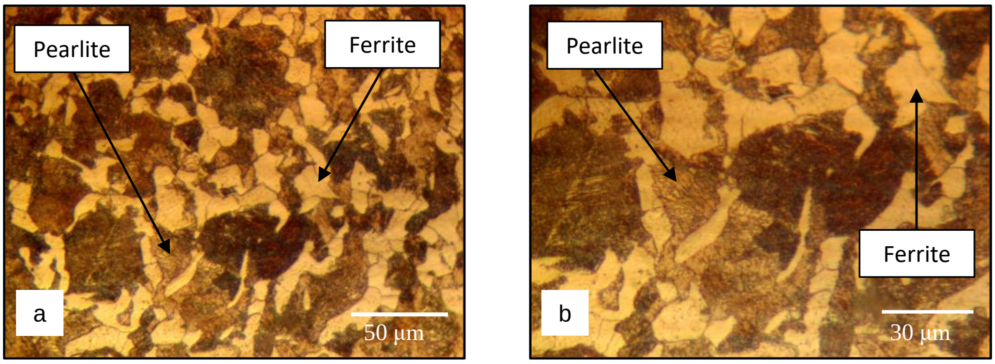


Figure 1. The microstructure of the AISI 1045 steel used in the turning tests, magnified at (a) 500x and (b) 800x.

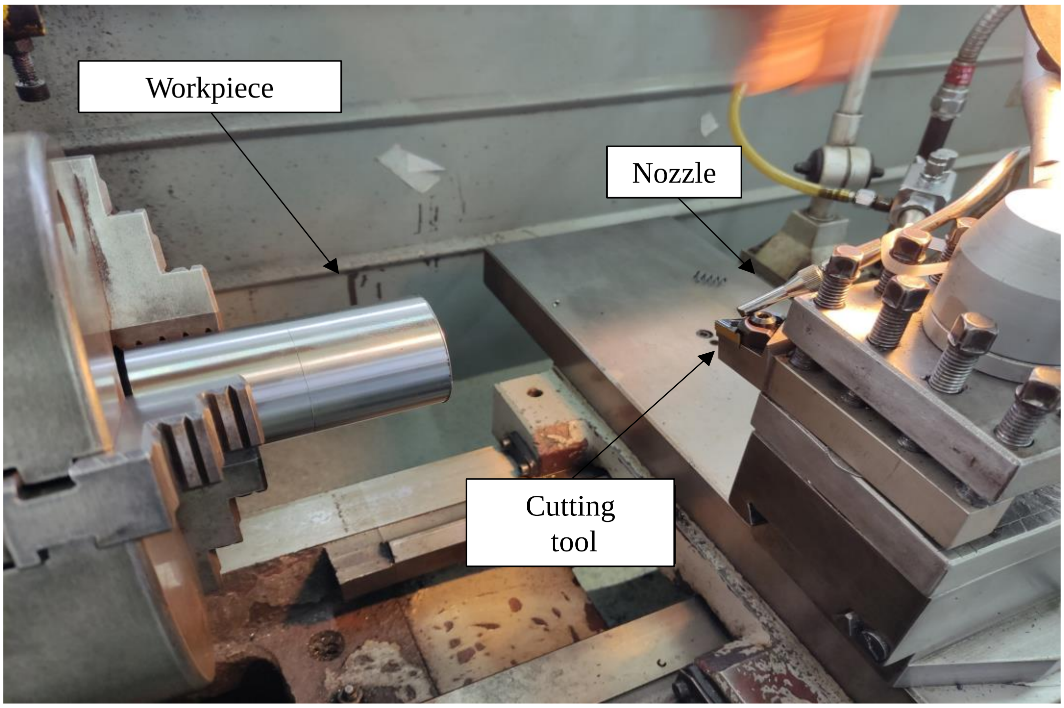


Figure 2. Configuration used in the experiments.

Table 2. Design of experiments for turning tests.

Test	**Cooling-lubrication condition**	**Feed rate (f), mm/rev**
1	Dry	0.23
2		0.35
3	Soybean	0.23
4		0.35
5	Corn	0.23
6		0.35
7	Sunflower	0.23
8		0.35
9	Vascomill	0.23
10		0.35

2.3 Output variables

The output parameters evaluated in this study were the surface roughness of the machined surface, the electrical current of the machine tool, and the chip generated in each test. The surface roughness values after turning were obtained using the Mitutoyo SJ-210 roughness tester. A cut-off of 0.8 mm, 4.0 mm of sample length and Gaussian filter were used. For each test, five measurements of Ra and Rz parameters were taken, and the average and standard deviation values were considered for the analysis of the obtained results.

The electric current of the machine tool electric motor was measured using a setup composed of an Arduino ATmega 2560 microcontroller, an electronic circuit for current acquisition, and a non-invasive Hall Effect sensor with a measurement range of 0-100 A, model SCT-013-000, following the methodology used by De Paiva and Barbosa (2018). The sensor measured the RMS value of the electric current from one phase of the electric motor.

Figure 3 shows the obtained results regarding the electrical current values for a single phase. It can be observed that initially, when the machine is turned off, the current value is zero. Then, with the activation of the spindle, there is a peak in the current followed by stabilization during the approach movement of the cutting tool to the workpiece. When the contact is made and the cutting begins, there is an increase in the electric current value that is maintained until the end of the cutting process. The average of the electric current obtained during the cutting interval was considered for the analysis of the results.

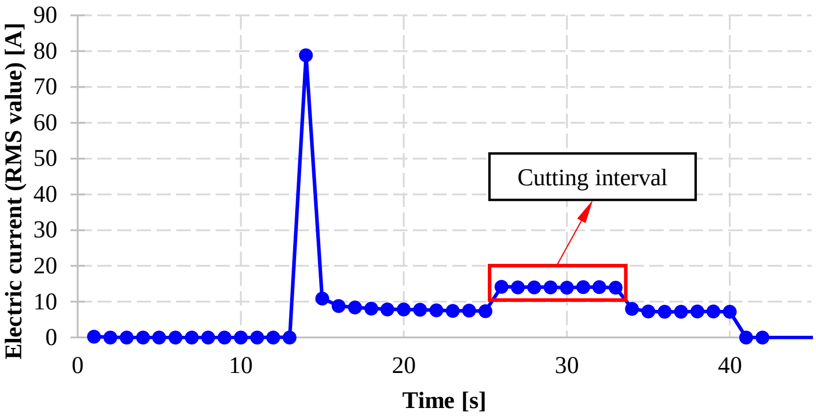


Figure 3. Electric current obtained in test 2.

After each test, a careful collection of a portion of the generated chips was performed. Subsequently, the characteristics of the chip, such as its shape and color, were examined for each test conducted.

3. RESULTS AND DISCUSSION

3.1 Surface roughness

The surface roughness Ra and Rz as a function of the cooling-lubrication condition are shown in Figure 4 and Figure 5, respectively, for the two values of feed rate (0.23 mm/rev and 0.35 mm/rev) tested in this work.

The effect of the cooling-lubrication condition shown in Figure 4 reveals that for both feed rates the variation of roughness Ra when applied vegetable oils by MQL technique is not very expressive when compared with dry conditions. For the lowest feed rate (f = 0.23 mm/rev), the use of soybean and corn oils applied via MQL technique contributed to decreasing Ra parameter by 2.5% and 1.5%, respectively, while using the sunflower oil increases Ra by 1.0%. For the highest feed rate (f = 0.35 mm/rev), an increase in Ra parameter was observed in comparison to dry condition: 1.7%, 4% and 5.6% for soybean, corn, and sunflower oil. For both feed rates, the values of roughness Ra obtained after turning with Vascomill applied via the MQL technique were the highest.

Variations in roughness Rz values (Figure 5) present a similar behavior in comparison to roughness Ra. Compared to dry condition, for the lowest feed rate (f = 0.23 mm/rev), a decrease in Rz parameter of 4.6% and 1.0% was observed after turning with soybean and corn oil, respectively. The use of sunflower oil slight increased Rz in comparison to dry condition. The application of Vascomill by the MQL technique also promoted the highest values of Rz parameter.

According to Machado et al. (2015), the surface roughness of a given machined surface depends, theoretically, only on the tool geometry and the feed rate. Thus, a minor influence of the cooling-lubrication conditions was expected, compared to the effect of the feed rate. In other way, the increase of the feed rate reveals a large variation in surface roughness in all the results, indicating that the feed rate was found to be the most significant parameter for surface roughness, which is in good agreement with the results observed by Gupta (2020).

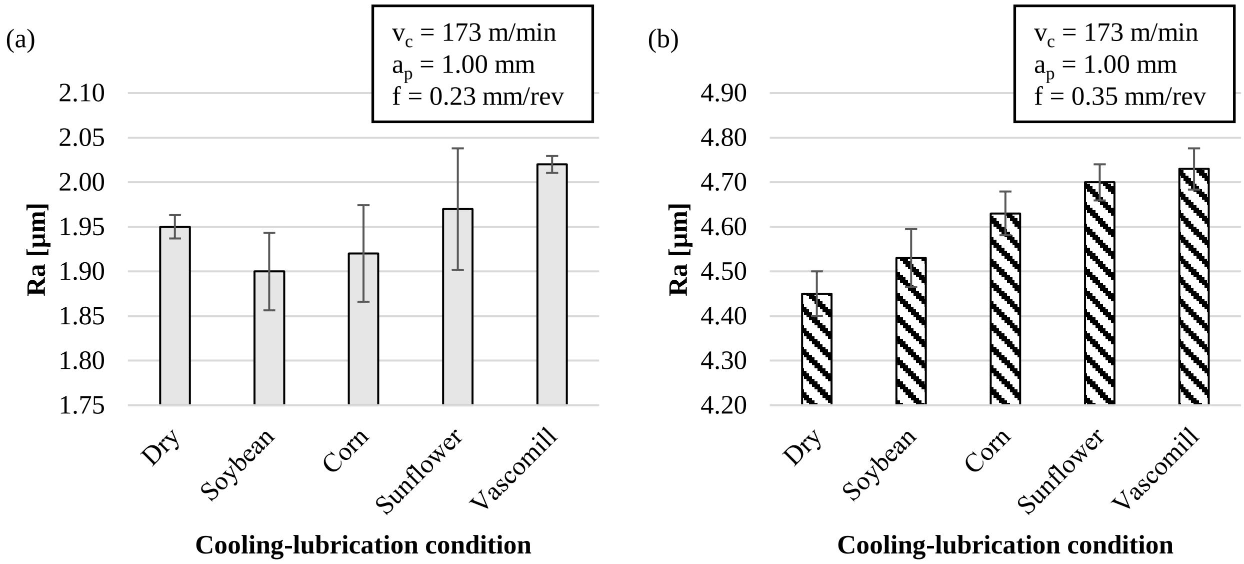


Figure 4. Surface roughness Ra of the machined surface. (a) f = 0.23 mm/rev. (b) f = 0.35 mm/rev.

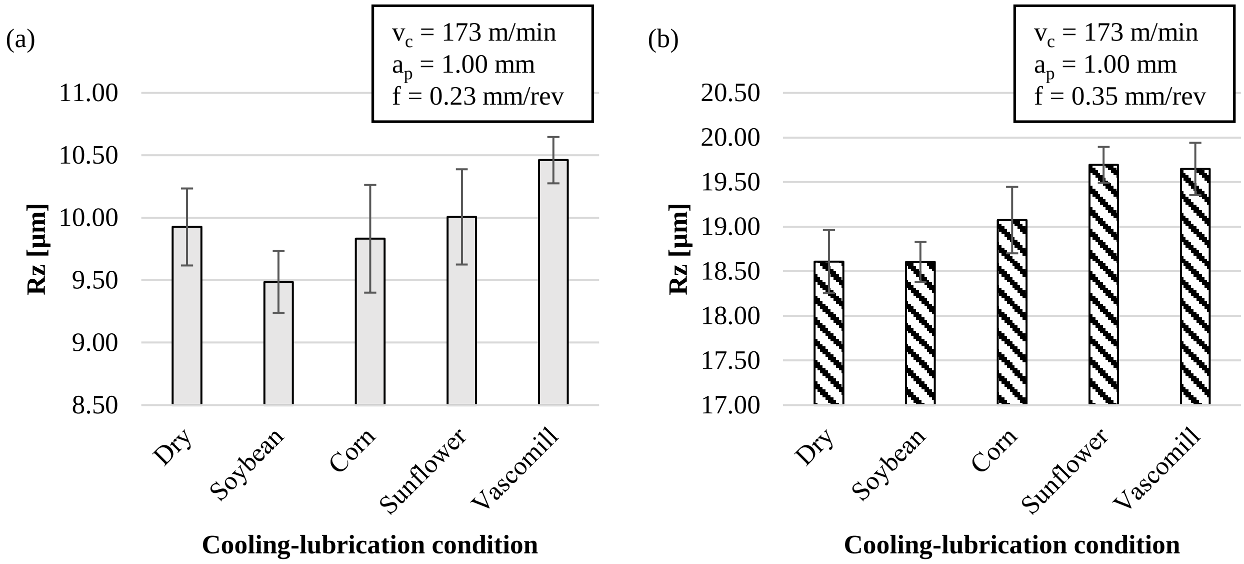
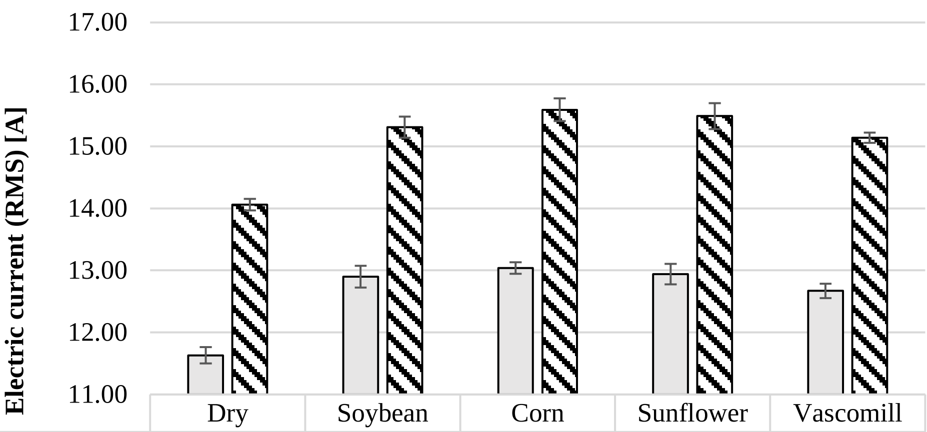


Figure 5. Surface roughness Rz of the machined surface. (a) f = 0.23 mm/rev. (b) f = 0.35 mm/rev.

3.2 Eletric current

The mean values of electric current during turning with the different conditions testes in this work are shown in Figure 5. One notes that the electric current significantly increased with the feed rate, irrespective to the cooling-lubrication condition. This indicates an increase in the power required for cutting the workpiece material, which, in turn, suggests an increase in the cutting force. Such increase was expected, since the cutting area increases with the feed rate and, therefore, higher cutting efforts are required to shear the workpiece material (Machado et al., 2015).

Regarding the effect of the cooling-lubrication conditions, one notes from Figure 6 that for f = 0.23 mm/rev, compared with dry conditions, the use vegetable oils with MQL technique increased the electric current by about 10%, 12% and 11% for soybean, corn, and sunflower oils, respectively. The use of the Vascomill also increased the electric current in comparison to the dry condition (9% increase). Similar behavior can be observed for the highest feed rate (f = 0.35 mm/rev). Such results suggest that the use of cutting fluid, even though applied via MQL technique, contributed to reducing the temperature at the contact zone in comparison to dry turning. At lower temperatures, the workpiece mechanical resistance is higher, thereby requiring more power to cutting the workpiece material, which explains the lower electric current observed when turning in dry conditions, irrespective to the feed rate.



	Dry	Soybean	Corn	Sunflower	Vascomill
f = 0.23 mm/rev	11.63	12.9	13.04	12.94	12.67
f = 0.35 mm/rev	14.06	15.31	15.59	15.49	15.14

Figure 6. Mean value of electric current during cutting operation.

3.3 Chip analysis

The chips obtained after turning using each cutting condition tested in this work are shown in Figure 7. The chip generated under dry condition showed blue/violet color while chip generated under MQL technique showed brown color, especially those generated after turning using the edible oils. This result indicates a reduction in chip temperature when turning using the MQL technique in comparison to dry condition (Gupta et al., 2018), which corroborates with electric current discussions.

As for the chip shape, Figure 7 shows that the application of vegetable oils by MQL technique results in longer helical chips for both feed rate, same when applied the Vascomill oil. For turning in dry conditions, the chips generated under the highest feed rate (0.35 mm/rev) were shorter.

The reduction in chip temperature when turning with the MQL technique in comparison to dry condition is expected, since both cutting fluid and compressed air can act in order to dissipate the heat by force convection. Additionally, the presence of the cutting fluid can contribute to friction reduction, thereby improving the sliding process of the chip under the rake face of the cutting fluid. This may be an explanation for the longer chips generated during turning with MQL technique.

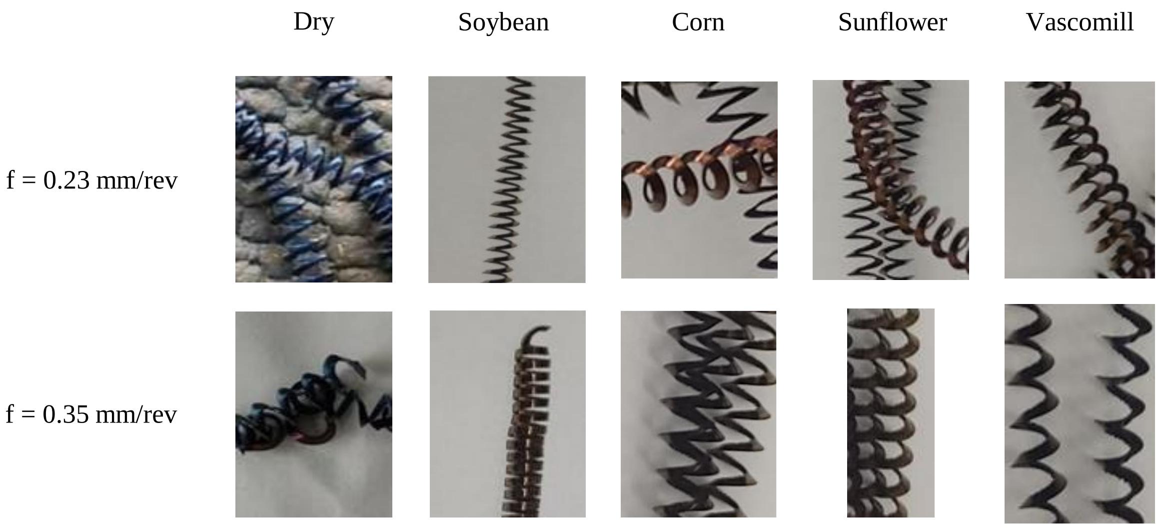


Figure 7. Chips generated for the different cutting conditions tested in this work.

4. CONCLUSIONS

In this research, the performance of three edible vegetable oils (soybean, corn, and sunflower) applied via the MQL technique were compared with dry and the MQL technique using an industrial oil. Based on experimental results, the following conclusions can be drawn:

- The application of edible vegetable oils presented minor influence on the surface roughness of the machined surface in comparison to dry turning. Between the edible oils tested, the soybean was the one that presented best results (lower values of Ra and Rz parameters).
- Compared with dry conditions, the application of vegetable oils by MQL technique promoted higher values of electrical current from machine-tool electrical motor, about 8% to 12% higher. Corn oil show higher electrical current values than the other vegetable oils and soybean the smallest. A specific integral oil for MQL application had the smallest electric current variation.
- Dry conditions generate blue/violet chips, while in machining using vegetables and integral oils applied by MQL technique generate brown chips, suggesting lower chip temperatures when applied the MQL technique.
- For the conditions used in this work, the feed rate variation presented more influence in comparison to the cooling-lubrication conditions tested in this work, irrespective to the output parameter evaluated.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Bedi, S.S., Behera, G.C. & Datta, S. Effects of Cutting Speed on MQL Machining Performance of AISI 304 Stainless Steel Using Uncoated Carbide Insert: Application Potential of Coconut Oil and Rice Bran Oil as Cutting Fluids. Arab J Sci Eng 45, 8877–8893, 2020.

Cordeiro de Lisboa, f. Fluidos de Corte: Uma Abordagem Geral e Novas Tendências. [s.l: s.n.]. Disponível em: <https://abepro.org.br/biblioteca/enegep2013_TN_STO_185_056_23095.pdf>.

Chetan, Ghosh, S., Rao, P. V. Application of sustainable techniques in metal cutting for enhanced machinability: a review. Journal of Cleaner Production, 100, 2015, 17-34.

De Paiva, R. L.; Barbosa, M. G. C. B. Análise da Medição de Potência Elétrica da Máquina-Ferramenta no Processo de Furação. XXI Colóquio de Usinagem - UFTM, Uberaba MG, 2018.

Debnath, Suja; Reddy, Moola Mohan; YI, Qua Sok. Environmental friendly cutting fluids and cooling techniques in machining: a review. Journal of Cleaner Production 83, 2014, 33-47.

Gupta, Munish Kumar; Pruncu, Catalin Iulian; MIA, Mozammel; Singh, Gurraj; Singh, Sunpreet; Prakash, Chander.; Sood, P. K.; Gill, Harjot Singh: Machinability investigations of Inconel-800 super alloy under sustainable cooling conditions. Materials, 11, 2088. 2018.

Gupta, A., Kumar, R., Kumar, H. and Garg, H. Comparative performance of pure vegetable oil and Al2O3 based vegetable oil during MQL turning of AISI 4130. Materials Today: Proceedings, Vol. 28, pp. 1662-1666, 2020.

Kalpakjian, S; Schmid, S. Manufaturing Engineering and Technology. 6 ed: Pearson, 2009.

Machado, A. R.; Abrão, A. M.; Coelho, R. T.; da Silva, M. B. Teoria da Usinagem do Materiais. 1ed. SP: Editora Blucher, 2015.

Pusavec, Franci; Krajnik, Peter; Kopac, Janez. Transitioning to sustainable production – Part I: application on machining Technologies. Journal of Cleaner Production, 18, 2010, 174 – 184.

Revuru, R.S., Zhang, J.Z. & Posinasetti, N.R. Comparative performance studies of turning 4140 steel with TiC/TiCN/TiN-coated carbide inserts using MQL, flooding with vegetable cutting fluids, and dry machining. Int J Adv Manuf Technol 108, 381–391, 2020.

Shashidhara, Y. M; Jayaram, S. R. Vegetables oils as a potential cutting fluid – An Evolution. Tribology International 43, 2010, 1073-1081.

Shubrajit Bhaumik, Viorel Paleu, Rajan Pathak, Rishabh Maggirwar, Jitendra Kumar Katiyar, Anuj Kumar Sharma,Tribological investigation of r-GO additived biodegradable cashew nut shells liquid as an alternative industry lubricant, Tribology International,Volume 135, 2019, 500-509.

Viera, J. M; Machado, A. R; Ezugwu, E. O. Performance of cutting fluids during face milling of steels. Journal of Materials Processing Technology 116, 2001, 244-251.

Walker, T. The MQL handbook: A guide to machining with Minimum Quantity Lubrication. Unist Guide, 2015.

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