The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2023

Volume 26, Pages 395-403

IConTES 2023: International Conference on Technology, Engineering and Science

Comparison of the Effects of Vegetable Oils such as Castor and Canola Oil and Polyol Esters on the Metalworking Performance of Ti-6Al-4VAlloy by Tapping Torque Method

Kubra Kavut
Marmara University
Belgin Oil R&D Center

Hanife Gulen -Tom
Belgin Oil R&D Center

Tugce Ozpercin
Belgin Oil R&D Center

Abstract: Ti-6Al-4V material is an alloy of particular interest for engineering applications in a wide range of industries, especially aerospace and medicine, due to its outstanding corrosion resistance, favorable strength-to-weight ratio and biocompatibility properties. Due to the low thermal conductivity and high chemical reactivity of this alloy, its machinability is quite limited and is therefore referred to as the "difficult-to-cut" alloy. When the problems encountered in the processing of Ti-6Al-4V alloy are evaluated, the preparation of the appropriate cutting environment, ensuring optimum cutting parameters and the use of appropriate coolant are the priorities in overcoming these problems. Vegetable oil and polyol esters are biodegradable base fluids that can be used as a sustainable alternative to petroleum-derived oils in many lubricant applications. In this study, the effects of castor and canola oils and trimethylolpropane trioleate (TMPTO) and trimethylolpropane trioleate complex (TMPCX), neopentyl glycol (NPG) and pentaerythritol tetra-oleate (PE-TO) type polyol esters on the machining performance of Ti-6Al-4V alloy were investigated using the Tapping Torque test method. In the tests performed on Ti-6AL-4V, it was determined that the tapping performances of TMP-TO, TMP-CX, PE-TO and castor oil were close to each other and gave the best results. It has also been determined that the tapping performance of canola oil is lower than these oils. NPG-DO gave a striking result for Ti-6AL-4V and the tapping performance was found to be very low.

Keywords: Sustainability, Metalworking fluids, Tapping torque, Vegetable oils, Polyol ester, Ti-6Al-4V

Introduction

Titanium is considered to be one of the strongest metals. Its strength, heat, water and salt resistance, and its light weight make it the ideal metal for a variety of applications. Titanium alloys retain the same strength and corrosion resistance, but takes on the greater flexibility and malleability of the metal it is combined with. Titanium alloys, therefore, have more applications than pure titanium (Biesiekierski et al., 2021). Titanium alloys with low density, high specific strength, corrosion resistance, good process performance and biocompatible are of particular interest in engineering applications in a wide range of industries, such as aerospace engineering and medicine (Cui et al., 2011). Recently, the application ratio of CFRP (Carbon Fiber Reinforced Plastic) to airframes and engine parts has been growing to improve aircraft fuel consumption. Similarly, demand for titanium is also growing as it has excellent compatibility with CFRP with respect to corrosiveness and coefficient of thermal expansion issues (Inagaki et al., 2014). In addition to the advantages of titanium alloys, they also have a major disadvantage such as difficult machinability. Titanium alloys are extremely difficult to machine due to their relatively high tensile strength, low ductile yield rate, 50% lower modulus of elasticity (104 GPa), and approximately 80% lower thermal conductivity than steel (Ahmed et al., 2012). Due to the low thermal conductivity of titanium, the heat generation during machining operation is very high which badly affects the machining performance and life of the tool. Due to heat generation at the machining zone, the surface quality of the workpiece gets hampered (Roy et al., 2018). Since the most important parameter in the machining of titanium is to ensure the removal of heat resulting from the friction between the tool and the material, it is extremely important to ensure cooling and lubrication balance during machining. In this regard, utilization of metal working fluids is crucial for effective machining of titanium alloys. Heat generated can be reduced in the cutting zone and excessive friction can be prevented by helping of metal working fluids. As a result, life of mechanical systems can be extended. When the problems encountered in the machining of titanium alloys are evaluated, the preparation of the appropriate cutting environment, ensuring optimum cutting parameters and the use of appropriate coolant are the first priorities in overcoming these problems.

The difficult machinability properties of titanium limit the use of traditional metalworking fluids in the processing of these alloys, and therefore special processing fluids need to be developed in the processing of these types of alloys. The use of metalworking fluids with flood lubrication operations is the most common use in the machining of light alloys (Priarone et al., 2014). However, conventional metalworking fluid formulations used in flood lubrication consist of toxic, non-biodegradable, unsustainable and environmentally harmful petroleum-derived products based on mineral oil as base oil. In line with the increasing demand for the use of light alloys in the aerospace, automotive and medical sectors, the environmental and health risks caused by flood lubrication, which is widely used in the processing of these alloys, and the demand for reducing the cost factor have increased the interest in research on the development of more economical and environmentally friendly production technologies. Another reason for the need to develop new products and technologies in the machining of light alloys is the need to produce alternative lubricants that can ensure sustainability due to the depletion of petroleum reserves (Kavut et al., 2022). There are various sustainable feedstocks to produce bio-lubricants. Highly unsaturated or high oleic vegetable oils (HOVOs), low viscosity polyalphaolefins (PAOs), polyalkylene glycols (PAGs), dibasic acid esters (DEs) and polyol esters (PEs) are categories of biodegradable base oils (Nagendramma & Kaul, 2012).

Vegetable oils which have large market share for biolubricants, are abundant and non-toxic feedstocks. They exhibit higher lubricity, higher flash point, lower volatility, and higher viscosity index than mineral oils. Presence of long chain fatty acid and polar groups in the structure of vegetable oil make them suitable for both boundary and hydrodynamic lubrications. Besides their advantages, they have low oxidation stability and their low temperature properties are poor. Thus, they can easily polymerize in the harsh working condition. This situation limits their industrial application (Wickramasinghe et al., 2021). Low viscosity biodegradable polyalphaolefins (PAOs) are another alternative for environmentally friendly lubricants and can be defined as low molecular dimers to tetramers. While low molecular weight causes undesirable high volatility for these fluids, it becomes an advantage at low temperatures where PAOs perform excellently. The absence of polarity of PAOs cause to problems of additive acceptability, but this results in excellent hydrolytic stability. Since PAOs have no double bonds or other reactive functional groups in their structure, oxidative stability of PAO with antioxidant additive is competitive to petroleum-based products. PAOs are finding increasing use as hydraulic and engine oils, especially in cold climate applications and where hydraulic pressures increase, as they are an attractive option for converting biodegradable lubricants to water in low temperature applications. PAOs are also used as gear lubricants because of their ability to provide lower operating temperatures and lower coefficients of friction, which helps reduce wear.

On the contrary of PAOs, polyalkylene glycols (PAGs) have high polarity as they have alternating ether linkages rather than essentially having a hydrocarbon backbone. However, they can be easily contaminated with moisture, resulting in increased solubility in water, which is detrimental for many lubricant applications. The solubility problem of organic additives in PAGs and the incompatibility of PAGs with conventional petroleum-based lubricants are often problematic for this species. For biodegradable PAGs usage, fire resistant fluids are often the best option. The high molecular weight of diesters makes volatility problems negligible and ester bonds provide high solubility power. Branching in alcohol fragments results in very good low temperature performance, but diesters score poorly in final biodegradability tests. For this species, ester linkages are not sterically hindered to restrict hydrolytic decomposition. Diesters find use in biodegradable hydraulic fluids with long drain intervals, compressor oils turbine oils, and are mixed with PAOs in some synthetic lubricants. Diester fluids have outstanding solubility and cleaning ability. Because of these properties, it can have a negative effect on certain varnish or paint surfaces. This limits the use of dibasic acid esters. The most main area where dibasic acid esters find use is paint and coating applications.

At last, but not least, PEs are effective feedstocks. They consist of fatty acids attached to an alcohol and hydrogen atom on the β-carbon atom does not exist in their backbone. PEs are used as environmentally acceptable base fluids in high performance lubricants. PEs have found application in many lubricants due to its very good low temperature behavior, high thermo-oxidative stability of some types, very high viscosity index, good anti-wear and low evaporation properties. The physico-chemical characteristics of PEs indicate that the properties are matching with the conventional base stocks. The development of new synthetic-based base fluids to meet the needs of high-performance lubricants is increasing day by day. As a result, the use of synthetic esters as base fluids has gained great importance in various industrial and military applications. Examples of lubricant types using PEs are engine oils, gear oils, hydraulic oils, compressor oils, pump and turbine oils. Also, PEs are being evaluated for lubricity performance with a view for their application as metal working fluids (Kavut et al, 2022). In addition to the limited number of studies in the literature on comparing the metal processing behavior of these biodegradable base stocks, this study we will present can provide a very valuable perspective on the literature, considering the abundance of vegetable oils and the advantages of PEs.

There are various performance tests for metal working fluids. Lubricity behavior of metal working fluids can be investigated with Tapping Torque test method. It is a favorable method as bench scale test and combines qualitative and quantitative techniques. Tapping is a metal machining process to cut or form threads in a pre-drilled hole in a metal specimen which can be made of various metals while lubricating the contact zone between tap and hole wall by a metalworking fluid. Finally, a torque value to cut or form a thread is obtained. Smaller torque values indicate better metal working performance (Demmerling, & Söffker, 2020) In this study, metal working performance of vegetable oils and PEs were evaluated with Tapping Torque test method. Ti-6Al-4V alloy was selected as the metal sample to be machined.

In this study, machining performance of the castor and canola oils and trimethylolpropane trioleate (TMPTO) and trimethylolpropane trioleate complex (TMPCX), neopentyl glycol dioleate (NPGDO) and pentaerythritol tetra-oleate (PETO) type PEs on the Ti-6Al-4V alloy were investigated using the Tapping Torque test method.

Method

Materials

In the present study castor and canola oils and TMPTO, TMPCX, NPGDO and PETO type polyol esters were used and their technical properties were given in Table 1. Castor oil and canola oil were supplied from Kim-paş A.Ş and Oleo Kimya, respectively. NPGDO, TMPTO and PETO supplied by Oleon. TMPCX was supplied from Temix Oleo.

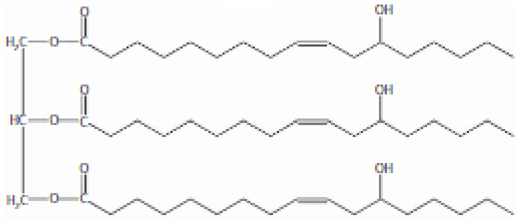
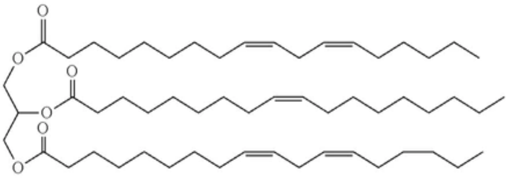
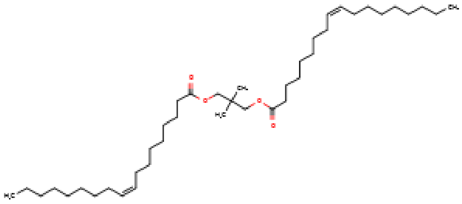
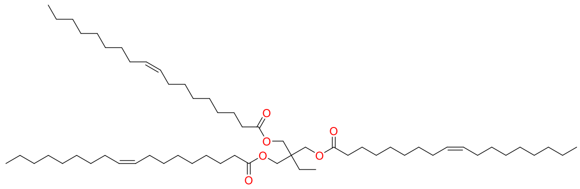
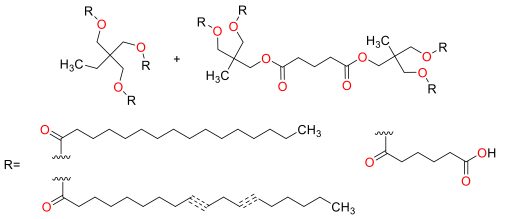
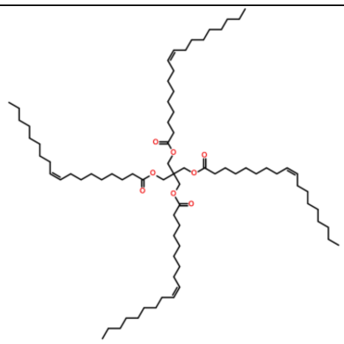
Table 1. Technical properties of used compounds in the study.

Test Parameter	Test Method	Castor Oil	Canola Oil	NPGDO	TMPTO	TMPCX	PETO
Kinematic Viscosity (40℃, cSt)	ASTM D 445	150	46	23	46	70	65
Kinematic Viscosity (100℃, cSt)	ASTM D 445	14.4	10	6	9.2	12.5	14
Viscosity Index	ASTM D 2270	93	212	228	187	180	225
Flash Point (℃)	ASTM D 92	172	≥ 190	≥ 250	≥ 270	300	≥ 280
Pour Point (℃)	ASTM D 97	≤-21	≤-18	≤-18	≤-42	-33	≤-25

Molecular Structure of Compounds

Molecular structure of used compounds in the study was shown in Table 2. Machining performance of castor and canola oils and TMPTO, TMPCX, NPGDO and PETO type polyol esters were investigated by Tapping Torque Test. In Tapping Torque Test, Ti-6Al-4V alloy were used and test was carried out with 5.0 mm depth and 800 rpm.

Table 2. Molecular structure of used compounds in the study.

 CASTOR OIL	 CANOLA OIL
 NPGDO	 TMPTO
 TMPCX	 PETO

Tapping Torque Test

To understand of the machining performance of the neat fluids, a tapping torque test was conducted in Labtap G8 (Microtap, Munich, Germany). Comparison of vegetable oils and PEs using tapping torque testing machine was performed according to ASTM D8288. The material used for the machining was a Ti-6Al-4V alloy with pre-drilled holes as shown in Figure 1. A TTT-Ti6Al4V-M6C tool, size M6 with 69 helical channels per test plate was used for each fluid. Tapping Torque Test was performed using a Titanium Carbonitride (TiCN) coated tip suitable for the operation. The cutting fluid was poured in the holes to lubricate them during the tapping process at 300 rpm, with a 5.0 mm length of thread and each tapping process was repeated 3 times.

Figure 1. Tapping Torque Test System

Figure 2 shows the tapping process graphically where: (a) shows the beginning of the forming; (b) indicates the torque increasing and the tool penetrating the workpiece as a result of increasing contact surface between the workpiece and the tool; (c) implies the tool forming with all its chamber teeth until the length's thread is achieved and (d) indicates the beginning of the reversal of the forming tap to bring the tool to the initial position. Consequently, the forming performance results of the fluids were determined averaging the tapping torque values (N·cm) in the 0 to 14,4 mm range of form.

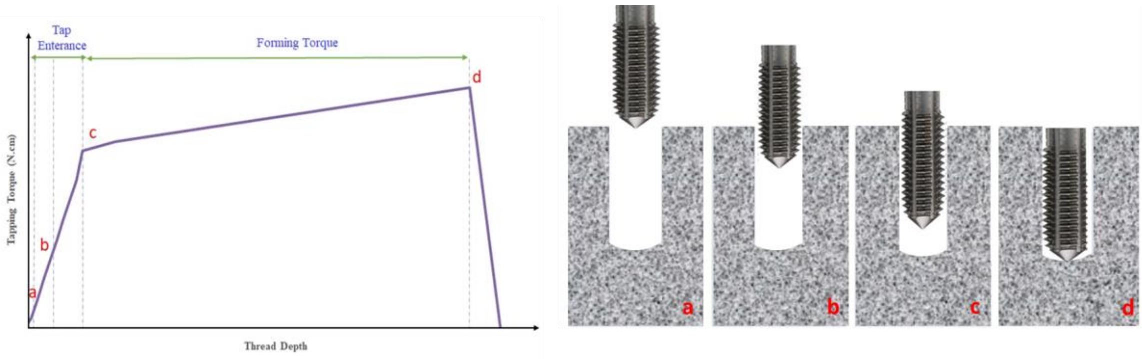


Figure 2. Graphical illustration of the tapping process and different positions of the tap during working. (a) beginning of the forming, (b) tool penetrating on workpiece, (c) teeth entering the chamber completely and (d) beginning of the reversal of the forming tap.

Results

Tapping torque test results of samples on Ti-6AL-4V series were shown in Table 3. In addition, torque graphs were obtained against the depth of cut applied to each sample, as shown in Figure 3 to Figure 8. Even a small difference observed in the torque value in the Ti-6AL-4V Tapping torque test is quite significant. It was determined that TMPTO exhibited the best machining performance on Ti-6Al-4V alloy, and the measured torque values of TMPCX and PETO were close to TMPTO. The measured torque value of castor oil was found to be close to TMPCX and PETO, but much worse than TMPTO. Canola oil was giving the most dramatic processing performance result.

Table 3. Tapping torque test results of neat fluids on Ti-6AL-4V alloy.

Test plate	Test Method	Castor Oil	Canola Oil	NPGDO	TMPTO	TMPCX	PETO
Ti-6Al-4V (300 rpm, d 5mm) (Nm)	ASTM D8288	149,9	152,8	187,1	146,5	147,4	148,2

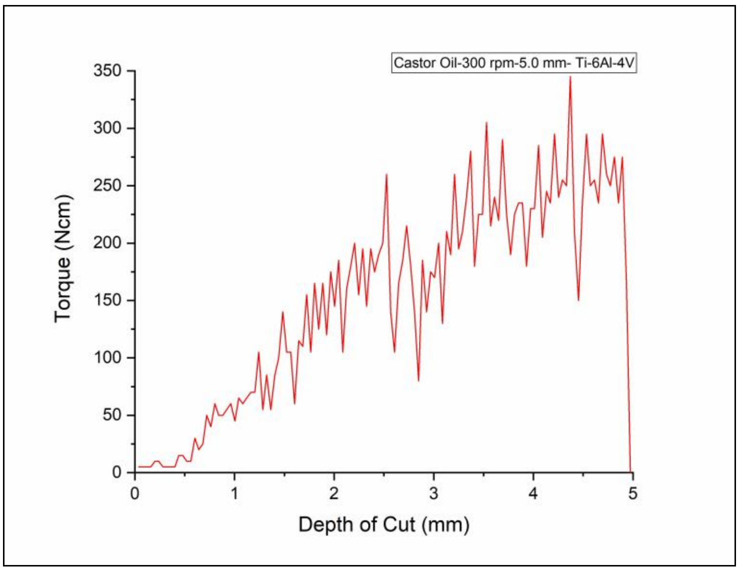


Figure 3. Tapping performance graphs of Castor Oil on Ti-6AL-4V.

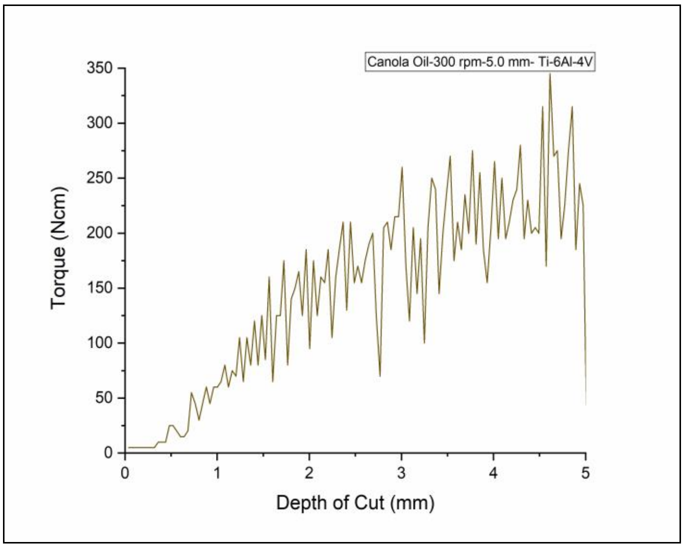


Figure 4. Tapping performance graphs of Canola Oil on Ti-6AL-4V.

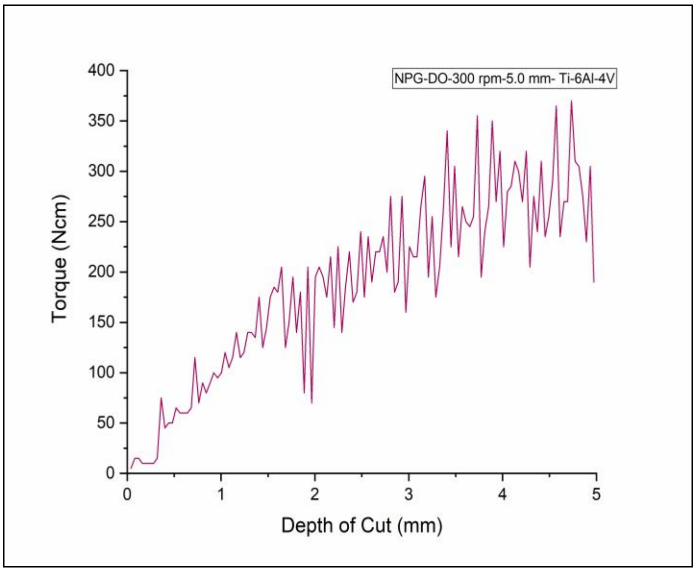


Figure 5. Tapping performance graphs of NPGDO on Ti-6AL-4V.

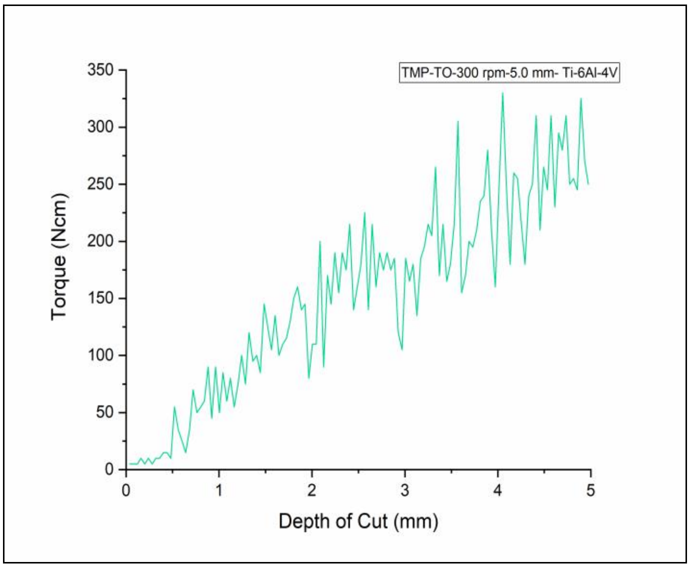


Figure 6. Tapping performance graphs of TMPTO on Ti-6AL-4V.

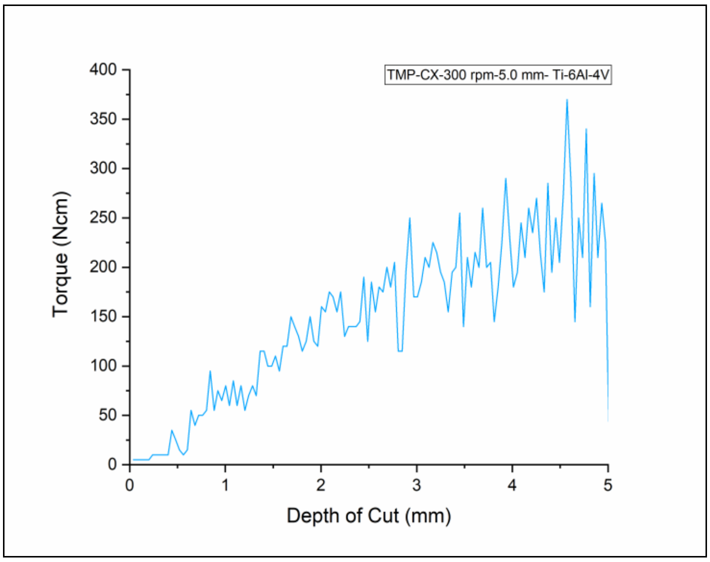


Figure 7. Tapping performance graphs of TMPCX on Ti-6AL-4V.

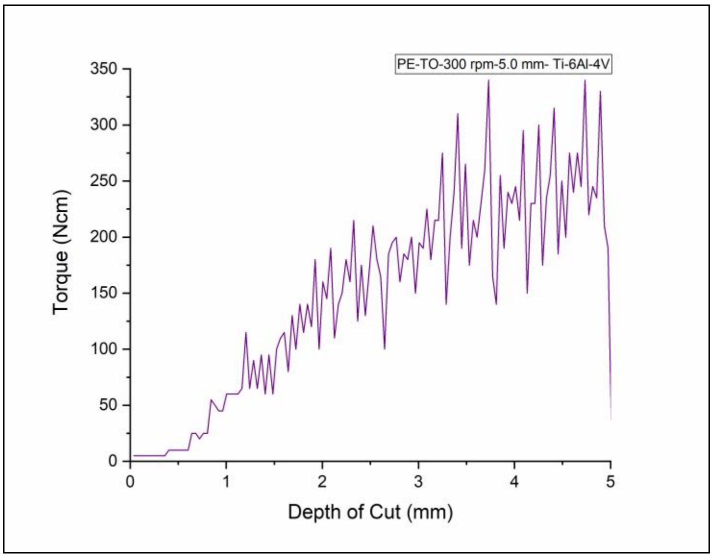


Figure 8. Tapping performance graphs of PETO on Ti-6AL-4V.

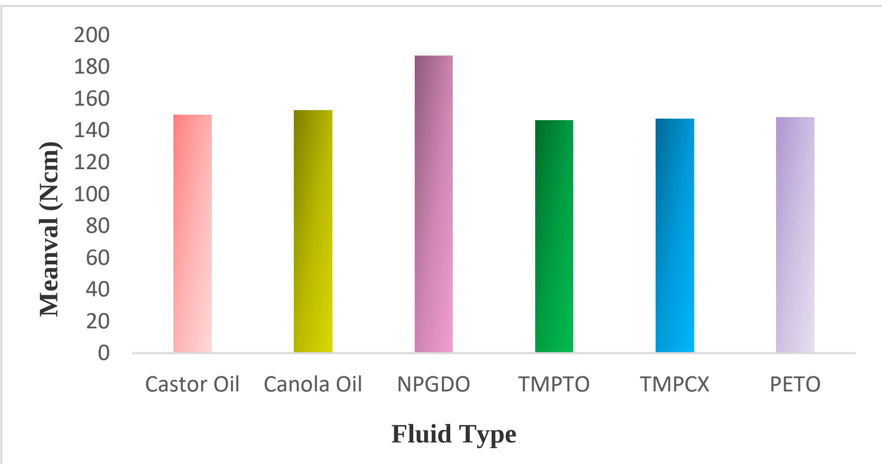


Figure 9. Tapping performance graphs of vegetable oils and esters on Ti-6Al-4V.

Conclusion

Machining performance of castor and canola oils and TMPTO and TMPCX, NPGDO and PETO type polyol esters were investigated by Tapping Torque Test on Ti-6Al-4V type titanium alloy. It was determined that TMPTO exhibited the best processing performance and NPGDO showed the worst performance machining performance on the Ti-6Al-4V. Samples was found as follows from best to worst:

TMPTO > TMPCX > PETO > Castor Oil > Canola oil > NPGDO.

Tapping torque test result graphs for neat liquids performed on the Ti-6Al-4V 1 are shown in Figure 9. Based on the above results, the following inferences can be drawn:

1. Since vegetable oils lack the oxidation stability, extreme pressure and anti-wear properties required to meet the demanding machining requirements of the Ti-6Al-4V alloy, as a result of the tests carried out on this alloy, the metal processing performance of both vegetable oils was determined to be quite low torque values compared to polyol esters.
2. The molecular structure of esters has a high impact on the conformation of the lubricant film, and increasing the ratio of esters in the lubricant film increases tribological performance. When the study was evaluated specifically for polyol esters, processing performance improved by increasing the ester parts on the molecule, resulting in stronger adsorption on the metal surface.
3. In the tests carried out on Ti-6Al-4V, TMPTO showed the best metal processing performance because it formed the highest lubricating film on the metal surface and therefore its lubricating effect was better than other polyol esters.
4. NPGDO exhibited the lowest adhesion ability to the Ti6Al4V surface among the tested vegetable oil and polyol esters, could not remove the heat generated on the tool and workpiece surface during operation, and exhibited the lowest metal processing performance with the highest torque value.
5. TMPCX and PETO similarly exhibited very good but relatively lower lubricity than TMPTO. This corresponds to a lower metal processing performance than TMPTO but very good compared to vegetable oils.
6. The results in this study indicate that oleate-type polyol esters, excluding NPGDO, have significant potential to be used as a sustainable and environmentally friendly alternative to mineral oil-based cutting fluids in machining operations of Ti-6Al-4V alloy.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 16-19, 2023.

* This study was carried out within the scope of the project labeled ARISEN, coded S0411 and financially supported by SMART Eureka.

References

Ahmed, W., Elhissi, A., & Jackson, M.J. (2012). The design and manufacture of medical devices. In *Precision Machining of Medical Devices* (pp. 59–113), Elsiever.

Biesiekierski, A., Munir, K., Li, Y., & Wen, C. (2021). Titanium alloys. In *Structural Biomaterials Properties, Characteristics and Selection* (pp.157-158). Woodhead Publishing Series in Biomaterials

Cui, C., Hu, B., Zhao, L., & Liu, S. (2011). Titanium alloy production technology, market prospects and industry development. *Materials and Design, 32*(3), 1684–1691.

Demmerling, A., & Soffker, D. (2020). Improved examination and test procedure of tapping torque tests according to ASTM D5619 using coated forming taps and water-mixed metalworking fluids. *Tribology International, 145*. 106151.

Inagaki, I., Takechi, T., Shirai Y., & Ariyasu, N. (2014*) Application and features of titanium for the aerospace industry.* Nippon Steel & Sumitomo Metal Technical Report No. 106. Retrieved from https://www.nipponsteel.com/en/tech/report/nssmc/pdf/106-05.pdf

Kavut, K., Tom, H.G., & Ozpercin, T. (2022). Comparison of the effects of vegetable oils such as castor and canola oil and polyol esters on the metalworking performance of Al 6061 and Al 7075 metal alloys by Tapping Torque method. *The Eurasia Proceedings of Science Technology Engineering and Mathematics*, (21), 248 – 257.

Nagendramma, P., & Kaul, S. (2012). Development of ecofriendly/biodegradable lubricants: An overview. *Renewable and Sustainable Energy Reviews*, *16*(1), 764-774.

Priarone, P. C., Robiglio, M., Settineri, L., & Tebaldo, V. (2014), Milling and turning of titanium aluminides by using minimum quantity lubrication, *Procedia CIRP*, *24,* 62–67.

Roy,S., Kumar, R.A., Sahoo A.K., & Das, R. K. (2018). A brief review on machining of Ti-6Al-4V under different cooling environments. *IOP Conf. Series: Materials Science and Engineering*, *455*(1).

Author Information

Kubra Kavut
Marmara University, Maltepe-Istanbul, Turkey,
Belgin Oil R&D Center Gebze-Kocaeli, Turkey
Contact e-mail: kubra.kavut@belginoil.com

Hanife Gulen -Tom
Belgin Oil R&D Center
Gebze -Kocaeli, Turkey

Tugçe Ozpercin
Belgin Oil R&D Center
Gebze-Kocaeli, Turkey

To cite this article:

Kavut, K., Gulen-Tom, H., & Ozpercin, T. (2023). Comparison of the effects of vegetable oils such as castor and canola oil and polyol esters on the metalworking performance of Ti-6Al-4V alloy by tapping torque method. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 26,* 395-403.