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Grape seed oil as a sustainable cutting fluid in minimum quantity lubrication (MQL) for enhanced surface roughness and corrosion resistance in 316L stainless steel face milling

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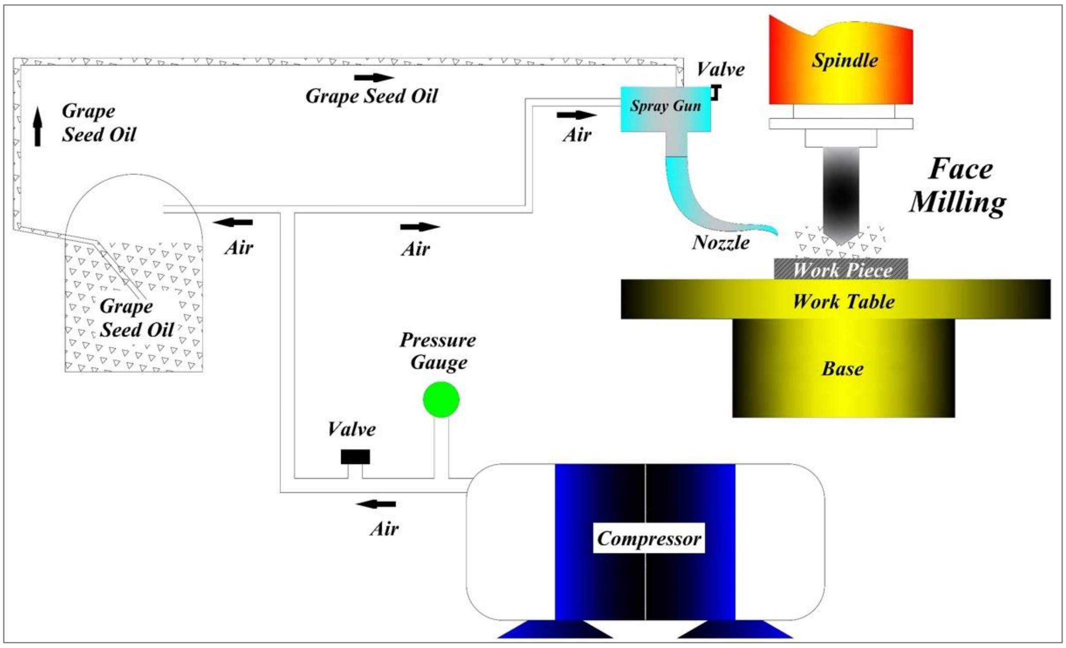

Highlights:

- First-time application of grape seed oil in MQL machining of 316L stainless steel.
- Surface roughness reduced by up to 61.6% compared to dry machining.
- Corrosion rates decreased by up to 80.8% across all spindle speeds.
- Grape seed oil proven as an effective, eco-friendly cutting fluid.

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Abstract

This work investigates grape seed oil as a green substitute for conventional mineral-based cutting fluids to reach sustainable manufacturing methods. The application of grape seed oil as a cutting fluid in the machining of 316L stainless steel using the MQL method has not been documented in prior research studies. In this work, the study focuses on determining the effect of the grape seed oil on the surface integrity and comparing these findings to standard dry machining conditions by examining surface topography, roughness, and corrosion resistance at three different spindle speeds (1500, 1800, and 2100 rpm). Results of experiments showed that grape seed oil greatly improved surface quality and corrosion resistance. Surface roughness dropped noticeably by 61.6% at 1500 rpm as opposed to dry machining. Likewise, changes in surface roughness noted were 54.0% at 1800 rpm and 54.9% at 2100 rpm. Furthermore, the potentiodynamic polarization data show that the grape seed oil greatly prevents post-machining corrosion of 316 L stainless steel. The corrosion rates of the material face milled using grape seed oil were decreased by 78.6%, 74.6%, and 80.8% at spindle speeds of 1500, 1800, and 2100 rpm, respectively, when compared with dry face milling. These results indicate that grape seed oil demonstrates its ability as a cutting fluid even for high-speed machining operations. Hence, grape seed oil can address industrial demands for more environmentally friendly manufacturing methods.

Keywords: Grape seed oil; Natural cutting fluid; Stainless steel 316L; Surface roughness; Corrosion

1. Introduction

Cost effective manufacturing is a necessity for survival in today's highly competitive world with substandard product quality. Concerning to be competitive, a business must consider cost-effective production. To achieve competitive pricing, high-speed manufacturing is required, which can be achieved by increasing the cutting speed, feeding speed, and cutting depth [1], [2]. However, it will provoke some disadvantages, e.g., increasing the heat generated [3], degrading product quality [4], and reducing the tool's life [5]. On the other hand, the development of cutting fluid has gained significance to overcome this problem. Recently, cutting fluid has become a critical instrument for increasing product quality [6], [7]. In the machining process, cutting fluids are primarily used to reduce cutting temperature and friction wear via lubrication or cooling [8], [9].

The cutting fluid is applied to the tool-chip interface and the tool-work piece interface, removing heat from the work piece and cutting zone, as well as removing chips from the region [10], [11]. As people become more aware of the importance of environmentally friendly manufacturing, industries are working harder to reduce their reliance on cutting fluids. To decrease the dependence on mineral-based cutting fluid, dry machining has become the conventional alternative [12]. This technique has garnered significant attention in recent years for its potential to reduce environmental impact and enhance operational efficiency in various manufacturing processes [13]. Dry machining, on the other hand, implies more friction and adhesion between the workpiece and the tool contact led to coarse abrasion, diffusion, and oxidation occur concurrently, putting stress on the workpiece and the tool [14], [15]. Several studies have also demonstrated that an improper lubrication procedure will not make the surface smooth but will increase surface roughness and cause scar mark on the surface [16].

Researchers also have developed solid lubricants for lubrication and cooling in their study [17], [18], however, recently they have shifted their focus to the environmentally benign Minimum Quantity Lubricant (MQL) method, which keeps using liquid cutting fluid but requires much less coolant quantity [19], [20]. In the MQL process, the oil and compressed air are delivered to the ejector nozzle, and the aerosol is produced immediately after the nozzle. These aerosols are injected directly into the tool-workpiece contact and provide optimal lubrication while using the least amount of cutting fluid possible. Hence, instead of using a flood coolant, which needs a significant quantity of cutting fluid, MQL requires just a few milliliters (ml) of cutting fluid per hour for the machining operation in the MQL process [21].

Mineral-based lubricants are the most widely used cutting fluids on the market today. This is partially attributable to the fact that the petroleum sector has such a dominant position [22]. But these mineral-based lubricants are considered pollutants because they emit significant amounts of carbon monoxide (CO) and sulfur dioxide (SO_2), all of which have a detrimental impact on the quality of the environment. A side from that, most of these mineral-based lubricants are not biodegradable at least in 7 years [23]. The result may be pollution of waterways and other environmental issues [24], [25]. Several studies have also shown that mineral-based lubricants are harmful to operators. The International Agency for Cancer Research (IRAC) has stated that although raw materials may be safe, petroleum-based cutting fluids containing heterocyclic and polyaromatic rings are carcinogenic and can cause skin cancer [26], [27]. Consequently, the use of natural-based cutting fluids has gained significant attention in recent years.

The increasing interest in natural-based cutting fluids has emerged from their favorable properties and the growing emphasis on environmental sustainability in manufacturing processes. Various studies highlight that natural base fluids, particularly vegetable oils, have shown significant advantages over traditional mineral oil-based cutting fluids in terms of lubricity, biodegradability, and overall performance in metal cutting operations. Vegetable oils such as coconut, soybean, and palm oils are being recognized for their superior thermal and tribological properties. For instance, Suvin *et al*. demonstrated that cutting fluids containing coconut oil exhibit enhanced lubricity compared to mineral-based alternatives, attributed to the tribofilm formed during machining [28]. This property is crucial in reducing tool wear and heat generation, thereby improving machining efficiency [29]. Additionally, Jeevan and Jayaram emphasized the effectiveness of Jatropha and

Pongamia oil-based cutting fluids, which not only improve tool life and surface quality but also contribute to better chip management during turning operations [30]. The shift towards environmentally friendly options correlates with an increasing number of studies illustrating the detrimental effects of conventional mineral oils on health and the environment. Tumba discusses how the environmental persistence and toxicity of mineral oils lead to increasing regulatory scrutiny, pushing the industry towards more sustainable solutions [31]. Research indicates that vegetable-based cutting fluids are easier to dispose of and do not contribute significantly to ecological damage, making them preferable in modern machining scenarios [32], [33]. Furthermore, contemporary regulations on chemical exposure in workplaces are steering manufacturers away from potentially harmful substances [34].

Moreover, the integration of natural-based fluids into machining processes has been linked to enhanced performance metrics such as surface finish and operational efficiency due to their natural properties that facilitate cooling and lubrication [35], [36]. A study by Ghuge and Mahalle corroborates this observation, showing that natural cutting fluids can significantly enhance tool life and productivity while aligning with sustainable manufacturing practices [37].

Studies like those conducted by Singh *et al*. and Katam *et al*. also highlight recent advancements in bio-lubricant formulations capable of matching or exceeding the performance metrics of traditional cutting fluids under various machining conditions [38]. The application of Minimum Quantity Lubrication (MQL) techniques further complements this trend, reducing fluid consumption and minimizing waste while still leveraging the benefits of natural oils [39], [40]. The study shows that most of them use the flood method instead of MQL to compare the effectiveness of this natural-base cutting fluid.

Natural base cutting fluid has distinctive properties that depend on the source from which the oil was extracted. Numerous studies have been conducted on natural-base cutting fluid; however, it did not find any studies related to the use of grape oil in cutting fluid. To justify grape seed oil's use as a cutting fluid, its effect on the surface of the material face milled using this oil needs to be confirmed. In particular, no prior research has investigated the effect of this natural-based cutting fluid on the corrosion properties of face-milled workpieces. Corrosion deserves special attention in manufacturing due to its effect on the degradation of material quality [41], [42], [43]. This study aims to reveal the effect of grape seed oil as a natural base cutting fluid combined with the MQL lubrication system in the face milling process on stainless steel 316L surface properties. Meanwhile, the objective is to determine the ability of grape seed oil to be a cutting fluid in the MQL system during face milling processes at various spindle speeds on surface topography, surface roughness, and corrosion characteristics of stainless steel 316L.

Stainless steel 316L is often used in medical equipment and tools due to its competitiveness, not only in terms of properties like excellent modulus of elasticity and corrosion resistance but also in terms of price. Meanwhile, corrosion properties are one of the most important properties in medical applications because they are directly related to biocompatibility.

2. Materials and Method

This experiment uses AISI 316L stainless steel plate having the following chemical properties (in weight percent): 0.03 C, 16.69 Cr, 10.57 Ni, 2.39 Mo, 1.74 Mn, 0.67 Si, 0.34 Cu, and balanced Fe. Meanwhile, the grape seed oil properties are shown in **Table 1**.

The 316L stainless steel plate is sheared into the 10 x 200 mm size and face milled with a head tool with a size of 6 mm. Prior to the face milling process, the samples were annealed at 1100 °C and cooled at room temperature to relieve residual stresses induced during manufacturing. The samples then polished with silica paper to determine the homogeneity of the surface. The face milling is done using the dry technique (without lubrication) and the MQL lubrication method. The face milling process was conducted using a HAAS VF-2 series machine, equipped with a down milling setup and an MQL system. The MQL system diagram is shown in **Figure 1**.

The cutting tools used carbide end mills as tools which is supplied by Nachi VG. The specification of the cutting tools is shown in **Table 2**. The lubrication rate in this study was set at 100 ml/hour, and the face milling processes were performed with 3 variants of spindle speed (1500 rpm, 1800 rpm, and 2100 rpm) both with and without MQL grape seed oil lubrication at depth of cut 0.5 mm and feeding speed 130 mm/min.

After face milling, the material is then tested for surface roughness, corrosion, and macro photos. Moreover, a scanning electron microscope (SEM) was used in order to observe the incision marks left by the face milling procedure as well as the specimen following corrosion using a Quanta

Table 1. Grape seed oil viscosity and flash point

Properties	Value
Viscosity	12,423 cSt at T 40 °C and t = 55.87 s
Flash point	190 °C

Table 2. Tools specification

Specification	Value
Material	Carbon carbide
Number of flutes	2
Cutting diameter	6 mm
Length of cut	20 mm

Table 3. Properties of HBSS

Constituent	Composition (g/L)
NaCl	8.0
KCl	0.4
$NaHCO_3$	0.35
NaH_2PO_4,H_2O	0.25
$Na_2HPO_4,2H_2O$	0.06
$CaCl_2, 2H_2O$	0.19
$MgCl_2$	0.19
$MgSO_4, 7H_2O$	0.06
Glucose	0.06

FEG 650 in the United States. The values of surface roughness (Ra) are obtained by the roughness tester using the Mitutoyo SJ301 machine made in Japan. Meanwhile, corrosion properties were carried out using the Palmsense 4 potentiostate machine made in the Netherlands under almost steady-state conditions (dE/dt = 1 mV/s) utilizing Ag/AgCl as reference electrodes and Pt as counter electrodes. This corrosion test was done in Hanks' Balanced Salt Solution (HBSS) solution with pH 6.9 supplied by Sigma Aldric, United States. The chemical composition of HBSS is shown in **Table 3**. This test was conducted at room temperature.

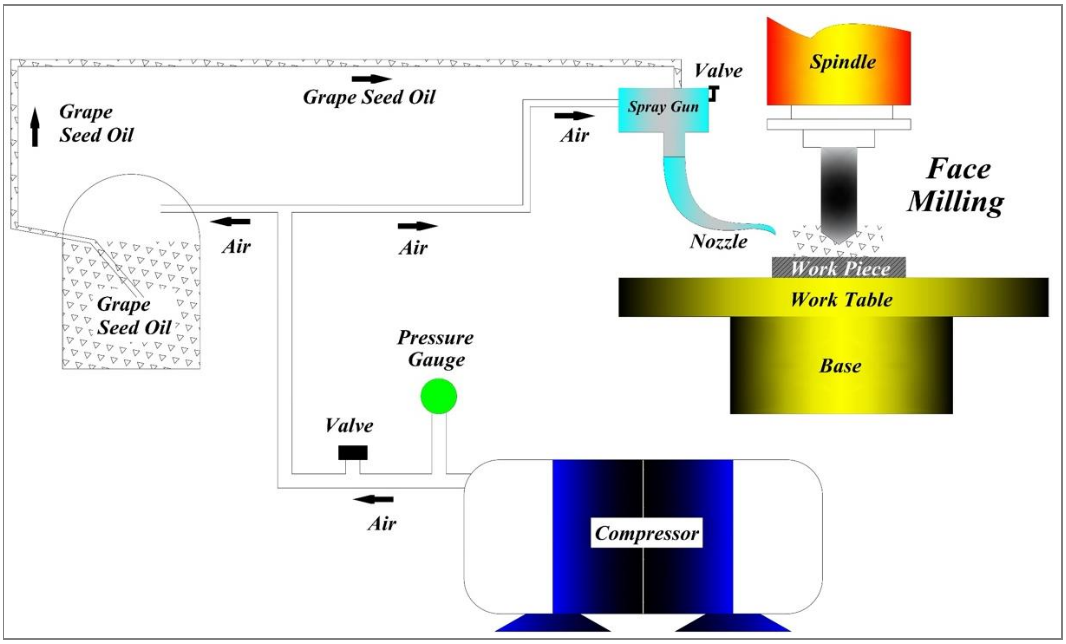

Figure 1. MQL system design used in this study

3. Results

3.1. Surface Roughness

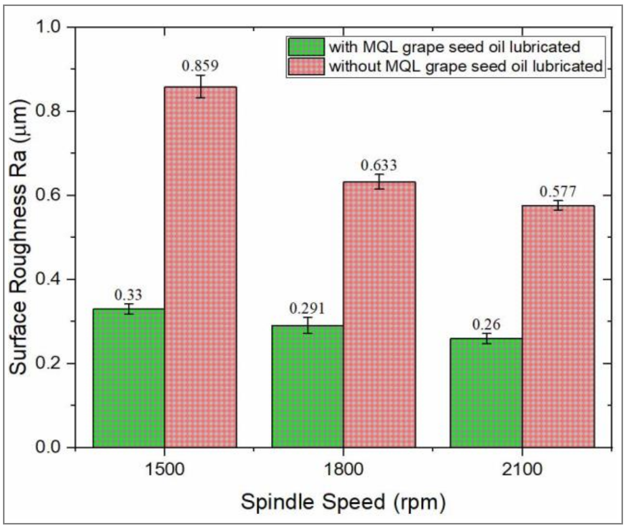

Figure 2. Surface roughness (Ra) of face milled 316L stainless steel at various spindle speed

Figure 2 shows surface roughness test with Mitutoyo SJ 301 Machine. The roughness test showed that the surface roughness got smoother as the face milling speed went up, whether the process was done dry or with grape seed oil cutting fluid. Additionally, because the surface roughness of specimens that were cut with grape seed oil cutting fluid was reduced at all speeds when compared to specimens that were cut without grape seed oil (dry), it may be hypothesized that grape seed oil can serve as a cutting fluid at high cutting speeds.

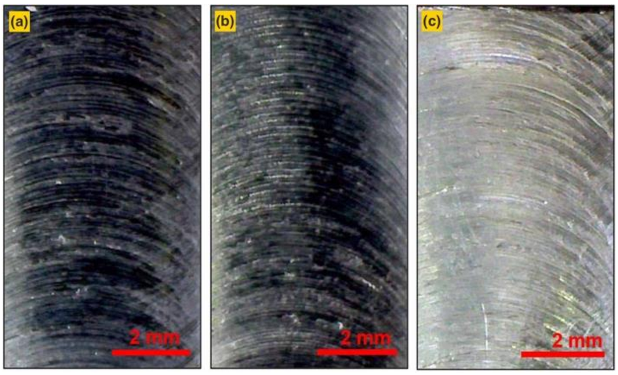

Figure 3. Macrostructures of 316L after face milling process without MQL grape seed oil lubricated: (a) Spindle speed 1500 rpm; (b) Spindle speed 1800 rpm; (c) Spindle speed 2100 rpm

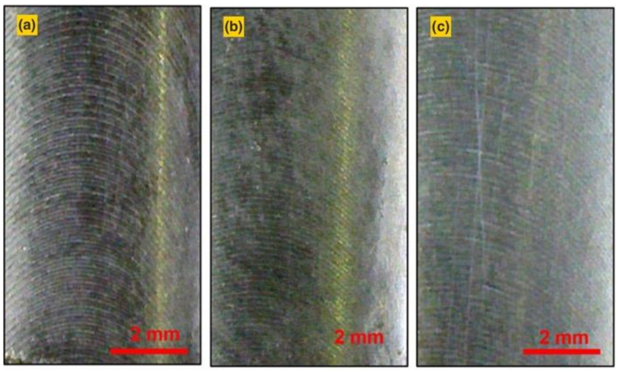

Figure 4. Macrostructures of 316L after face milling process with MQL grape seed oil lubricated: (a) Spindle speed 1500 rpm; (b) Spindle speed 1800 rpm; (c) Spindle speed 2100 rpm

The maximum degree of surface roughness is found at 1500 rpm, while the lowest value is found at 2100 rpm. In detail, the results show that at 1500 rpm, the roughness decreased from 0.85 mm without grape seed oil to 0.33 mm with grape seed oil. Similarly, at 1800 rpm and 2100 rpm, the values decreased from 0.633 to 0.291 and 0.577 to 0.26 µm, respectively.

Figure 3 and **Figure 4** show a macro picture of the surface of stainless steel 316L that has been subjected to a face milling process prior to the corrosion process, with and without the use of MQL grape seed oil cutting fluid, respectively. It can be seen that as the spindle speed increases, the more unclear the scar of the cutting mark becomes, both with and without MQL grape seed oil cutting fluid. It is reasonable to assume that as speed increases, the surface roughness is reduced. The most ambiguous mark occurs at 2100 rpm, both with and without grape seed cutting fluid (**Figure 3c** and **Figure 4c**). However, it can be observed that the use of grape seed oil greatly affects the results of the face milling process at each spindle speed. It can be seen that there is a significant change in the cutting marks after the machining processes use grape seed oil at all the spindle speeds (1500, 1800, and 2100) when compared to the face milling process before using grape seed oil. The cut marks on the surface of 316L stainless steel which uses grape seed oil are increasingly fading, this shows that the surface of 316 can be machined well.

3.2. Corrosion Properties

Figure 5 and **Figure 6** show corrosion marks on the sample surface after potentiodynamic polarization test was conducted. It can be observed that the dots are clearly visible on both samples processed with and without grape seed cutting fluid at 1500 and 1800 rpm. However, at a speed of 2100 rpm, the corrosion marks on the specimens can be seen clearly only in the specimens that have not been cut with grape seed oil. Meanwhile, in the specimens lubricated with grape seed oil, the corrosion spots are hardly visible. It is also clear that the dot is less visible on specimens milled with grape seed oil at all spindle speeds.

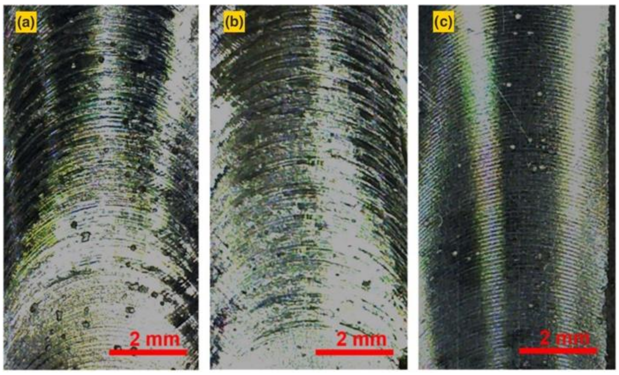

Figure 5. The 316L surface after corrosion (face milling process without cutting fluid): (a) Spindle speed 1500 rpm; (b) Spindle speed 1800 rpm; (c) Spindle speed 2100 rpm

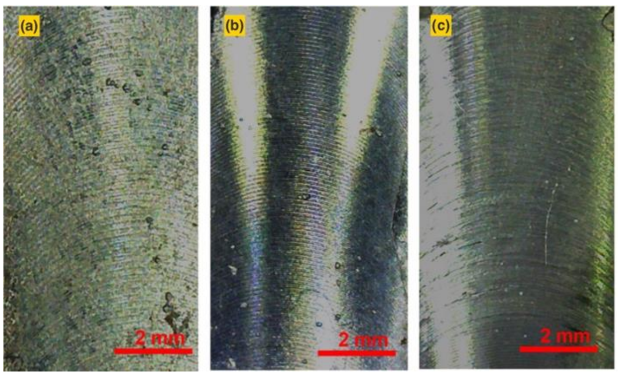

Figure 6. The 316L surface after corrosion (face milling process with cutting fluid): (a) Spindle speed 1500 rpm; (b) Spindle speed 1800 rpm; (c) Spindle speed 2100 rpm

Corrosion properties were also verified by potentiodynamic polarization findings, as shown in **Figure 7**. The polarization graph shows that when specimens are exposed to face milling with MQL grape seed oil cutting fluid, the corrosion potential for all spindle speed parameters, as well as the transpassive potential, changes to noble. The noble corrosion potential provides a critical metric for predicting and controlling corrosion

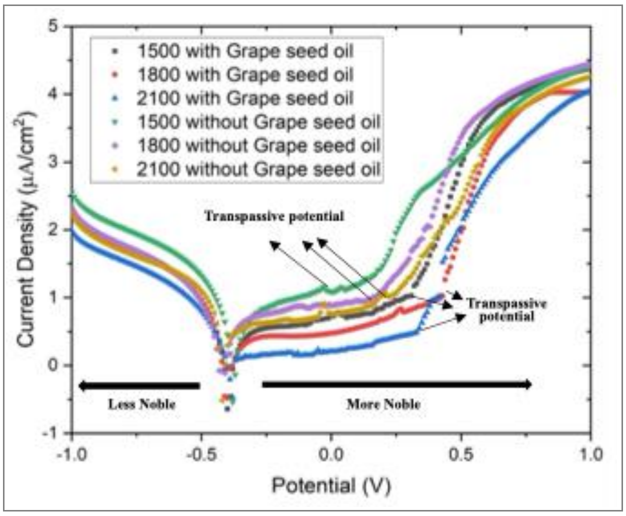

Figure 7. Potentiodynamic polarization data of face milled 316L stainless steel

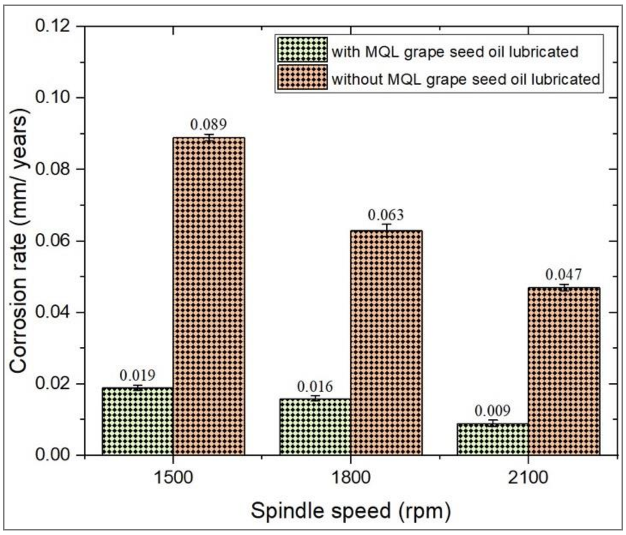

Figure 8. Corrosion rate of 316L stainless steel at various spindle speed

behavior in practical engineering and materials selection. Metals or alloys with more noble potential inherently offer better corrosion resistance and stability in various aggressive environments.

Meanwhile, as shown in **Figure 8**, the corrosion rate reduces when specimens are machined using grape seed oil compared to when specimens are cut without using it at all spindle speeds. The corrosion rate tends to decrease as spindle speed increases. The lowest corrosion rate, $9x10^{-3}$ mm/year, was obtained by face milling specimens with vegetable oil at a spindle speed of 2100 rpm. On the other hand, the material that was face milled at a speed of 1500 rpm without using grape seed oil cutting fluid shows the highest corrosion rate of $89x10^{-3}$ mm/year.

4. Discussion

The findings of this study indicate that the use of grape seed oil in the face milling process can reduce the corrosion rate of 316L stainless steel when compared to the dry face milling process at all spindle speed variations. When face milling at 2100 rpm with a cutting fluid, the rate of corrosion decreases the most. This indicates that grape seed oil can continue to serve as a cutting fluid even at high velocities. The decrease in corrosion rate because the process of using a cutting fluid reduces the surface scar of the specimen, as depicted in **Figure 4**, will influence the corrosion rate value, as depicted in **Figure 8**. Moreover, surface roughness test of the specimens shows that the specimens which were face milled with MQL grape seed oil at 1500 rpm, 1800 rpm, and 2100 rpm decreased by 61.6%, 54.1%, and 54.93% compare to without using grape seed oil, respectively. It can be interpreted that the lubrication is highly effective not only for lower spindle velocities but also for higher speeds.

The effectiveness of grape seed oil as a cutting fluid also confirms by the Scanning Electron Microscope (SEM) image as show in **Figure 9**. **Figure 9a** and **Figure 9b** depict SEM images of stainless steel 316L faces milled with grape seed oil lubrication, whereas **Figure 9c** and **Figure 9d** depict SEM images of stainless steel 316L faces milled without grape seed oil lubrication. It can be seen the surface sample which face milled using grape seed oil smoother than without using grape seed oil even at spindle speeds 2100 rpm. The SEM results in **Figure 9a** and **Figure 9b** indicate that the deformation lines on the substrate of the material treated with lubricating oil are slightly visible when compared to those treated without lubricating oil **Figure 9c** and **Figure 9d**. Cutting fluid reduces friction between the tool and the substrate's surface, resulting in a smoother surface.

The primary goal of employing a cutting fluid in machining is to reduce the amount of friction, heat, and damage formed during the cutting process. In addition to taking away the heat and chips generated during machining from the cutting zone, it is required to increase tool life and workpiece surface quality. Grape seed oil is able to reduce among of friction and damage that occurs on the sample surface during face milling processes. This is possible because at that speed the grape seed oil has not yet reached the flash point and the viscosity of the grape seed oil is still in the range to become a lubricant. It also supported by the ability of grape seed oil in MQL that could improve the quality of lubrication system. The MQL process provides a good lubrication process where grape seed oil can enter the small gap between the workpiece and the tool so that the friction between the workpiece and the tool is also reduced.

The results of this study also indicate that the value of surface roughness has an impact on the corrosion properties of a substrate's surface. The lower the roughness value, the lower the rate of corrosion. The corrosion testing in the HBSS environment revealed the existence of a pit, which was shown by tiny holes in the damaged region after the corrosion test, as seen in the SEM image in **Figure 10**. It is suspected that the pitting is initiated by the severely deformed surface area as a result of friction between the tool and the substrate. Particularly, it is seen that the utilization of cutting fluids during machining operations leads to a reduced level of deformation compared to instances when cutting fluids are not employed, which consequently leads to a decreasing probability of pitting corrosion occurring on that surface area.

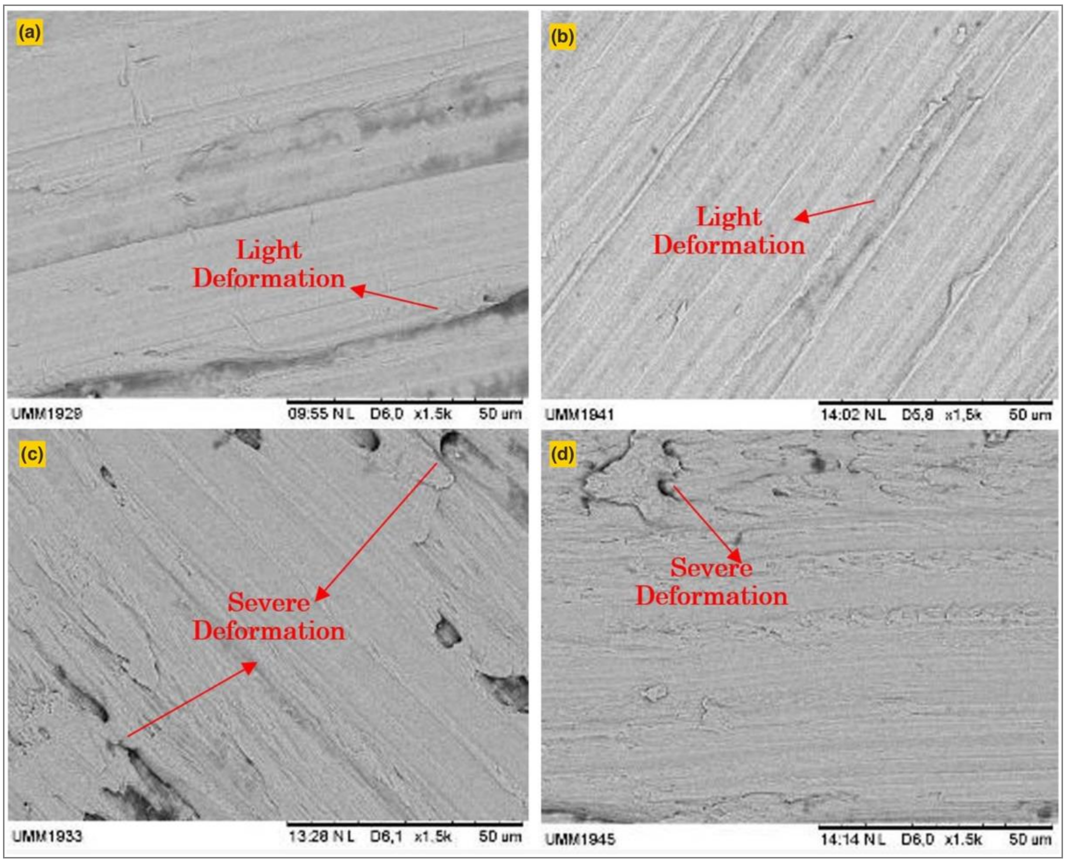

Figure 9. SEM image of face milled stainless AISI 316L before corrosion test: (a) 1500 rpm with grape seed oil; (b) 2100 rpm with grape seed oil; (c) 1500 rpm without grape seed oil; (d) 2100 rpm without grape seed oil

The pit hole of the specimens that were subjected to the face milling process with grape seed oil cutting fluid were brighter as shown in **Figure 10a** and **Figure 10b** than the pit areas of the specimens that were subjected to the face milling process without grape seed oil cutting fluid as shown **Figure 10c** and **Figure 10d**. According to this, specimens treated with grape seed oil cutting fluid had a shallower pit hole compared to those processed without grape seed oil cutting fluid which has deeper pit hole. The observed phenomenon can be attributed to the presence of grape seed oil as a lubricating agent in the machined specimens. In the absence of grape seed oil, the surfaces and sub-surfaces of the specimen exhibited a higher degree of plastic deformation (severe), resulting in corrosion that propagated inward. Conversely, in specimens utilizing grape seed oil, the corrosion manifested as a widening of pits, displaying a slight difference in behavior compared to the former case.

As is well known, the pit is one of the most dangerous sections of the corrosion region because in this location there will be an auto catalytic response termed current (i) that will rise fast as the potential increases, resulting in severe substrate damage. The process of pitting in stainless steel begins with the process of penetrating the passive layer by Cl^{-}ion which then causes a redox reaction process due to metal exposure to the electrolyte due to the damaged passive film. Because the reaction is concentrated at a certain point or area, the reaction is concentrated in that area and causes the area to be severe.

Several researchers have reported that using a cutting fluid (mineral-base cutting fluid) during machining can enhance the surface properties of the material. Researchers report that the use of mineral-based cutting fluid can effectively reduce surface roughness [44], [45]. Additionally, research has been conducted on machining using a natural base, specifically corn oil, which also demonstrates a decrease in surface roughness [46]. The same thing also happened in this research, where surface roughness decreased by using grape seed oil, so grape seed oil was considered to be able to be used as a substitute material for mineral-based cutting fluid. Moreover, corrosion testing shows that 316L stainless steel exhibits improved properties when cutting fluid is used compared to when it is not used.

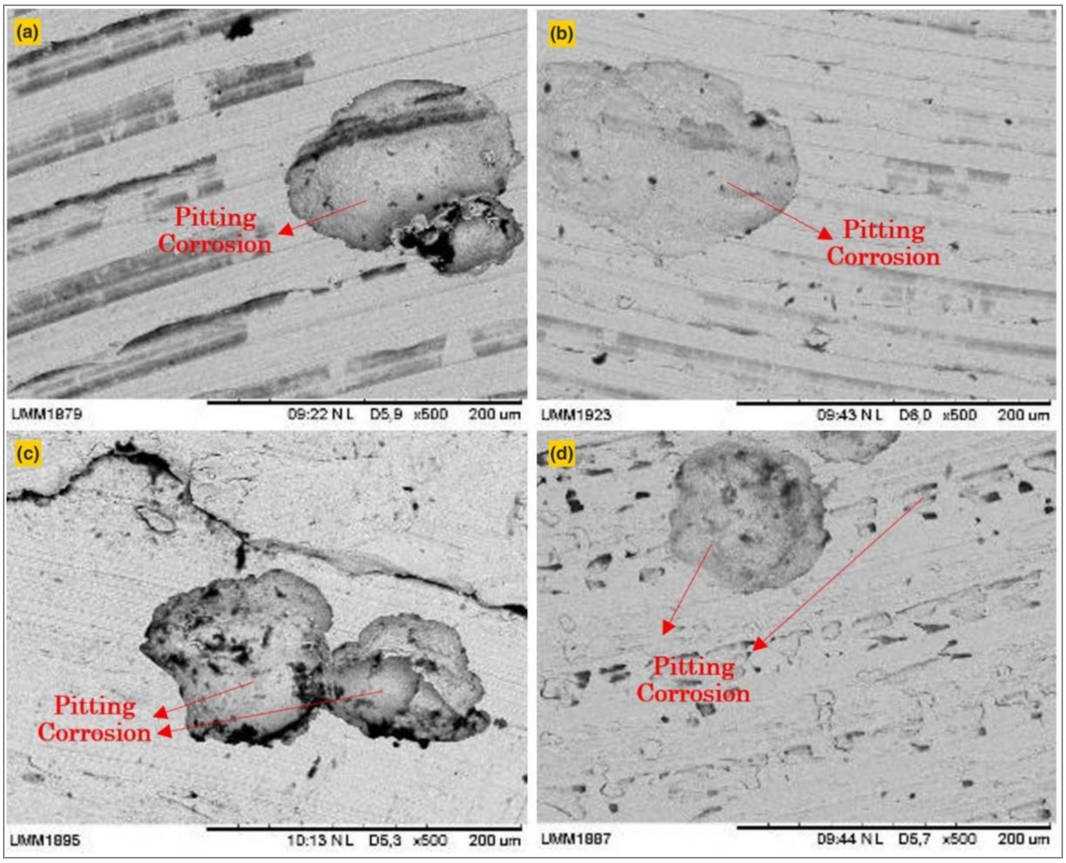

Figure 10. SEM image of face milled stainless AISI 316L after corrosion test: (a) 1500 rpm with grape seed oil; (b) 2100 rpm with grape seed oil; (c) 1500 rpm without grape seed oil; (d) 2100 rpm without grape seed oil

5. Conclusion

From this study, it can be concluded that grape seed oil can be used as lubricating oil in the face milling process from low speed to high speed. This is evidenced by the results of the surface roughness and corrosion rate of the AISI 316L material which decreased after the face milling process using grape seed oil compared to dry method. The application of grape seed oil also show effectively diminish scars on the surface of 316L stainless steel. Furthermore, a deeper examination reveals that grape seed oil also contributes to a reduction in plastic deformation on the 316L surface. Moreover, the pit hole indicate that the pitting corrosion damage observed on materials face milled with grape seed oil is less severe compared to those processed without it.

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Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials - All data is available from the authors.

Competing interests - The authors declare no competing interests.

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References

[1] A. Polishetty and G. Littlefair, “Enhancing post machining surface finish of titanium alloy by cutting parameter optimization using ANOVA analysis,” *The International Journal of Advanced Manufacturing Technology*, vol. 136, no. 1, pp. 187–194, Jan. 2025, doi: 10.1007/s00170-024-13878-0.

[2] M. Zheng, H. Teng, and Y. Wang, “Robust design in material machining on basis of probability multi-objective optimization,” *Materialwissenschaft und Werkstofftechnik*, vol. 54, no. 2, pp. 180–185, Feb. 2023, doi: 10.1002/mawe.202200162.

[3] O. Outemsaa, O. El Farissi, L. Hamouti, and M. Modar, “Cutting Forces and Temperature Optimization in Turning using a Predictive Machining Theory, ANN, and MOGA,” *International Journal of Emerging Technology and Advanced Engineering*, vol. 12, no. 12, pp. 51–60, Dec. 2022, doi: 10.46338/ijetae1222_06.

[4] S. R. Das, A. Kumar, and D. Dhupal, “Experimental investigation on cutting force and surface roughness in machining of hardened AISI 52100 steel using cBN tool,” *International Journal of Machining and Machinability of Materials*, vol. 18, no. 5/6, p. 501, 2016, doi: 10.1504/IJMMM.2016.078997.

[5] L. Xu *et al.*, “Estimation of tool life and cutting burr in high speed milling of the compacted graphite iron by DE based adaptive neuro-fuzzy inference system,” *Mechanical Sciences*, vol. 10, no. 1, pp. 243–254, Jun. 2019, doi: 10.5194/ms-10-243-2019.

[6] S. Pang *et al.*, “Effect of Cutting Fluid on Milled Surface Quality and Tool Life of Aluminum Alloy,” *Materials*, vol. 16, no. 6, p. 2198, Mar. 2023, doi: 10.3390/ma16062198.

[7] P. Yan, Y. Rong, X. Wang, J. Zhu, L. Jiao, and Z. Liang, “Effect of cutting fluid on precision machined surface integrity of heat-resistant stainless steel,” *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 232, no. 9, pp. 1535–1548, Jul. 2018, doi: 10.1177/0954405416673684.

[8] R. K. Singh, A. R. Dixit, A. Mandal, and A. K. Sharma, “Emerging application of nanoparticle-enriched cutting fluid in metal removal processes: a review,” *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 39, no. 11, pp. 4677–4717, Nov. 2017, doi: 10.1007/s40430-017-0839-0.

[9] N.-C. Vu, H.-T. Nguyen, V.-H. Nguyen, Q.-N. Phan, N.-T. Huynh, and X.-P. Dang, “Experimental and Metamodel Based Optimization of Cutting Parameters for Milling Inconel-800 Superalloy Under Nanofluid MQL Condition,” *Mathematical Modelling of Engineering Problems*, vol. 10, no. 1, pp. 189–194, Feb. 2023, doi: 10.18280/mmep.100121.

[10] M. S. Dennison, S. N M, D. Barik, and S. Ponnusamy, “Turning operation of AISI 4340 steel in flooded, near-dry and dry conditions: a comparative study on tool-work interface temperature,” *Mechanics and Mechanical Engineering*, vol. 23, no. 1, pp. 172–182, Jul. 2019, doi: 10.2478/mme-2019-0023.

[11] S. P. Somarajan and S. V. Kailas, “Study and Comparison of Lubricity of Green and Commercial Cutting Fluid Using Tool-Chip Tribometer,” *Tribology Online*, vol. 13, no. 6, pp. 340–350, Dec. 2018, doi: 10.2474/trol.13.340.

[12] J. Singh *et al.*, “State of the art review on the sustainable dry machining of advanced materials for multifaceted engineering applications: progressive advancements and directions for future prospects,” *Materials Research Express*, vol. 9, no. 6, p. 064003, Jun. 2022, doi: 10.1088/2053-1591/ac6fba.

[13] G. S. Goindi and P. Sarkar, “Dry machining: A step towards sustainable machining – Challenges and future directions,” *Journal of Cleaner Production*, vol. 165, pp. 1557–1571, Nov. 2017, doi: 10.1016/j.jclepro.2017.07.235.

[14] L. Pelikán, M. Slaný, L. Beránek, V. Andronov, M. Nečas, and L. Čepová, “Experimental Investigation of Suitable Cutting Conditions of Dry Drilling into High-Strength Structural Steel,” *Materials*, vol. 14, no. 16, p. 4381, Aug. 2021, doi: 10.3390/ma14164381.

[15] A. De Bartolomeis, S. T. Newman, D. Biermann, and A. Shokrani, “State-of-The-Art Cooling

and Lubrication for Machining Inconel 718," *Journal of Manufacturing Science and Engineering*, vol. 143, no. 5, May 2021, doi: 10.1115/1.4047842.

[16] G. Manohar R and R. R, "Exploratory data analysis & EDS analysis on tool chip adhesion under dry and nano minimum quantity lubrication machining environment," *Materials Research Express*, vol. 11, no. 9, p. 096515, Sep. 2024, doi: 10.1088/2053-1591/ad5e3a.

[17] S. Kumar, D. Singh, and N. Singh Kalsi, "Improvement in machining performance of inconel 718 with solid lubricants," *Jurnal Teknologi*, vol. 80, no. 6, Aug. 2018, doi: 10.11113/jt.v80.12563.

[18] B.-A. Behrens *et al.*, "Investigation of the Hardness Development of Molybdenum Coatings under Thermal and Tribological Loading," *Lubricants*, vol. 11, no. 7, p. 283, Jun. 2023, doi: 10.3390/lubricants11070283.

[19] B. Sen, M. Mia, G. M. Krolczyk, U. K. Mandal, and S. P. Mondal, "Eco-Friendly Cutting Fluids in Minimum Quantity Lubrication Assisted Machining: A Review on the Perception of Sustainable Manufacturing," *International Journal of Precision Engineering and Manufacturing-Green Technology*, vol. 8, no. 1, pp. 249–280, Jan. 2021, doi: 10.1007/s40684-019-00158-6.

[20] A. Salem, C. Hopkins, M. Imad, H. Hegab, B. Darras, and H. A. Kishawy, "Environmental Analysis of Sustainable and Traditional Cooling and Lubrication Strategies during Machining Processes," *Sustainability*, vol. 12, no. 20, p. 8462, Oct. 2020, doi: 10.3390/su12208462.

[21] S. F. Altaf, M. A. Parray, M. J. Khan, M. F. Wani, and F. A. Bhat, "Machining with Minimum Quantity Lubrication and Nano-Fluid MQL: A Review," *Tribology Online*, vol. 19, no. 3, pp. 209–217, May 2024, doi: 10.2474/trol.19.209.

[22] M. Naveed *et al.*, "State-of-the-Art and Future Perspectives of Environmentally Friendly Machining Using Biodegradable Cutting Fluids," *Energies*, vol. 14, no. 16, p. 4816, Aug. 2021, doi: 10.3390/en14164816.

[23] X. Wu *et al.*, "Circulating purification of cutting fluid: an overview," *The International Journal of Advanced Manufacturing Technology*, vol. 117, no. 9–10, pp. 2565–2600, Dec. 2021, doi: 10.1007/s00170-021-07854-1.

[24] P. Nowak, K. Kucharska, and M. Kamiński, "Ecological and Health Effects of Lubricant Oils Emitted into the Environment," *International Journal of Environmental Research and Public Health*, vol. 16, no. 16, p. 3002, Aug. 2019, doi: 10.3390/ijerph16163002.

[25] J. Lennartz, M. E. Toxopeus, and J. va. der Meulen, "Analysis of environmental transitions for tool development," *Procedia CIRP*, vol. 105, pp. 799–804, 2022, doi: 10.1016/j.procir.2022.02.132.

[26] P. E. Tolbert, "Oils and cancer," *Cancer Causes & Control*, vol. 8, no. 3, pp. 386–405, May 1997, doi: 10.1023/A:1018409422050.

[27] C. R. Mackerer, "Health Effects of Oil Mists: A Brief Review," *Toxicology and Industrial Health*, vol. 5, no. 3, pp. 429–440, Jul. 1989, doi: 10.1177/074823378900500304.

[28] S. P. Somarajan, J.-H. Horng, and S. V. Kailas, "Development and Testing of a Modular Lathe Tribometer Tool to Evaluate the Lubricity Aspect of Cutting Fluids on Freshly Cut Surfaces," *Tribology Online*, vol. 14, no. 5, pp. 417–421, Dec. 2019, doi: 10.2474/trol.14.417.

[29] J. Ma, O. A. Gali, and R. A. Riahi, "An Evaluation of the Tribological Behavior of Cutting Fluid Additives on Aluminum-Manganese Alloys," *Lubricants*, vol. 9, no. 8, p. 84, Aug. 2021, doi: 10.3390/lubricants9080084.

[30] T. P. Jeevan and S. R. Jayaram, "Performance Evaluation of Jatropha and Pongamia Oil Based Environmentally Friendly Cutting Fluids for Turning AA 6061," *Advances in Tribology*, vol. 2018, pp. 1–9, 2018, doi: 10.1155/2018/2425619.

[31] J. Tumba, "Local Content Utilization and Product Quality Standards Promotion for Industrial and Machine Tools Processes Application," *International Journal of Engineering and Advanced Technology Studies*, vol. 10, no. 4, pp. 7–19, Apr. 2022, doi: 10.37745/ijeats.13/vol10n4719.

[32] J. Singh, S. S. Gill, M. Dogra, and R. Singh, "A review on cutting fluids used in machining processes," *Engineering Research Express*, vol. 3, no. 1, p. 012002, Mar. 2021, doi: 10.1088/2631-8695/abeca0.

[33] R. G. Rengiah, "Effect of Coconut Oil-Based Cutting Fluid on Cutting Performance During

Turning With Minimal Fluid Application," *International Journal of Manufacturing, Materials, and Mechanical Engineering*, vol. 12, no. 1, pp. 1–14, Sep. 2022, doi: 10.4018/IJMMME.301611.

[34] M. Yogeswaran, K. Kadirgama, M. M. Rahman, and R. Devarajan, "Temperature analysis when using ethylene-glycol-based tio2 as a new coolant for milling," *International Journal of Automotive and Mechanical Engineering*, vol. 11, pp. 2272–2281, Jun. 2015, doi: 10.15282/ijame.11.2015.10.0191.

[35] S. Mane and S. Kumar, "Investigation on Effects of Cutting and Jet Parameters in Turning of AISI 4140 Hardened Alloy Steel," *Materials Science Forum*, vol. 969, pp. 732–737, Aug. 2019, doi: 10.4028/www.scientific.net/MSF.969.732.

[36] S. U. Gunjal, S. B. Sanap, N. C. Ghuge, and S. Chinchanikar, "An Experimental Investigation on Vegetable Oils as a Cutting Fluid under Minimum Quantity Lubrication: A Sustainable Machining Approach," *Journal of University of Shanghai for Science and Technology*, vol. 23, no. 04, pp. 143–155, Apr. 2021, doi: 10.51201/JUSST/21/04204.

[37] N. C. Ghuge and A. M. Mahalle, "Influence of Cutting Fluid on Tool Wear and Tool Life during Turning," *International Journal of Modern Trends in Engineering & Research*, vol. 3, no. 10, pp. 23–27, Oct. 2016, doi: 10.21884/IJMTER.2016.3078.9LPXS.

[38] A. K. Katam, R. C. Mohanty, and A. Kolakoti, "The role of bio-based cutting fluids for sustainable manufacturing and machining processes: A holistic review," *Mechanical Engineering for Society and Industry*, vol. 3, no. 3, pp. 166–180, Dec. 2023, doi: 10.31603/mesi.10680.

[39] Q. M. Nguyen, T.-V. Do, and T.-N. Nguyen, "Minimization of Temperature in Cutting Zone: A Case Study of Hard Milling of SKD 61 Steel," *Universal Journal of Mechanical Engineering*, vol. 8, no. 2, pp. 97–104, Mar. 2020, doi: 10.13189/ujme.2020.080204.

[40] S. Mahapatra, A. Das, P. C. Jena, and S. R. Das, "Turning of hardened AISI H13 steel with recently developed S3P-AlTiSiN coated carbide tool using MWCNT mixed nanofluid under minimum quantity lubrication," *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, vol. 237, no. 4, pp. 843–864, Feb. 2023, doi: 10.1177/09544062221126357.

[41] S. F. Lone, D. W. Rathod, and S. N. Ahmad, "Exploring the feasibility of SS316L fabrication via CMT-based WAAM: A Comprehensive study on microstructural, mechanical and tribological properties," *Mechanical Engineering for Society and Industry*, vol. 4, no. 2, pp. 237–251, Nov. 2024, doi: 10.31603/mesi.11848.

[42] J. Andrean, A. Harmayanti, A. Wahjudi, and A. Syamlan, "Analysis of The Corrosion Inhibition Efficacy of Camellia Sinensis Extract on Aluminium 6061 Alloys using Artificial Neural Network (ANN)," *Mechanics Exploration and Material Innovation*, vol. 1, no. 2, pp. 67–74, Apr. 2024, doi: 10.21776/ub.memi.2024.001.02.5.

[43] N. P. Parahdiba, H. Salafy, A. Marizki, and A. N. Camila, "Effect of Heat Treatment Variation on Grain Boundary Corrosion of Austenitic Stainless Steel," *Mechanics Exploration and Material Innovation*, vol. 1, no. 3, pp. 94–101, 2024, doi: 10.21776/ub.memi.2024.001.03.4.

[44] V. Baldin *et al.*, "Dry and MQL Milling of AISI 1045 Steel with Vegetable and Mineral-Based Fluids," *Lubricants*, vol. 11, no. 4, p. 175, Apr. 2023, doi: 10.3390/lubricants11040175.

[45] A. Das, S. K. Patel, B. B. Biswal, N. Sahoo, and A. Pradhan, "Performance evaluation of various cutting fluids using MQL technique in hard turning of AISI 4340 alloy steel," *Measurement*, vol. 150, p. 107079, Jan. 2020, doi: 10.1016/j.measurement.2019.107079.

[46] B. Arsene, C. Gheorghe, F. A. Sarbu, M. Barbu, L.-I. Cioca, and G. Calefariu, "MQL-Assisted Hard Turning of AISI D2 Steel with Corn Oil: Analysis of Surface Roughness, Tool Wear, and Manufacturing Costs," *Metals*, vol. 11, no. 12, p. 2058, Dec. 2021, doi: 10.3390/met11122058.