Performance and evaluation of vegetable oil-based fluids as future cutting fluids in turning of duplex stainless steel

K. Arul1*, J. Rajaparthiban2, V.Mohanavel3, T Sathish4, Ram Subbiah5, M.Ravichandran6

1Department of Mechanical Engineering, Agni College of Technology, Chennai - 603130, Tamilnadu, India.
2Department of Mechanical Engineering, Chennai Institute of Technology, Chennai - 600069, Tamilnadu, India.
3Centre for Materials Engineering and Regenerative Medicine, Bharath Institute of Higher Education and Research, Chennai - 600073, Tamilnadu, India.
4Department of Mechanical Engineering, Saveetha School of Engineering, SIMATS, Chennai ~ 602 105, Tamil Nadu, India.
5Department of Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, Telangana 500090
6Department of Mechanical Engineering, K.Ramakrishnan College of Engineering, Trichy-621112, Tamilnadu, India.

*Corresponding author mail ID: arulroll7@gmail.com

Abstract: This experimental study article analyses the machinability of Duplex Stainless Steel when turned using various wet coolants, including as (Coconut, Mustard, Soyabean oil). Cutting speed, feed, depth of cut, nozzle inclination angle, pressure, and standoff distance are all input process factors. The output response parameters were considered such as thrust force, machining zone temperature, tool wear and surface roughness. In this experimental study, Taguchi technique was used to design the experimental runs under three different level combination of process parameters. The experimental result indicates that the turning performance has been improved at coconut oil condition over the other coolant conditions and it produces the uniform surface finish throughout the length of the workpiece.

Keywords: Duplex Stainless Steel, Vegetable oil, MQL/Coconut, MQL/Mustard

1. Introduction
Metal cutting fluids (MCFs) are classified into different types such as straight oil, synthetic oil, semi-synthetic oil, soluble oil and vegetable based cutting oils. Synthetic and Petroleum based coolants are pollutes the environment and several negative effects to the operators. The machine operators work continuously at the same environment on longer period of time causes the severe health issues such as cancer, breathing issues, skin allergies, eye burning etc [1]. Due to the better physical and chemical properties of vegetable oil is the perfect alternative for synthetic and petroleum-based products. Modified vegetable oils are providing superior boundary and hydrodynamic lubrication on the contact surface it reduces the coefficient of friction and improves pitting resistance. Because of these excellent properties of vegetable oil increases the machinability characteristics in terms of lowers the cutting force, cutting tool contact temperature, surface roughness and tool wear [2]. The generation of high
heat in the machining zone during turning process which increases roughness, machining zone temperature, wear & cutting force [3]. Flank wear is the reason for an increased chatter marks and dimensional deviation in the workpiece. The formation of unstable Built-up edge (BUE) chips is the reason for increasing roughness on the workpiece. This BUE creates direct contact between the finished component and tool insert [4]. The purpose of lubrication is to lower the temperature and cutting force, so that tool insert is to facilitate penetration action while being environmentally friendly. Coconut oil, for example, is highly oxidatively stable and contains over 90% saturated fatty acids. The viscosity index of coconut oil is 130, and the flash point is 294 degrees Celsius. The performance of extreme pressure particles in sunflower and canola, on different forces in the turning of AISI 304L steel was investigated. Alves and Oliveira reported that the performance of castor oil was found to be better to mineral based oil. Here the wheel life and surface finish were higher and no corrosion inhibiting characteristics were observed under the corrosion test [5]. Ojolo et al experimented with different fluids like coconut, ground nut, palm kernel oils and shear butter on cylindrical turning of mild steel, aluminium and copper materials. They reported that those fluids are more suitable in machining applications [6]. Minimum Quantity Lubrication (MQL) is used to reduce the supply excess amount of wet coolants in the machining zone and this technique is right alternative for the research community [7-21]. Duplex stainless-steel (DSS) serves in different industry like chemical, oil & gas, petrochemical, geothermal, solar power and nuclear power. The operators discovered some challenges while machining the DSS, such as early tool failure and poor surface polish due to high temperatures at the tool-chip–work piece interface.

Vegetable-based oils have been found to be comparable to mineral, synthetic, and semi-synthetic oils in terms of performance. A small amount of research has been done on the performance of vegetable oils in a duplex stainless steel turning process. The major goal of this study was to assess the performance of three vegetable oils (Coconut, Mustard, and Soyabean oil) during the turning of duplex stainless steel in terms of surface finish, tool wear, and cutting zone temperature.

2. Material and Methods:

![Figure 1. Schematic view of Turn master universal Lathe](image)

A Duplex stainless-steel workpiece with a hardness of 34 HRC and a Coated Carbide cutting tool insert with a hardness of 40HRC were employed in this study. The workpiece was 40 mm in diameter and 200 mm in length. Table.1 shows the input parameters and their levels. The chemical compositions of the workpiece and tool insert were determined using the spectrometer. The use of vegetable oil is critical for removing heat and extending the tool's life. The turning trials were carried out on a Turn Master universal lathe. Figure 1 is a schematic view of the Turn Master Universal Lathe. Coated carbide inserts have a tendency to lower the coefficient of friction in the machining zone while also adhering to the rake face. Surface roughness (Ra) measurements were taken with a Taylorsurf surtronicmeter. For the first experiment, surface roughness measurements were conducted on DSS at three locations to limit the deviation, and then an average value of the surface roughness was recorded. Tool wear was measured using SEM analysis. Cutting force was measured using a Kistler 9257B
dynamometer. The temperature of the tool chip contact cutting tool was measured using an embedded thermocouple.

3. Results and Discussions:

![Effects of Surface Roughness](image)

**Figure 2. Effects of Surface Roughness**

The machined component surface finish for nine experimental runs was shown in Figure 2. Surface finish is one of the important indexes in assessing machinability characteristics. The machined component loses its durability due to the surface roughness, residual stresses, and surface or subsurface micro voids. Generating feed marks on the workpiece, chipping, deformation, vibration, built-up edge formation (BUE) are the reasons for increasing surface roughness on the machined component. Nonetheless, it is clear that MQL enhances surface finish dependent on the work-tool materials, primarily by limiting the abrasion, chipping, and built-up edge development of the auxiliary cutting edge. [8]. Coconut oil forms the boundary layer on the workpiece and it reduces the friction coefficient. It leads to reduce the severe stresses on the cutting tool insert and MQL also promotes better cooling and lubrication between the cutting edge of the insert and workpiece. It was evident that MQL/Coconut Oil reduces the surface roughness compare to the other two coolants by controlling abrasion, diffusion, attrition, adhesion wear on the cutting tool insert.
Figure 3 shows the Effects of Thrust Force. Thrust force is the predominant parameter in affecting dimensional accuracy and stability of the machining system. The maximum peak thrust force of 187N, 226N, 242N and the minimum peak thrust force of 154N, 166N, 178N was observed in MQL/Coconut, MQL/Mustard and MQL/Soyabean oil-based vegetable machining process. As a result, while the adsorption films are sliding, the adsorption film separates the friction contact, which appears as extrinsic friction between the adsorption films. Furthermore, coconut oil layer has high resistant wear and weight-carrying characteristics, which reduces tool–workpiece (tool–chip) friction [9]. Higher abrasion resistance of mustard oil reduces the cutting force than soyabean oil. Coconut oil was found to superior in reducing the thrust forces than commercial cutting fluids.
From the above figure 4, it was noted that cutting temperature is increases with increase in speed, feed, depth of cut and stand-off distance. This is due to improper cooling at the machining zone. Vegetable oil couldn’t penetrate in between tool and workpiece so that physical contact distance increases and it tends to increase the machining zone temperature. When the fluid (vegetable oil) pressure increases, the cutting temperature decreases. The proper cooling and lubrication of vegetable oil in between tool and workpiece carry away the heat from the machining zone. Figure 3 shows the Effects of Cutting Temperature. The minimum peak temperature of 130°C, 148°C, 167°C was observed during turning of DSS using coconut, mustard and soyabean oil. The chemical nature of molecules of coconut oil and high lubricating property are the reasons for creating a chemical affinity and durable film layer on the surface of the workpiece [10].
Figure 5. SEM Images of Flank Wear

Figure 5 shows that SEM images of flank wear on tool insert under coconut, mustard and soyabean oil. Tool wear is the most important factor impacting tool life and machined component surface quality. The rapid increment of flank wear with the cutting time (240 min) and failure of the tool (Penetrated tunnel cracks) was observed during MQL/Soyabean oil-based machining process. The flank wear of 0.20 mm and abraded layer was observed at a cutting time of 240 min in the MQL/Coconut oil-based machining process. The flank wear of 0.29 mm was observed at a cutting time of 240 min in the MQL/Mustard oil-based machining process. The viscosity of coconut oil is higher than that of mustard and soyabean oil. High viscosity and surface tension of coconut oil maintains the lubrication oil film stability than other two cutting fluids (oils).

4. Conclusions:
Experiments were carried out to see how MQL/Coconut, MQL/Mustard, and MQL/Soyabean oils performed on Duplex Stainless Steel utilising a coated carbide insert. It was noted that MQL/Coconut oil increased the machining performance than other two cutting fluids. The major experimental findings are drawn below.

- The minimum peak surface roughness value of 0.656µm was observed in MQL/Coconut oil-based machining process. MQL/Coconut oil-based machining process is found to reduce surface roughness to an extent of 43% than MQL/Soyabean oil-based machining process.
• The minimum peak thrust force value of 154N was observed in MQL/Coconut oil-based machining process. MQL/Coconut oil-based machining process is found to reduce thrust force to an extent of 15% than MQL/Soyabean oil-based machining process.

• The minimum peak cutting temperature value of 130°C was observed in MQL/Coconut oil-based machining process. MQL/Coconut oil-based machining process is found to reduce cutting temperature to an extent of 24% than MQL/Soyabean oil-based machining process.

• The minimum peak tool wear value of 0.20mm at 240 min was observed in MQL/Coconut oil-based machining process. MQL/Coconut oil-based machining process is found to improve tool life to an extent of 37% than MQL/Soyabean oil-based machining process.

References:

1. Ozcelik, B., Kuram, E., Huseyin Cetin, M., & Demirbas, E. (2011). Experimental investigations of vegetable based cutting fluids with extreme pressure during turning of AISI 304L. *Tribology International*, 44(12), 1864–1871. doi:10.1016/j.triboint.2011.07.01

2. Arul, K & Senthil Kumar, VS 2020, ‘Effects of Nano Additives in Bio Cutting Fluid for Turning of Monel K500 Alloy’, Journal of the Balkan Tribological Association, vol. 26, no. 3, pp. 589-600. ISSN : 1310-4772.

3. Arul, K & Senthil Kumar, VS 2020, ‘Effect of Magneto Rheological Minimum Quantity Lubrication on Machinability, Wettability and Tribological Behavior in Turning of Monel K500 Alloy’, International Journal of Machining Science and Technology, vol. 24, no. 5, pp. 810-836, ISSN : 1091-0344.

4. Park, K.-H., & Kwon, P. Y. (2009). Flank Wear of Multi-Layer Coated Tool and Wear Prediction Using Abrasion Wear Model. ASME 2009 International Manufacturing Science and Engineering Conference, Volume 1. doi:10.1115/msec2009-84100.

5. Alves, S. M., & de Oliveira, J. F. G. (2006). Development of new cutting fluid for grinding process adjusting mechanical performance and environmental impact. Journal of Materials Processing Technology, 179(1-3), 185-189. doi:10.1016/j.jmatprot.2006.03.

6. Ojolo S J, Amuda M O H, Ogunmola O Y, Ononihu C U. Experimental Determination Of The Effect Of Some Straight Biological Oils On Cutting Force During Cylindrical Turning Revista Matéria 2008; 13:4, 650–663.

7. Arul, K & Senthil Kumar, VS 2020, ‘Magnetorheological Based Minimum Quantity Lubrication (MR-MQL) With Additive n-CuO’, Materials and Manufacturing Processes, vol. 35, no. 4, pp. 404-414, ISSN : 1042-6914.

8. M.M.A. Khan, M.A.H. Mithu, N.R. Dhar Effects of minimum quantity lubrication on turning AISI 9310 alloy steel using vegetable oil-based cutting fluid Journal of Material Processing Technology 209(2009),5573-5583.

9. Padmini, R., Vamsi Krishna, P., & Krishna Mohana Rao, G. (2016). Effectiveness of vegetable oil based nanofluids as potential cutting fluids in turning AISI 1040 steel. *Tribology International*, 94, 490–501. doi:10.1016/j.triboint.2015.10.006

10. Sajeeb, A., & Rajendrakumar, P. K. (2019). Comparative evaluation of lubricant properties of biodegradable blend of coconut and mustard oil. Journal of Cleaner Production, 240, 118255. doi:10.1016/j.jclepro.2019.118255

11. V. Mohanavel, M. Ravichandran, 2019, Experimental investigation on mechanical properties of AA7075-AlN composites. *Mater Test.* 61 (6), 554-558.

12. B. NagarajaGanesh, P. Ganeshan, P. Ramshankar, K. Raja, 2019, Assessment of natural cellulose fibers derived from Senna auriculata for making light weight industrial biocomposites, *Industrial Crops & amp; Products* 139, 111546.
13. Vinayagam Mohanavel, Thandavamoorthy Raja, Anshul Yadav, Manickam Ravichandran, Jerzy Winczek, Evaluation of Mechanical and Thermal Properties of Jute and Ramie Reinforced Epoxy-based Hybrid Composites, Journal of Natural Fibers, DOI : 10.1080/15440478.2021.1958432

14. V. Mohanavel, K. Rajan, M. Ravichandran, 2016, Synthesis, characterization and properties of stir cast AA6351-aluminium nitride (AIN) composites, Journal of Materials Research, 31 (2), 3824-3831.

15. V. Mohanavel, M. Ravichandran, 2019, Influence of AIN particles on microstructure, mechanical and tribological behavior in AA6351 aluminum alloy. Mater Res Exp. 6 (10), 106557.

16. K. Raja, B. Prabu, P. Ganeshan, V. S. Chandra Sekar & B. NagarajaGanesh, 2020, Characterization Studies of Natural Cellulosic Fibers Extracted from Shwetark Stem, Journal of Natural Fibers, DOI: 10.1080/15440478.2019.1710650

17. Thanikodi Sathish, Abdul Razak R Kaladgi, V Mohanavel, K Arul, Asif Afzal, Abdul Aabid, Muneer Baig, Bahaa Saleh, 2021, "Experimental Investigation of the Friction Stir Weldability of AA8006 with Zirconia Particle Reinforcement and Optimized Process Parameters" Materials 14 (11), 2782

18. B. Chaitanya Kumar, P. Sri Charan, Kanishkar Jayakumar, D. Alankrutha, G. Sindhu, Ram Subbiah, 2020, Assessment Of Wear Properties On Low Temperature Molten Salt Bath Nitriding On Austenitic Stainless Steel, Materials Today: Proceedings, 27, 2, 1541-1544.

19. T. Lakshmi Deepak, G. Ananda Mithra, K. Lokesh, B. Sai Chandra, Ram Subbiah, 2020, Stability Of Expanded Austenite By Gas Nitriding Process On Austenitic Stainless Steel Material Under Low Temperature Conditions, Materials Today: Proceedings. 27, 2, 2020, 1681-1684.

20. Ram Subbiah, Md. Rahel, A Sravika, R.Ambika, A.Srujana, E.Navya, 2019, Investigation on Microstructure and Mechanical Properties of P91 Alloy Steel Treated With Normalizing Process - A Review, Materials Today: Proceedings, 18, 7, 2265-2269.

21. A. Rohit Sai Krishna, B. Vamshi Krishna, T. Sashank, D. Harshith, Ram Subbiah, 2020, Influence and Assessment of Mechanical Properties on Treated P91 Steel with Normalizing Processes, Materials Today: Proceedings. 27, 2, 1555-1558.