The Effect of Adding Zinc titanate Nanoparticle and Eco-Friendly Sunflower Oil to MQL on Surface Roughness and Cutting Temperature in Turning of Inconel -718.

Pandi Jyothish
Research scholar, Department of Mechanical Engineering
National Institute of Technology (NIT), Warangal, India.
jy719054@student.nitw.ac.in

V. Vasu
Professor, Department of Mechanical Engineering
National Institute of Technology (NIT), Warangal, India
vasu@nitw.ac.in

Dhurke Kashinath
Professor, Department of chemistry
National Institute of Technology (NIT), Warangal, India.
kashinath@nitw.ac.in

Abstract

Turning, as well as other types of mechanical cutting operations, are absolutely necessary for the machining of advanced cutting materials (Inconel718). For the manufacturing of aerospace components, pressure vessels, and race car engine parts, Inconel 718 superalloy has been widely used in the manufacturing industries, Due to its excellent mechanical properties such as high impact and tensile strength at very high temperatures, high-temperature resistance, and corrosion resistance. But machining Inconel-718 is restricted to use in some industries due to the inability of tool material to survive for a longer period of time due to the work-hardened effect and it is having low thermal conductivity, due to this property, a huge amount of the cutting temperature dissipates towards the cutting tool instead of the cutting chip. When machining processes are performed, heat dissipation becomes a more difficult task. Because of this, the tool life and the quality of the machined surface are negatively affected. As a result of this, while machining advanced materials the Flood coolant (FC) cutting fluid was used in order to reduce the enormous amounts of heat that are produced at the cutting zone; however, the government has released restrictions on the usage of alternative cooling (FC) techniques to reduce its "effects on the atmosphere and the operator's health"(Gupta et al., 2021a). MQL is employed as a substitute for traditional cutting fluids since it reduces lubricant consumption, and environmental & health impacts. However, pure MQL cooling does not provide appropriate cooling performance. The introduction of eco-friendly vegetable oil (sunflower oil) and nanoparticles (Zinc Titanate, $ZnTiO_3$) into the Minimum quantity lubrication led to significant improvements to the fluid's viscosity, thermal conductivity, and wettability which further reduces the cutting temperatures and cutting forces. In this research, a number of experiments were performed on Inconel-718 "under different cooling conditions such as dry machining, pure MQL, and MQL-nanofluid using the same cutting parameters (Depth of cut, feed, cutting speed)"(Tamang et al., 2018) with regard to surface roughness, and cutting temperatures. An interesting result showed that the MQL-nanofluid technique was more effective in reducing cutting temperature and enhanced surface finish when compared to pure-MQL, dry cutting. Using Eco-Friendly cutting fluid with MQL shows promising outcomes in terms of sustainability and machining outputs.

Keywords
Inconel-718, MQL, Eco-Friendly cutting fluid, dry cutting, Zinc Titanate ($ZnTiO_3$).

1. Introduction

Nickel-based Inconel-718 material has been used, in many industries for manufacturing critical parts with its special features like superior creep strength(Gupta et al., 2021a) oxidation resistance, high-temperature resistance(Khanafer et al., 2020), and corrosion resistance(Zhang et al., 2012a), and high strength-to-weight ratio. Inconel-718 is used in aviation engines, nuclear reactors, turbine components(Ucun et al., 2015), marine, chemical and heavy industry, etc. In recent years, many industries that manufacture aerospace engines have used more than 50 percent of nickel-based superalloys due to capable of maintaining their thermal stability under extreme conditions. Due to their face-centered cubic structure, “Ni-based superalloys remain ductile even at cryogenic temperatures”(Yildirim et al., 2020), making them useful for cryogenic tanks, superconductor materials, and space-rocket motor bodies. Different grades of nickel-based superalloys, including Inconel-100, FGH-95, Inconel-718, Inconel-800, and ME-16 are utilized in a variety of high-temperature applications. Out of which Inconel-718 is one mostly used to manufacture critical parts. At higher temperatures, Inconel-718 has superior rupture strength and creep properties.

Despite its many benefits and applications, Inconel 718 is having some limitations due to its “high hot-hardness, low heat transfer capacity, and high chemical affinity to cutting tool materials. The above-mentioned limitations result in rapid tool wear, and poor surface quality which results in increased carbon emissions” (Nwoguh et al., 2021), and high cutting tool power consumption. when cutting Difficult to cut materials, very high cutting forces are generated at the tool-workpiece interface which causes work materials to weld or adheres to the tool inserts. This leads to increased tool wear, cutting temperatures, and altering the surface finish. Therefore, A newly prepared cutting fluid ($ZnTiO_3$ /SF) using the MQL technique is introduced to lower cutting temperature, total energy consumption, and surface roughness.
Machining with an MQL is one of the environmentally friendly techniques that has been investigated to a great extent over the years that supplies a tiny quantity of oil to the machining zone with the assistance of compressed air in order to generate atomized molecules of oil with the air. “An aerosol that has been delivered to the cutting zone through a nozzle generates a lubricating film, which reduces temperature, & friction and flushes chips away from the machining zone”(Krolczyk et al., 2019). Additionally, many benefits are given to production operations, including clean chips and enhanced lubrication in the tool-workpiece cutting zone.

Vegetable-based biodegradable (Tazehkandi et al., 2015) oil is widely recommended in the context of current sustainability trends in the manufacturing industry. It is well known that the composition of the fatty acids in vegetable oils has “an effect on the thermophysical properties of the fluid and protects against corrosion. Vegetable oils are excellent lubricating fluids and are made up mostly of saturated and unsaturated fatty acids(Kazeem et al., 2022)”. Saturated fatty acids (palmitic and stearic acids) coexist with unsaturated fatty acids in fatty acids (i.e., oleic, linoleic, and linolenic) Saturated fatty acids have more lubricating properties than unsaturated fatty acids. Saturated fatty acids, particularly stearic acids, considerably minimize friction and wear. Because saturated fatty acids improve the intermolecular force, they give great protection to the lubricating thin layer. The fundamental cause for changing “cohesion between molecules, which promotes the adsorption of lubricant thin layer on the workpiece surface, is the various molecular structures and quantities of saturated fatty acids”(Kazeem et al., 2022). The strength of the adsorption film is also affected by the varying absorption energies. Unsaturated fatty acids' double bonds are not as stable as saturated fatty acids, and they can also lower the bonding strength between molecules, resulting in poor lubrication. This is primarily owing to the stiffness generated by the molecules' double bonds. The fatty acid chains in unsaturated fatty acids are not tightly packed with each other due to stiffness, resulting in lower intermolecular forces. Saturated fatty acids, on the other hand, are less stiff “due to the absence of a double bond in their structure. As a result, saturated fatty acid chains are more tightly packed. Sunflower oil has a higher concentration of stearic saturated fatty acids. According to the film-formation rule, sunflower oil provided an excellent lubrication effect due to the high presence of saturated fatty acids and the great absorption capability of the lubrication film”(Rojas et al., 2013). Furthermore, sunflower oil contains a significant number of linoleic acids, which improves the lubricating film's capability and stability when compared to other vegetable oils. In addition, because Inconel alloys have a low capacity to transfer heat, nanofluids(Amrita et al., 2014) are introduced to the cutting zone in order to dissipate the heat generated by the shearing and friction. In addition to enhancing heat conductivity, the polishing effects and ball-bearing of nanofluids make them an ideal candidate for enhancing the MQL system's performance. The shape, morphology, and crystal structure of the nanoparticles have a significant impact on efficient lubrication. The use of nano additions enhanced the efficiency of vegetable oils, which led to a decrease in temperature and friction, as well as improved surface finish and tool's life span. A comparison was made between Dry cutting, MQL/SF

(Marques et al., 2017), MQL/NF environments on hard-to-cut material(Gupta et al., 2021b) regarding cutting temperature and surface finish. MQL/NF provided lower temperatures, better tool lifespans, and improved chip morphologies in comparison to pure MQL and dry machining.

1.1 Objectives

- Preparation of vegetable oil-based Eco-Friendly cutting fluid(Das et al., 2019), using $ZnTiO_3$, and Sunflower oil for machining of difficult-to-cut material(Zhang et al., 2012b).
- Characterization and analysis of prepared Eco-Friendly cutting Nano-fluid. (Figure.2)
- Experimental work on lathe machine (Figure.6) using three "machining cutting parameters (feed, Cutting speed, depth of cut) and various cooling/lubrication conditions"(Chinesta et al., 2010) (Dry, MQL/SF, MQL/Nanofluid).
- Evaluation of machining output parameters of prepared Eco-Friendly cutting Nanofluid (Figure.3). (Surface roughness, Cutting temperature).
-

2. Literature Review

Many investigators found that adding nanoparticles to conventional fluids increased thermal conductivity.(Ross et al., 2021) (Naresh Babu et al., 2019)(Das et al., 2019)(Singh et al., 2017)(Yildirim et al., 2020)(Musavi et al., 2019)(Majak et al., 2020)It has been found that an increase in volumetric cont. of NPs in the base oil leads to an increase in the thermal-conductivity(k)(Nwoguh et al., 2021) of nanofluids(Kumar Sharma et al., 2016). By incorporating 6 percent Al_2O_3 into the base fluid, a conventional fluid's thermal conductivity at ambient temperature could see an increase of up to 22.4 percent(Vajjha & Das, 2012,. Lee et al., 2009) found that thermal-conductivity increased by 150% when compared to its base oil. The research study that has been significant in the area of nanofluid was reviewed by (Sharma et al., 2015), and they found that the inclusion of nanoparticles(NP) into base liquid increases its thermal conductivity. This, in turn, enhances surface quality(Musavi et al., 2019) and (Zhang et al., 2012c) also reducing the cutting temperature and cutting force. Along with thermal conductivity, friction(Nasiri et al., 2012) between the tool and the workpiece is a key factor in how much heat is produced in the cutting zone. Because of this, the temperature at the tool edge increases, which in turn may cause the cutting tip of the tool becomes hard and sharp. In addition to influencing the surface finish of the machined product, this has a significant impact on the wear of the cutting tools. It has been found that using graphene nanoparticles(Li et al., 2019) in traditional lubricants results in an improvement in the tribological property of the lubricant due to a reduction in the friction coefficient(Lee et al., 2009). "As a result of their low friction behavior, graphite and MoS_2 solid lubricants were able to reduce surface roughness and the amount of cutting temperature required during the machining process. On the other hand, as compared to dry machining and flood colling machining, MQL machining has been shown to result in a reduction in surface roughness"(Pal et al., 2021, Yildirim et al., 2020), tool wear(Thakre et al., 2019, Zhang et al., 2012c), and chip thickness. Prasad and Srikant observed that an increase in the concentration of graphite resulted in a reduction in the surface roughness as well as the cutting forces.(Krolczyk et al., 2019)presented a variety of approaches to environmentally responsible manufacturing that aim to maximize the use of available resources while minimizing the impact of those techniques on the surrounding environment. (Zhang et al., 2012b) conducted a study on machining nickel alloys utilizing MQL and dry cutting environments with the aim of determining the surface quality of the workpiece and the tool life. While using MQL, the authors found that the tool life is 1.5 times longer when compared to dry machining conditions. Additionally, the surface quality was found superior when using minimum quality lubrication. It was discovered that the micro-droplets entered the cutting zone and decreased friction, which led to relatively lowered cutting force, and low chip adhesion, and gave energy savings. (Tamang et al., 2018)examined the surface roughness, tool wear, and cutting power during the machining of Inconel-825 by using dry and MQL techniques. The results of the experiments showed that MQL machining reduced cutting power by 8.47 percent, surface roughness by 10.41 percent, and tool wear by 16.57 percent as compared to dry machining. It is generally proposed that biodegradable vegetable oil be used during the machining process in view of the growing sustainability trends in the industry(Krolczyk et al., 2019). There are numerous distinct varieties of nanoparticles found, some of which are listed below: carbon sheets; zinc oxide; graphene; alumina; carbon nanotubes with single and more walls. During the cutting process, the nano-additive lubricants helped to reduce the coefficient-of-friction(COF) by reducing the friction that occurred between the workpiece and cutting tool. The utilization of nano-additives with vegetable oil results in a reduction in the usage of mineral lubricants and an increase in the efficiency of vegetable lubricants. This results in a reduction in friction and temperature, as well as enhanced tool life and surface finish (Gajrani & Sankar, 2020).

3. Methods

Nanofluid preparation:

Sunflower oil (SO) with Zinc Titanate ($ZnTiO_3$) nanoparticles (NP) was chosen based on their compatibility with sophisticated materials for cutting Inconel-718 using the MQL technique. Sunflower oil utilized in this research was purchased from MEL, Hyd, INDIA. The zinc-titanate($ZnTiO_3$) nanoparticles utilized in this research were purchased from SR Lab, India. A weighing machine with an accuracy of 0.0001 g was used to determine the different wt.% concentrations of NPs ranging from 1 to 4 percent, as well as the sunflower oil, and nanoparticles. A one-step method is followed for dispersing nanoparticles throughout the base fluids, which is shown in Figure 1.

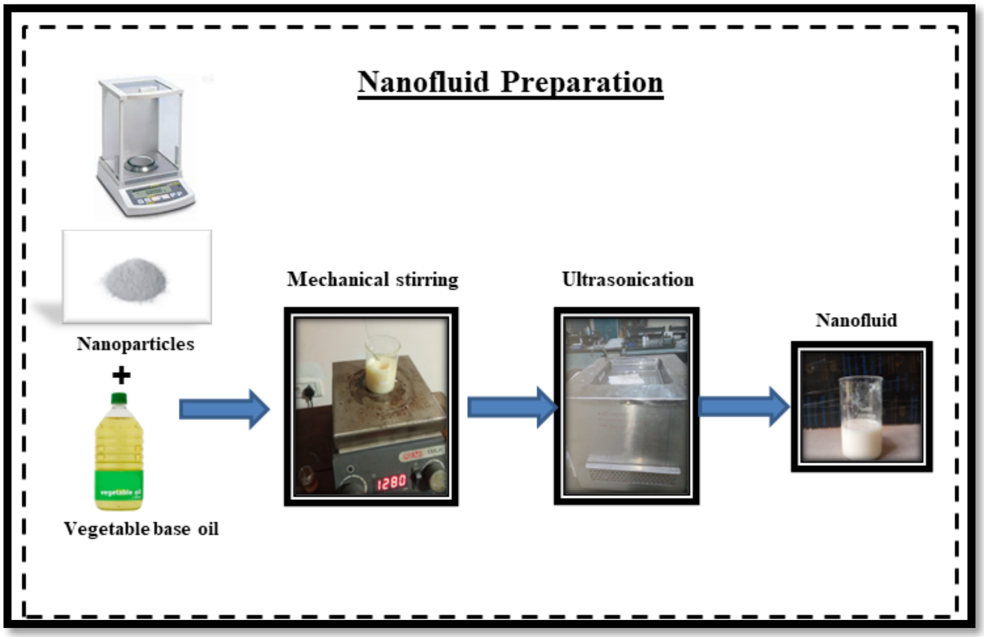

Figure 1. Nanofluid preparation

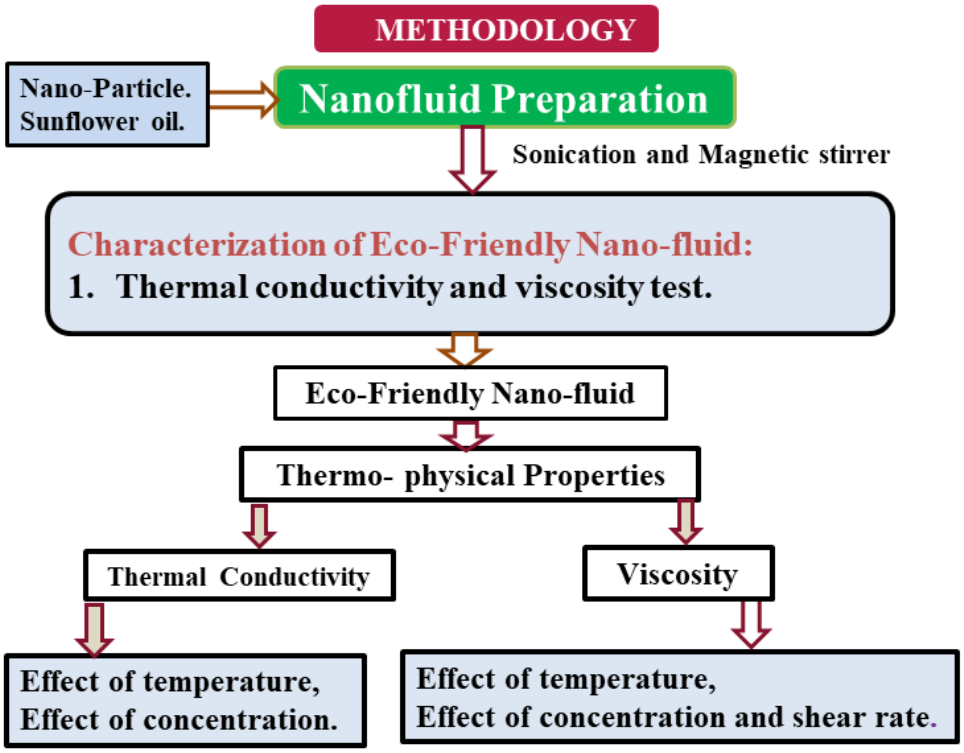

Figure 2. METHODOLOGY adopted for Characterization of Nanofluid.

In this method, the Zinc-Titanate was mixed throughout the base oil with the assistance of a variety of different physical techniques, such as an ultrasonic disruptor, stirrer, and (Sharma et al., 2016) ultrasonic bath (Chinesta et al., 2010). This method is utilized in the process of dispersing nanoparticles in sunflower oil in order to produce NFs with varying amounts of NP dispersion as measured in terms of weight %. And finally, ultrasonication is utilized for two hours with the highest sonicating power of 350 watts and a frequency of twenty kilohertz in order to disrupt particles that are similar to one another and further improve the liquid-solid mixture. After the sonication process is finished, the NF has mechanically stirred again, before each experiment is carried out.

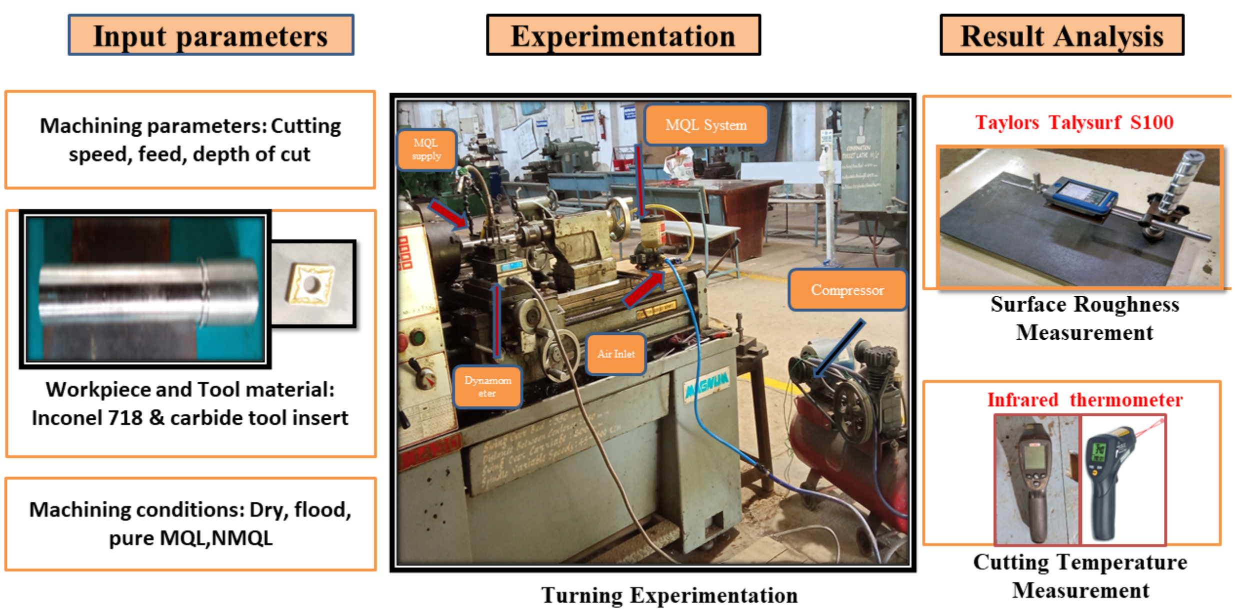

Figure 3. Methodology adopted for Experimentation Work.

4. Data Collection

4.1 Thermal conductivity measurement

The thermal-conductivity (TC)(Cherkasova & Shan,) of the newly developed cutting fluid was evaluated with the assistance of professional equipment manufactured by KD_2 (Decagon Devices, USA). The KD2 Pro-designed sensors offered by Decagon are remarkable for their big size, impressive power, and simple use. Heating durations are kept as brief as feasible in order to cut down on the amount of time needed for measurement and to reduce the amount of movement and free convection that occurs in liquid. The KD_2 Pro is capable of resolving temperatures in the region of 0.001 Celsius thanks to the utilization of specialized algorithms for the analysis of high-resolution temperature measurement techniques. One of the primary purposes of a KS sensor is to determine the TC(k) of the fluids. In order to determine the thermal conductivity (k) of material using KD2 pro equipment at a variety of temperatures, a specific configuration, which is depicted in Figure 4, has been created with the wooden box.

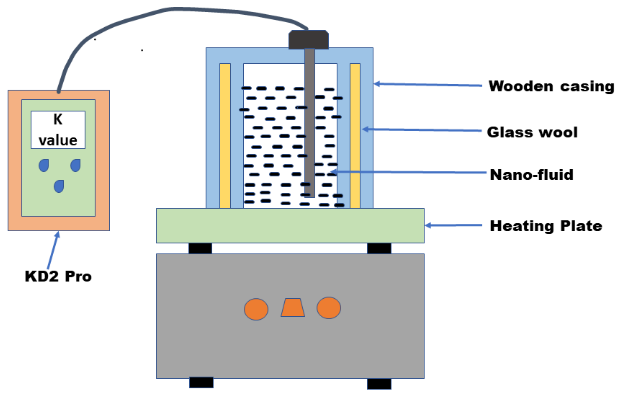

Figure 4. Thermal-conductivity experimental setup

4.2 Viscosity measurement

The primary function of a rheometer (RheolabQC- Figure 5) is to measure the viscosity of fluids. The viscosity of the Nanofluid can be determined by measuring the resistance that the fluid's viscous drag has against the spinning of the spindle. A wide variety of viscosity measurements are possible due to the many different types of spindles and speeds that can be combined. A thermostat bath was utilized so that temperatures could be kept stable during the various measurements. The filling cup was prepared for use by having the fluids whose viscosity was going to be measured placed into it. Viscosity was measured at temperatures ranging from 30 to 90 degrees Celsius (Figure 6).

Figure 5. viscosity measurement setup

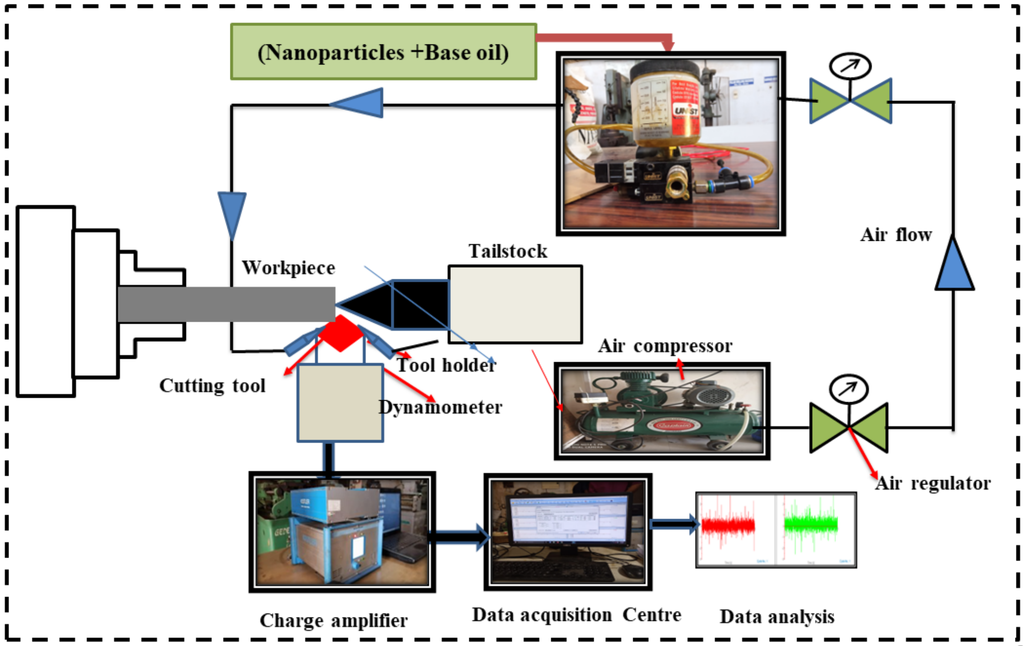

Figure 6. MQL Experimental setup For Inconel-718 Material.

5. Results and Discussion.

5.1 Graphical Results

Thermal conductivity of nanofluids:

Thermal conductivity of $ZnTiO_3$/SF nano-cutting fluid is tested at temperatures ranging from 30 to 90 degrees Celsius from 1-4 wt. percent concentration. The results of measuring the thermal conductivity at various concentrations of $ZnTiO_3$ nano-cutting fluids against the temperature are given in Figure 7. The thermal conductivity increases with nanoparticle wt. percent concentration & temperature increases. This trend demonstrates that the inclusion of the nanoparticle results in an increase in thermal conductivity, which in turn results in an increased rate of heat transfer. When compared to the SF Vegetable oil, the thermal-conductivity of $ZnTiO_3$/SF nanofluid was found to be improved by 38.31 percent at a nanoparticle concentration of 4 weight percent at a temperature of 90 degrees Celsius. "This is because of the collision between the nanoparticles and the developing Brownian motion of the nanoparticles with temperature(Hong et al., 2000)". Another factor contributing to the increased thermal conductivity of the nanofluids may be the large surface area of the nanoparticle.

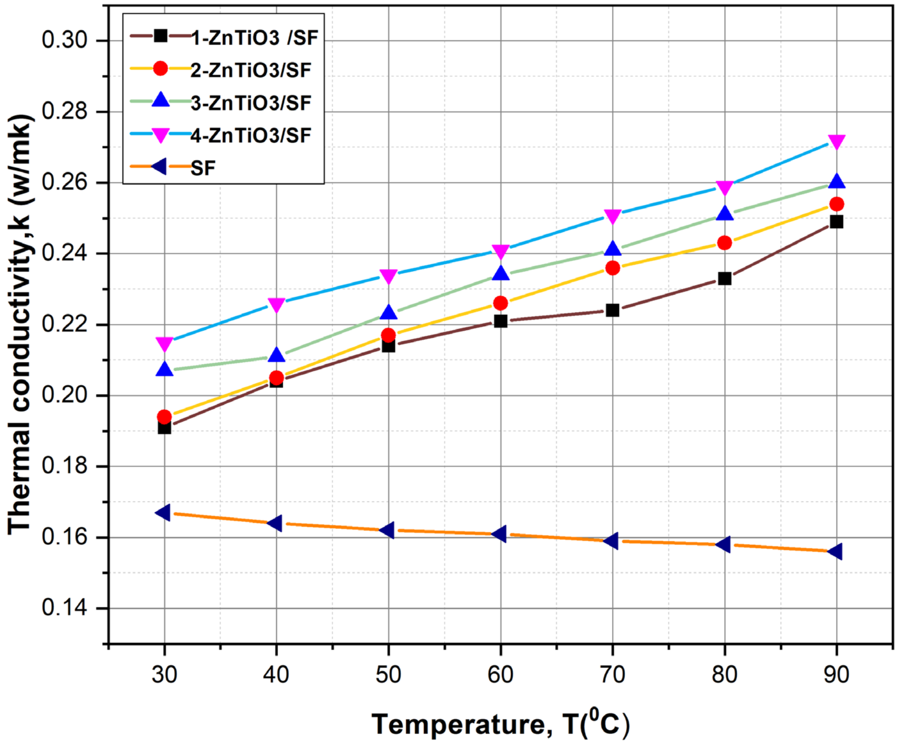

Figure 7. Thermal conductivity of $ZnTiO_3$/SF nanofluid w.r.t. nanoparticle Concentration**.**

Shear stress of Nanofluids:

The shear stress against shear rate graphs for SF vegetable oil, $ZnTiO_3$/SF based nanofluid for 1 wt. percent and 4.0 wt. percent concentrations are depicted in Figures 8 and 9 respectively. Shear-stress vs shear-rate plots of SF vegetable oil and $ZnTiO_3$ nanoparticle indicated a Newtonian linear trend. Shear stress for $ZnTiO_3$/SF nanofluid increases linearly with increasing shear rate, as seen in Fig 6, whereas shear stress reduces with increasing temperature. This is because of the mechanism behind the thickening process and entanglement process. The shear rate of 1000 1/s, NFs with 1wt. percent NP cont. produces shear stress of 23.7 Pa for $ZnTiO_3$/SF nanofluids at ambient temperature and 11.7 Pa at 90 °C.

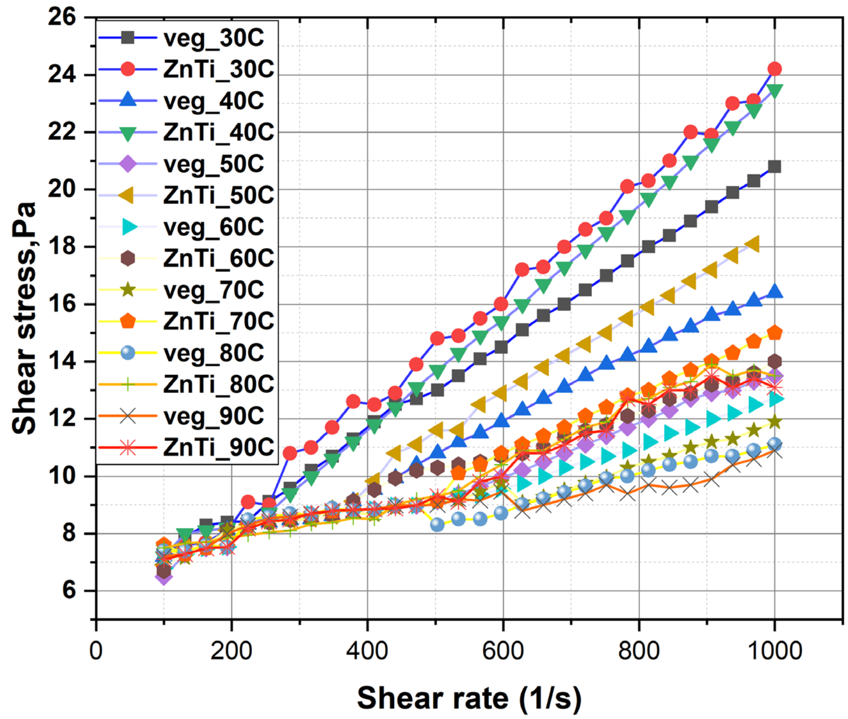

Figure 8. Shear stress of SF & 1wt.% $ZnTiO_3$/ SF

The shear rate of 1000 1/s, NFs with 4wt. percent NP cont. produces shear stress of 27 Pa for $ZnTiO_3$/SF nanofluids at ambient temperature and 8 Pa at 90 °C. Shear stress of SF nanofluid utilizing $ZnTiO_3$ nanoparticle as addition increases comparably to SF vegetable oil as nanoparticle wt. percent cont. increases.

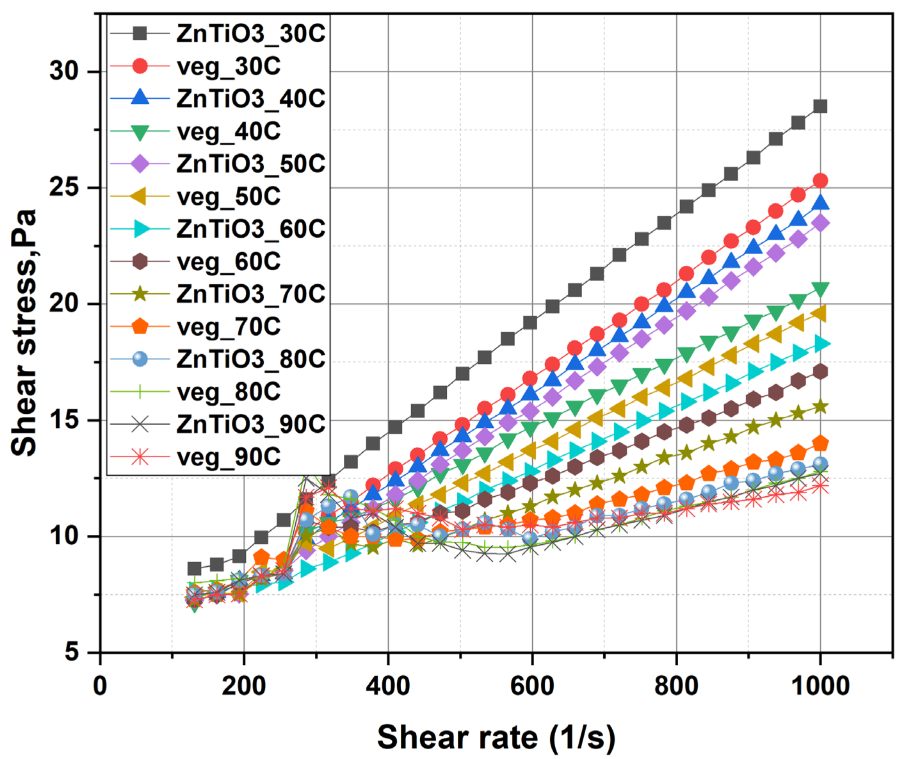

Figure 9. Shear stress of SF & 4wt.% $ZnTiO_3$/ SF

The viscosity of nanofluids:

This study investigates the effects of temperature and concentration of $ZnTiO_3$/SF nano cutting fluid on key parameters such as thermal conductivity, and viscosity. The viscosity of $ZnTiO_3$ nano cutting fluids is studied in a temperature range of 30–90 degrees Celsius at a shear rate of 100–1000 shear per second. The viscosity results of the $ZnTiO_3$/SF nano-cutting fluid are shown in Figure 10. When compared to the base oil, the $ZnTiO_3$/SF nano cutting fluids fluid exhibits a greater improvement in viscosity at particle concentrations ranging from 1 to 4 weight percent. When compared to the base fluid, the viscosity of $ZnTiO_3$/SF nanofluid was found to be improved by 26 percent% at a nanoparticle concentration of 4 weight percent at a temperature of 30 degrees Celsius. It has been observed that the viscosity of the $ZnTiO_3$/SF nano-cutting fluid increases as the particle concentration increases. As the temperature increased, there was a noticeable drop in viscosity. This property is reduced because the intermolecular force of attraction between the particles is reduced in strength when the temperature is increased. (Chinesta et al., 2010).

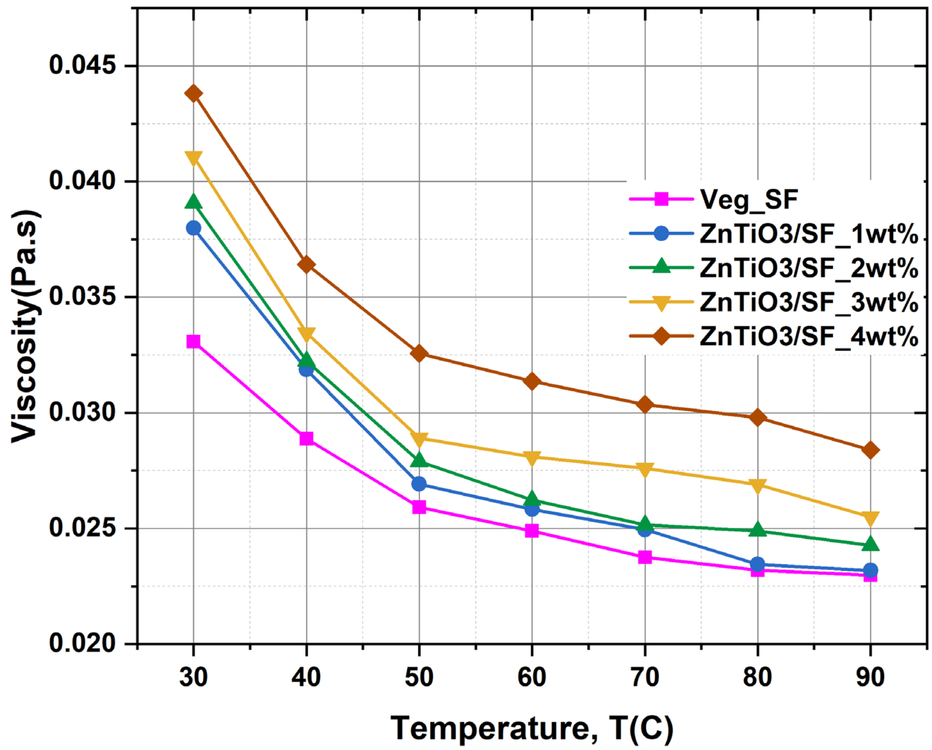

Figure 10. viscosity of ZnTiO3/SF nanofluid w.r.t. nanoparticle concentration and temperature

Surface Roughness (Ra)

The average surface roughness (Ra), which is a measurement that is commonly used in machining output parameters., The mechanical properties of the workpiece material is reduced by fatigue stresses if the surface quality is of an irregular texture. Hence, the surface quality of the material must be increased. In a dry machining environment, a large amount of friction is generated, which leads to excessive plastic distortion and immense stress at the cutting interface. As a result, the surface quality of the workpiece surface is reduced to an unacceptable level. The experiment results showed that MQL/NF had a surface roughness reduced by 41% when compared to dry machining and 19 % reduced when compared to MQL/Veg_SF machining which is shown in Figure 11. Nanofluid with MQL reveals that efficient lubrication may be given at the zone where the tool and the workpiece interact. As a result, the contact between the material used in the tool work is reduced to a minimum. In addition, nanofluid creates a barrier in the tool-workpiece zone, which reduces the amount of friction that is produced. Machining with MQL/nanofluids helps to reduce the temperatures experienced during the cutting process at the cutting zone. As a result, the surface finish has been observed to improve. The superior cooling makes it possible for chips to flow efficiently, which in turn reduces the amount of abrasion that occurs on the machined object. Through the use of nanofluids, an even surface profile may be created, which in turn helps to reduce the roughness value of the machined object.

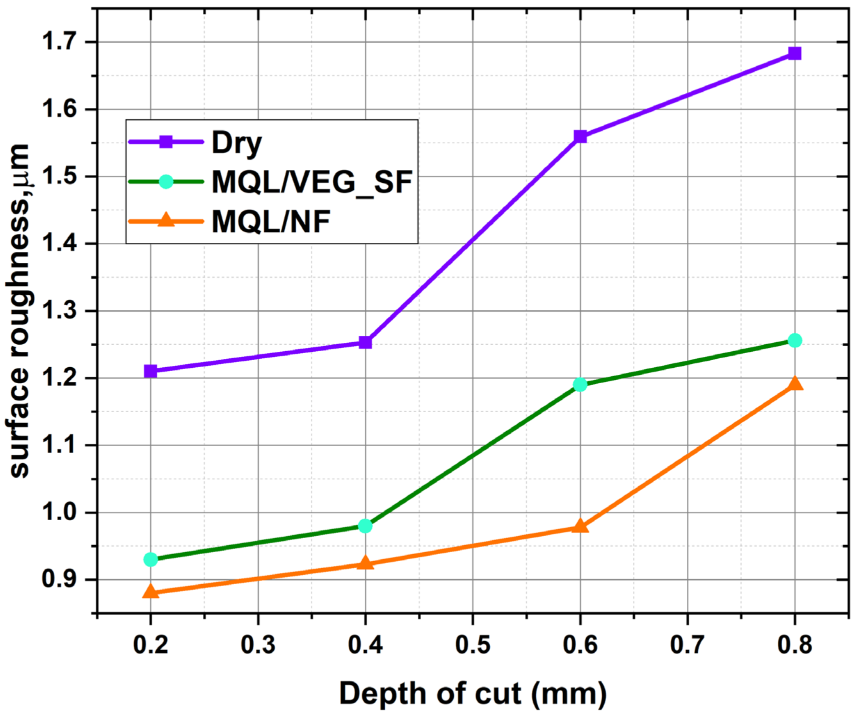

Figure 11. surface roughness w.r.t cutting conditions

Cutting Temperature

The cutting temperature that is produced during the machining operation is a critical parameter that should be investigated since it plays a significant role in deciding tool life. Metal is removed as a result of plastic deformation at the shear zone during the turning process, and friction develops at the flank and rake face during this process. The utilization of the lubrication and cooling method helps in the reduction of the heat that is generated during machining. The temperature of the tool-chip contact is represented in Figure 12 under a variety of cutting parameters and a variety of lubricating and cooling environments. When using MQL with nanofluid the tool–chip contact temperature is reduced to its lowest possible value. The outcomes of the experiments show a temperature increases with increasing cutting speed. It's because the high cutting speed creates more friction which increases the temperature of the cutting interface. The experiment results showed that MQL/NF had a temperature-reduced by 37.21% when compared to dry cutting and 14 % reduced when compared to MQL/Veg_SF environment. Because MQL effectively increases the penetration of Nano cutting fluid into the cutting area, hence minimizes the amount of friction that occurs between the workpiece and cutting tool. During the machining process, forced convection is identified as an important mechanism for the transfer of heat because of its ability to effectively remove heat. However, it was observed in the graph that the use of pure-MQL was not enough to sufficiently lower the temperature of the chip–tool contact. However, the usefulness of a mixture of vegetable oil-based MQL and nanoparticles has been demonstrated through the temperature reduction at the interface between the chip and the tool.

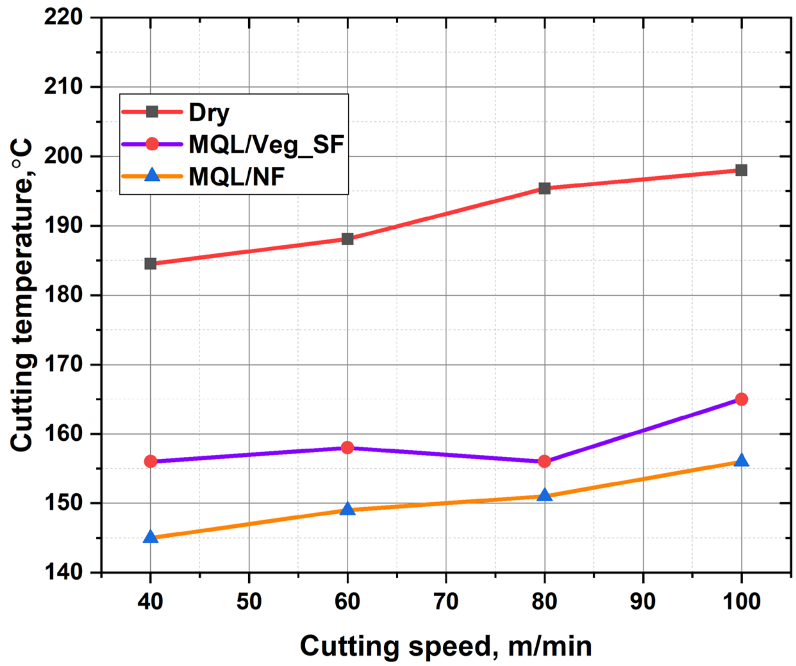

Figure 12. Cutting temperature w.r.t cutting conditions.

6. Conclusion

In this present study, a nanofluid (Zinc Titanate/SF) was prepared and then analyzed to identify its thermal conductivity and viscosity. This nanofluid is used as a cutting fluid during Inconel-718 turning, and its performance is compared between dry, MQL/Veg SF, and MQL/NF. The results that were obtained for MQL/NF, MQL/Veg_SF, and Dry cutting are comparable in terms of cutting temperature and surface roughness.

The following conclusions are to be drawn:

- Increasing the wt% concentration of nanoparticles in base oil results in improvements in the viscosity and thermal conductivity of the cutting fluid.
- When compared to the base fluid, the thermal-conductivity of $ZnTiO_3$/SF cutting fluid was found to be improved by 38.31 percent at a nanoparticle concentration of 4 weight percent at a temperature of 90 degrees Celsius.
- The shear rate of 1000 1/s, NFs with 1 wt. percent nanoparticle concentration produces shear stress of 23.7 Pa for ZnTiO3/SF nanofluids at ambient temperature and 11.7 Pa at 90 °C.
- When compared to the base fluid, the viscosity of $ZnTiO_3$/SF nanofluid was found to be improved by 26 percent at a nanoparticle concentration of 4 weight percent at a temperature of 30 degrees Celsius.
- The use of nano-cutting fluid enhanced the performance of machining by lowering the surface roughness by up to 42% relative to dry machining and by 19% relative to MQL/Veg SF machining, respectively.
- During machining, the use of nanofluid reduces the cutting temperature by 37.21% percent, and 14 percent, when compared to dry machining and MQL/Veg SF respectively.

References

Amrita, M., Srikant, R. R., & Sitaramaraju, A. V. Performance evaluation of nanographite-based cutting fluid in machining process. *Materials and Manufacturing Processes*, vol 29, no. 5, pp. 600–605, 2014.

Cherkasova, A. S., & Shan, J. W. Impact of altering aspect ratio of the loading particles on a suspension's thermal conductivity. *Proceedings of IMECE2008, Paper No: IMECE2008-67854, pp. 1979-1989,* Boston, Massachusetts, USA, 2008.

Chinesta, Francisco., Chastel, Yvan., & Mansori, M. Investigation on the Surface Integrity and Tool Wear in Cryogenic Machining. *International conference on advances in materials and processing technologies:* vol 1315, no. 1, 2010.

Das, A., Patel, S. K., & Das, S. R. Performance comparison of vegetable oil-based nanofluids towards machinability improvement in hard turning of HSLA steel using minimum quantity lubrication. *Mechanics and Industry*, vol 20, no. 5, 2019.

Gajrani, K. K., & Sankar, M. R. Sustainable Cutting Fluids: Thermal, Rheological, Biodegradation, Anti-Corrosion, Storage Stability Studies, and its Machining Performance. *Encyclopedia of Renewable and Sustainable Materials* pp. 839–852, 2020.

Gupta, M. K., Song, Q., Liu, Z., Sarikaya, M., Jamil, M., Mia, M., Singla, A. K., Khan, A. M., Khanna, N., & Pimenov, D. Y. Environment and economic burden of sustainable cooling/lubrication methods in the machining of Inconel-800. *Journal of Cleaner Production*, vol 287, 2021a.

Gupta, M. K., Song, Q., Liu, Z., Sarikaya, M., Jamil, M., Mia, M., Singla, A. K., Khan, A. M., Khanna, N., & Pimenov, D. Y. Environment and economic burden of sustainable cooling/lubrication methods in the machining of Inconel-800. *Journal of Cleaner Production*, vol 287, 2021b.

Hong, S. Y., Broomer, M., Hong, S. Y., & Broomer, M. Economical and ecological cryogenic machining of AISI 304 austenitic stainless steel. Em *Original Papers Clean Products and Processes* vol. 2, pp. 157-166, 2000.

Kazeem, R. A., Fadare, D. A., Ikumapayi, O. M., Adediran, A. A., Aliyu, S. J., Akinlabi, S. A., Jen, T.-C., & Akinlabi, E. T. Advances in the Application of Vegetable-Oil-Based Cutting Fluids to Sustainable Machining Operations—A Review. *Lubricants*, Volume 10, no 4, 2022.

Khanafer, K., Eltaggaz, A., Deiab, I., Agarwal, H., & Abdul-latif, A. Toward sustainable micro-drilling of Inconel 718 superalloy using MQL-Nanofluid. *International Journal of Advanced Manufacturing Technology*, vol 107, no 7-8, pp. 3459–3469, 2020.

Krolczyk, G. M., Maruda, R. W., Krolczyk, J. B., Wojciechowski, S., Mia, M., Nieslony, P., & Budzik, G. Ecological trends in machining as a key factor in sustainable production – A review. Em *Journal of Cleaner Production*, Vol. 218, pp. 601–615, 2019.

Kumar Sharma, A., Kumar Tiwari, A., Singh, R. K., & Dixit, R. Tribological Investigation of TiO 2 Nanoparticle based Cutting Fluid in Machining under Minimum Quantity Lubrication (MQL). *Recent Advances In Nano Science And Technology*, vol. 3, no 6, pp. 2155-2162, 2016.

Lee, C. G., Hwang, Y. J., Choi, Y. M., Lee, J. K., Choi, C., & Oh, J. M. A study on the tribological characteristics of graphite nano lubricants. *International Journal of Precision Engineering and Manufacturing*, vol. *10*, no 1, pp. 85–90, 2009.

Li, M., Yu, T., Yang, L., Li, H., Zhang, R., & Wang, W. (). Parameter optimization during minimum quantity lubrication milling of TC4 alloy with graphene-dispersed vegetable-oil-based cutting fluid. *Journal of Cleaner Production*, vol. *209*, pp.1508–1522, 2019.

Majak, D., Olugu, E. U., & Lawal, S. A. Analysis of the effect of sustainable lubricants in the turning of AISI 304 stainless steel. *Procedia Manufacturing*, vol. *43*, pp. 495–502, 2020.

Marques, A., Narala, S. K. R., Machado, A. R., Gunda, R. K., Josyula, S. K., da Silva, R. B., & da Silva, M. B. Performance assessment of MQSL: Minimum quantity solid lubricant during turning of Inconel 718. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. *231, no.* 7, pp. 1144–1159, 2017.

Musavi, S. H., Davoodi, B., & Niknam, S. A. Effects of reinforced nanoparticles with surfactant on surface quality and chip formation morphology in MQL-turning of superalloys. *Journal of Manufacturing Processes*, vol. *40*, pp. 128–139, 2019.

Naresh Babu, M., Anandan, V., Muthukrishnan, N., Arivalagar, A. A., & Dinesh Babu, M. Evaluation of graphene based nano fluids with minimum quantity lubrication in turning of AISI D3 steel. *SN Applied Sciences*, vol. *1*, no. 10, 2019.

Nasiri, A., Shariaty-Niasar, M., Rashidi, A. M., & Khodafarin, R. Effect of CNT structures on thermal conductivity and stability of nanofluid. *International Journal of Heat and Mass Transfer*, vol. *55, no.* 5–6, pp. 1529–1535, 2012.

Nwoguh, T. O., Okafor, A. C., & Onyishi, H. A. Enhancement of viscosity and thermal conductivity of soybean vegetable oil using nanoparticles to form nanofluids for minimum quantity lubrication machining of difficult-to-cut metals. *International Journal of Advanced Manufacturing Technology*, vol. *113*, no. 11–12, pp. 3377–3388, 2021.

Pal, A., Chatha, S. S., & Sidhu, H. S. Tribological characteristics and drilling performance of nano-MoS2-enhanced vegetable oil-based cutting fluid using eco-friendly MQL technique in the drilling of AISI 321 stainless steel. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. *43*, no. 4, 2021.

Rojas, E. E. G., Coimbra, J. S. R., & Telis-Romero, J. Thermophysical properties of cotton, canola, sunflower and soybean oils as a function of temperature. *International Journal of Food Properties*, vol. *16*, no. 7, pp. 1620–1629, 2013.

Ross, N. S., Mia, M., Anwar, S., G, M., Saleh, M., & Ahmad, S. A hybrid approach of cooling lubrication for sustainable and optimized machining of Ni-based industrial alloy. *Journal of Cleaner Production*, vol. *321*, 2021.

Sharma, A. K., Tiwari, A. K., & Dixit, A. R. Progress of Nanofluid Application in Machining: A Review. Em *Materials and Manufacturing Processes* Vol. 30, no. 7, pp. 813–828, 2015.

Singh, R. K., Dixit, A. R., Mandal, A., & Sharma, A. K. 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, 2017.

Tamang, S. K., Chandrasekaran, M., & Sahoo, A. K. Sustainable machining: an experimental investigation and optimization of machining Inconel 825 with dry and MQL approach. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. *40*, no. 8, 2018.

Tazehkandi, A. H., Shabgard, M., & Pilehvarian, F. Application of liquid nitrogen and spray mode of biodegradable vegetable cutting fluid with compressed air in order to reduce cutting fluid consumption in turning Inconel 740. *Journal of Cleaner Production*, vol. *108*, pp. 90–103, 2015.

Thakre, A. A., Lad, A. v, & Mala, K. *Measurements of Tool Wear Parameters Using Machine Vision System*, 2019.

Ucun, I., Aslantasx, K., & Bedir, F. The effect of minimum quantity lubrication and cryogenic pre-cooling on cutting performance in the micro milling of Inconel 718. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. *229*, no. 12, pp. 2134–2143, 2015.

Vajjha, R. S., & Das, D. K. A review and analysis on influence of temperature and concentration of nanofluids on thermophysical properties, heat transfer and pumping power. *International Journal of Heat and Mass Transfer*, vol. *55*, no. 15–16, pp. 4063–4078, 2012.

Yildirim, Ç. V., Kivak, T., Sarikaya, M., & Şirin, Ş. Evaluation of tool wear, surface roughness/topography and chip morphology when machining of Ni-based alloy 625 under MQL, cryogenic cooling and CryoMQL. *Journal of Materials Research and Technology*, vol. *9*, no. 2, pp. 2079–2092, 2020.

Zhang, S., Li, J. F., & Wang, Y. W. Tool life and cutting forces in end milling Inconel 718 under dry and minimum quantity cooling lubrication cutting conditions. *Journal of Cleaner Production*, vol. *32*, pp. 81–87, 2012a.

Zhang, S., Li, J. F., & Wang, Y. W. Tool life and cutting forces in end milling Inconel 718 under dry and minimum quantity cooling lubrication cutting conditions. *Journal of Cleaner Production*, vol. *32*, pp. 81–87, 2012b.

Zhang, S., Li, J. F., & Wang, Y. W Tool life and cutting forces in end milling Inconel 718 under dry and minimum quantity cooling lubrication cutting conditions. *Journal of Cleaner Production*, vol. *32*, pp. 81–87, 2012c.

Biographies

Pandi Jyothish graduated in Mechanical Engineering from Bapatla Engineering College, bapatla in the year 2014. And completed my post-graduation in Manufacturing Engineering dept. from NIT-TRICHY, in the year 2017, currently, I am pursuing a Ph.D. in Nit-Warangal. Totally I had two years of teaching experience in engineering colleges. My research area of Interest includes Nano lubricants, metal cutting, and sustainable manufacturing.

Dr. V. Vasu graduated in Mechanical Engineering from V R Siddhartha Engineering College, Vijayawada in 1999. Earned his post-graduation in Manufacturing Engineering from BITS, Pilani in 2003, Ph.D. from JNTU, Hyderabad in 2010, and POST-DOC under Erasmus Mundus fellowship from Politecnico Di Milano, Italy, Europe 2014. Presently, he is serving as a Professor at the National Institute of Technology, Warangal, India. He has published several papers in international journals and participated in several conferences and presented technical papers. He developed an online pedagogy course for "Mechatronics" and Systems & Controls under ICT MHRD, India. He has guided 4 Ph.D. works and is currently guiding 3. He was awarded the Young Engineer 2010 Award by IE India and Govt. of AP and Outstanding researcher in Nanotechnology Awards 2016. He is also a member of Siemens Centre of excellence Industry 4.0, NITW.

Dr. Dhurke Kashinath graduated with B.Sc. (chemistry, Biology) from Kakatiya University, Warangal in the year 1996, he earned his post-graduation in M.Sc. (organic chemistry) from Osmania University, Hyderabad during 1996-1998, Project Assistant, Indian Institute of Chemical Technology, Hyderabad, Aug 1998-Dec 1999, Ph.D. (Organic synthesis) from Indian Institute of Technology Bombay, Mumbai during the year 2000-2005. Postdoctoral Fellow, from University of Louis Pasteur, Strasbourg, FRANCE (June 2005-October 2006). He worked as **Assistant Professor**, National Institute of Technology, Warangal Nov 2006-May to 2007, and from April 2012 to March

2018. He worked as an Associate Scientific Manager, BBRC, Syngene International Ltd, Bangalore May 2009 to June 2011, Faculty Member, SPPSchool of Pharmacy and Technology Management, NMIMS, Mumbai, July 2011-April 2012. Presently, he is serving as a Professor at the National Institute of Technology, Warangal, India. He has published many papers in international journals and has participated in several conferences. He was awarded as Best Review Article Award from IIT Bombay for the academic year 2005. His research area of Interest is the Development of synthetic methods (Homogeneous and Heterogeneous catalysis,and the Synthesis of biologically active compounds.