EXPERIMENTAL & NUMERICAL INVESTIGATION OF MACHINABILITY OF INCONEL 718 BY USING MWCNT – REVIEW PAPER

Mr. Kamble A.V.[1], Dr. Patil A.A.[2]

[1] Research scholar, Mechanical Engineering Department, Sanjay Ghodawat University Kolhapur.

[2]Assistant Professor, Mechanical Engineering Department, Sanjay Ghodawat University Kolhapur.

Abstract- ***Inconel 718 is a nickel-based superalloy widely used in aerospace, marine, power generation, and nuclear industries due to its exceptional corrosion resistance, high-temperature strength, toughness, and phase stability. However, its poor machinability—arising from low thermal conductivity and severe work-hardening—challenges traditional flood-cooling turning processes, often compromising surface finish and subsurface integrity. To address this, Minimum Quantity Lubrication (MQL), which delivers just 5–500 ml/h of lubricant mist using compressed air (3–7 bar), has garnered attention as an eco-friendly alternative to conventional flood cooling. Yet, its efficacy in machining difficult alloys like Inconel 718 is limited—especially under conventional MQL—prompting exploration of nanofluid-enhanced MQL systems (NFMQL). Recent studies demonstrate that nanofluids—comprising nanoparticles such as Al_2O_3, MoS_2, MWCNT, Ag-coated ZnO, and Ag/ZnO hybrids suspended in vegetable or glycol-based oils—significantly improve thermal conductivity, lubrication, and heat dissipation when used in NFMQL. For instance, palm-oil-based nanofluid with 1 wt.% MoS_2 led to notable reductions in surface roughness and tool wear compared to dry, flood, and conventional MQL setups. Similarly, hybrid Al_2O_3+MWCNT nanosuspensions achieved roughness values of ~0.6–0.7 µm, lower cutting forces (≤80 N), and enhanced tool life (>10 min) under optimal conditions (50–70 m/min, 0.1 mm/rev, 0.2 mm depth)***

Additionally, insert micro-texturing (grooves/pits) synergizing with MoS_2/MWCNT nanofluids further reduced cutting forces and improved surface integrity. Advanced hybrid formulations—such as Ag/ZnO in glycol—have likewise demonstrated up to 23.5 % surface finish enhancement and 15 % lower cutting temperatures relative to conventional MQL. This review synthesizes experimental and analytical advances in applying nanofluid-enhanced MQL to Inconel 718 turning. Key trends include superior tribological performance, heat management, and sustainability of NFMQL over flood cooling and standard MQL, especially with tailored nanoparticle blends, base fluids, and surface-engineered tooling. However, to fully harness NFMQL's potential, future research should optimize particle concentration, nozzle design, fluid stability, and waste handling protocols to ensure industrial viability and eco-compliance.

Keywords- ***Inconel 718 superalloy . Flood coolant . MQL . MQL-nanofluid . Thrust force . Tool wear***

I. INTRODUCTION

Conventional machining is one of the most important metal removal methods. Turning operation is very important material removal process in modern industries. At least one fifth of all applications in metal cutting are turning operations. Inconel 718, a nickel based super alloy is an extensively used alloy in the aerospace industry, marine industry, steam turbine, power plants, nuclear reactors, pumps and aircraft engine. It is difficult to cut material due to its properties like low thermal conductivity, work hardening etc and retains its strength at high temperatures. Due to low machinability of this material, worked surface and subsurface are easily effected during machining operations. Close tolerance and outstanding surface finish become critical for their application. Therefore, surface finish plays a vital role in machining Inconel 718.

To achieve good surface finish, coated tools, cryogenic cooling, MQL, synthetic lubricants, micro and nano solid lubricants and vegetable oil-based lubricants, nanofluids are being explored by scientists and tribologists. The conventional approach is known as flood cooling in which coolants, generally emulsions of mineral oils, are applied with high delivery rate in the contact region during the machining process. However, the cost of recycling and disposal of cutting fluid is high and the environmental impacts are significant. It is a well-known fact that lubricants are used extensively in metal working industries to prolong the life of mechanical tools, improve surface finish, and slow down tool wear and to reduce friction. Nevertheless, this greatly contributes towards environmental pollution. There are a few alternatives to flood cooling, including cryogenic cooling, water vapour cooling, solid lubricants, and minimum quantity lubrication (MQL). Hence, minimal quantity of lubrication have been attempted and suggested by researchers worldwide for the metal cutting industries. The recent development of nanofluids provides alternative to cutting fluids and can be used as MQL in machining.

MQL technique employs a mixture of high-pressure air (3–7 bar) and small amount of lubricating fluid (5–500 ml/h), supplying it to the contact region during machining. To improve the lubrication properties of MQL system, application of different nanofluids is an ongoing research area.

MQL is proving a promising method in improving the performance of the machining process. Therefore, MQL system not only provides environmental friendliness but also improve machinability characteristics [5,6]. When it came to the machining of difficult to cut material like Inconel and titanium, MQL is not an effective replacement of flood cooling. In MQL system mixture of compressed air and oil is passed through nozzle onto the working area. System is represented in the simple form in the figure 1.

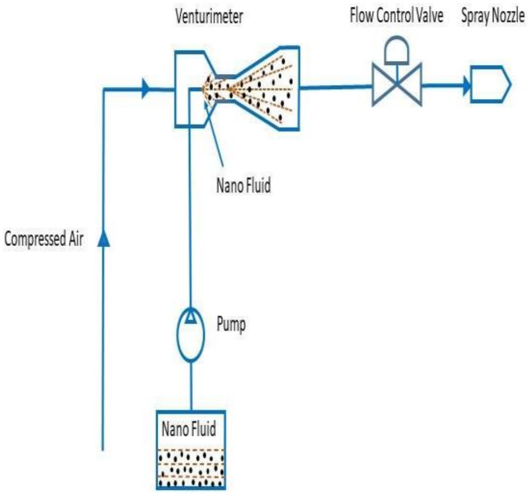


Figure 1. Schematic representation of MQL system

Inconel 718 has high corrosion resistance, hot strength, hardness, toughness, and phase stability at elevated temperature these super properties lead to its use in aeronautical industries. So, to give an edge to MQL while machining these materials MQL is assisted with nano lubricants to improve performance. From Economical, environmental and technical point of view nanofluids are the first choice among all other lubrication techniques. Multi-walled carbon nanotube (MWCNT)-based nanofluids are often preferred over other types of nanofluids due to their unique properties and performance advantages in various applications. Here are the key reasons:

1. Superior Thermal Conductivity

MWCNTs possess exceptional thermal conductivity (up to 3000–6000 W/m·K), which significantly enhances the thermal conductivity of the base fluid when dispersed. This makes MWCNT-based nanofluids highly efficient for heat transfer applications.

2. High Aspect Ratio

The elongated, tubular structure of MWCNTs provides a high aspect ratio, increasing the surface area for heat transfer and improving interactions with the fluid, which enhances thermal performance.

3. Mechanical Strength

MWCNTs are known for their remarkable mechanical properties, such as high tensile strength and elasticity, which contribute to the stability and durability of the nanofluid under high stress conditions.

4. Stability in Suspension

Proper functionalization and dispersion techniques ensure that MWCNTs remain stably suspended in the base fluid, reducing the likelihood of agglomeration and ensuring consistent performance over time.

5. **Electrical Conductivity**

MWCNTs have excellent electrical conductivity, making MWCNT-based nanofluids suitable for applications where both thermal and electrical conductivity are required, such as in electronic cooling or energy systems.

6.Wide Range of Applications

MWCNT-based nanofluids are versatile and can be used in various domains such as:

Heat exchangers

Solar thermal systems

Engine cooling

Biomedical cooling systems

7. Cost-effectiveness

Although MWCNTs are more expensive than some other nanoparticles, their higher efficiency often means less material is required to achieve a desired performance level, making them cost-effective in many applications.

8. Enhanced Rheological Properties

MWCNTs can improve the viscosity and flow behavior of the base fluid, optimizing the performance in specific engineering systems.

Comparison with Other Nanofluids

While other nanofluids, such as those based on metals (e.g., Al2O3, CuO) or non-metallic particles (e.g., graphene), also offer benefits, MWCNT-based nanofluids often outperform them in terms of:

1. Higher thermal and electrical conductivity
2. Better stability due to functionalization
3. Broader compatibility with different base fluids

However, challenges like ensuring uniform dispersion, controlling viscosity, and managing production costs must be addressed to maximize their potential.

II. Literature Review

Mathew et.al [1] optimized cutting parameters and nanoparticle concentration during turning of EN8 using Al2O3 as Nano fluid. Speed, Feed, depth of cut and nanoparticle concentration were the process parameters used to analyze surface roughness. By analysis of variance (ANOVA) it was found that nanoparticle concentration and feed were the most influencing factor on surface roughness.

Pasam et. Al [2] compared performance of surface roughness of nanofluid of MoS2 and microfluid of H3BO3 in MQL system during turning of AISI 1040. They perceived that at low-speed nano and microfluid exhibits almost similar performance but at high speed nanofluid outclasses microfluid due to super lubricating and cooling properties. MoS2 provides 30% less surface roughness than H3BO3. This is on the account of fact that nanofluid forms stable and consistence lubrication effect leading to reduce friction and associate effect.

Prasad et. al [3] evaluated inclusion of graphite nanoparticles in cutting fluid with MQL during turning of AISI 1040. Graphite nanoparticles were used in 0,0.1,0.3 and 0.5 weight percentage concentration in cutting fluid with MQL technique having 15ml/hr and 5 ml/hr flow rate. Surface roughness was decrease with inclusion of graphite nanoparticle and found minimum for 0.3 wt % inclusion of nanoparticles for 15 ml/hr flow rate.

Roy et. al [4] evaluated surface roughness of high speed turning of AISI 4140 using nanofluid with twin jet small quantity lubricant (SQL). MWCNT and Al_2O_3 nanoparticles were used during experimentation and they noted that Al_2O_3 which were spherical in shape produces rolling effect and MWCNT produces mending effect during turning process. They ascertained that surface roughness also depends upon the critical factor such as surface residual stress. During turning they found that residual stress were tensile in nature. Implementation of SQL significantly reduces surface roughness for MWCNT nanofluid.

Similarly, Roy and Ghosh [5] found that Multi-walled carbon nanotubes based nanofluid outperforms dry, wet and conventional cooling.

In another study of Thakur et. al [6] they tested SiC nanoparticles for EN-24 material with 0.5,1 and 1.5weight % and found 1.5 weight % SiC nanofluid shows minimum surface roughness. This may be due to 0.5 weight % SiC nanofluid have highest thermal conductivity and lowest coefficient of friction leading to cooling effect and hence less surface roughness and tool wear was obtained. Huang et.al [7] tested air pressure in MQL system and found with increasing air pressure surface roughness slowly decreases initially further increase in air pressure surface roughness decreases quickly up to 6 bar. The reason behind decrease in surface roughness may be with increasing air pressure the flow rate increases leading to formation of small droplets of aerosol from oil and its size decreases with increasing the air pressure. This small size aerosol easily enter into tool- cheap interface which leads to take away heat and consequently less surface roughness.
Grinding of AISI D3 steel was accomplished by using depth of cut, feed, and speed with and without MWCNTs nanofluid. Specimen machined with Nanofluid exhibits enhanced surface quality than specimen machined without nanofluid. The addition of nanoparticles increases the surface area to volume ratio, improving the surface roughness of the MWCNTs nanofluid [8]

Kumar et. al and Gupta et. al used approach angle as a process parameter with cutting speed and feed by keeping the depth of cut constant [9-10]. The impact of these factors on tool wear, cutting temperature, cutting force, and surface roughness was examined. Moving one step ahead researchers also analysed the result of single nanoparticles and hybrid nanoparticles on output parameters. To measure nodal temperature, some researchers have used the feed, depth of cut, nanoparticle concentration, and speed with three levels. They analysed these parameters by taking single nanoparticles and hybrid nanoparticles and compared results [11-12]. Alumina nanoparticles and Al-MWCNT hybrid nanoparticles' effects on nodal temperature and tool wear are compared. They found a 27.36 % nodal temperature reduction by using Al-MWCNT hybrid nanoparticles. Al-MWCNT hybrid nanoparticle's better thermal conductivity may be the cause of this. These lead to minimum tool wear with an increased percentage of nanoparticles. This effect is well illustrated in Figure.

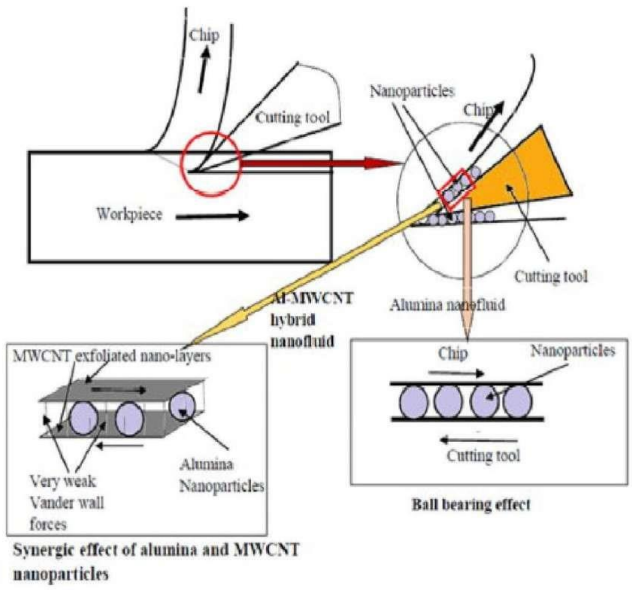


Figure 2. : Synergic effect of alumina and Al-GnP nanoparticles trapped between the sliding surfaces [12]

Paul et al.[13] found that grinding of Ti-6Al-V with nanofluid MWCNT demonstrated superior performance to Al_2O_3 nanofluid for specific grinding force and energy. Al_2O_3 nanofluid acts as an abrasive due to its aging effect caused by agglomeration even though they are spherical.
Prabhu et al. analyzed surface roughness this time by using single walled carbon nanotubes using electrolytic in-process dressing (ELID) technique. Figure 3 shows morphology images machined surfaces for with and without ELID and nanofluid obtained from AFM.

III. Gaps Identified

1. Limited work related to measurement of temperature using MWCNT While many studies explore measurement of surface roughness and tool wear, it has been observed that very little work has been reported for measurement of temperature during turning of Inconel 718 using nanofluid

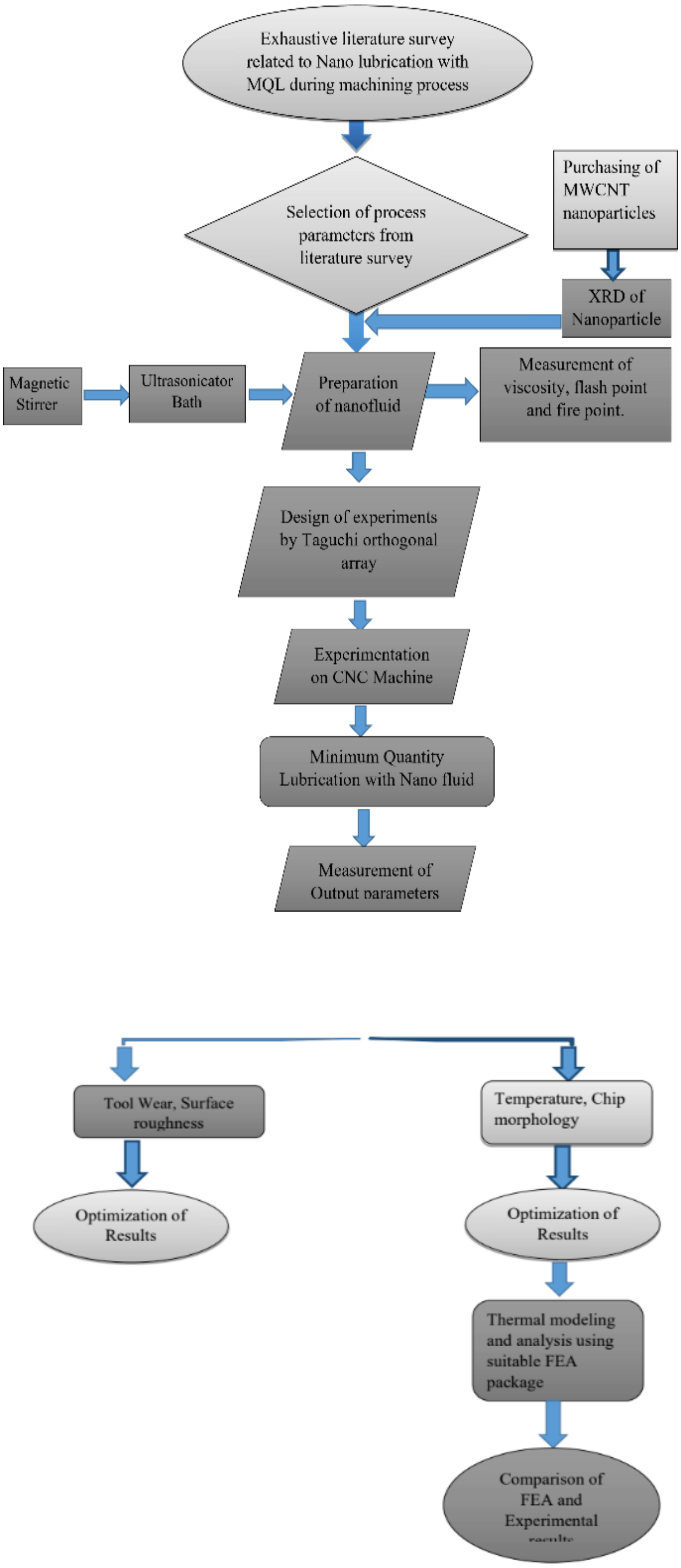
2. Limited work related to measurement of temperature using MWCNT very few work has been reported for analysis of chip morphology during turning of Inconel 718 using nanofluid with MWCNT.
3. Performance Evaluation of MWCNT MWCNT nanofluid evaluation for temperature and chip morphology study as a parameters has only been employed by a relatively smaller number of researchers and its effect on the output parameters.

4. MWCNT nanofluid has been found to be a better heat-carrying nanofluid than any other nanofluid because of its larger surface area to volume ratio. So, its effect during the machining of difficult-to-cut material like Inconel 718 needs to be studied.

5. Limited work n thermal modeling of Inconel 718 has been observed and its comparison and validation with the experimental results)

IV. Methodology

The Fig 3.1 describes the methodology followed for mechanical and abrasive studies respectively to complete the research work, and various tools that were employed at various stages of research.



V. Tools

Minitab software is available for Taguchi orthogonal design as well as for the optimization of process parameters. Magnetic stirrer and ultras nation bath are also available with the university. Ansys software is available with SGI University, Kolhapur for Thermal Modeling.

VI. Expected Outcome:

Inconel 718 belongs to difficult to cut material. It is extensively used in the application where there is necessity of high strength at the elevated temperature. Industries which are dealing with the machinability of this material will help to improve machinability in terms of surface roughness and tool wear. At the same time these industries will directly get the optimum process parameters at which minimum surface roughness, tool wear and temperature can be achieved during the machining of Inconel 718. From thermal modeling without doing experimentation, we can predict temperature during turning of Inconel 718.

References:

[1] Mani, N. K.; Mathew, C.; Kallanickal, P. M. Optimization of Cutting Parameters & Nanoparticle Concentration in CNC Turning of EN8 Steel Using Al2O3 Nanofluids as Coolant. Int. J. Eng. Trends Technol., 2015, 29 (6), 290–294. https://doi.org/10.14445/22315381/ijett-v29p254.

[2] Pasam, V. K.; Srikant Revuru, R.; Gugulothu, S. Comparing the Performance & Viability of Nano and Microfluids in Minimum Quantity Lubrication for Machining AISI1040 Steel. Mater. Today Proc., 2018, 5 (2), 8016–8024. https://doi.org/10.1016/j.matpr.2017.11.486.

[3]M. M. S. P. Performance Evaluation of Nano Graphite Inclusions in Cutting Fluids WithMql Technique in Turning of Aisi 1040 Steel. Int. J. Res. Eng. Technol., 2013, 02 (11), 381–393. https://doi.org/10.15623/ijret.2013.0211058.

[4] Roy, S. Msec2013-1067 High Speed Turning of Aisi 4140 Steel Using Nanofluid. 2016, 1–6. Roy, S.; Ghosh, A. High-Speed Turning of AISI 4140 Steel by Multi-Layered TiN TopCoated Insert with Minimum Quantity Lubrication Technology and Assessment of near Tool-Tip Temperature Using Infrared Thermography. Proc. Inst. Mech. Eng. Part B J. Eng.Manuf.,2014,228(9),1058–1067. https://doi.org/10.1177/0954405413514570.

[5] Thakur, A.; Manna, A.; Samir, S. Multi-Response Optimization of Turning Parameters during Machining of EN-24 Steel with SiC Nanofluids Based Minimum Quantity Lubrication. Silicon, 2020, 12 (1), 71–85. https://doi.org/10.1007/s12633-019-00102-y.

[6] Huang ,X; Ren,Y; Influence of Minimum Quantity Lubrication Parameters on Grindhardening Process, 2016, 9 (2), 118–131.

[7] Prabhu, S.; Vinayagam, B. K. AFM Investigation in Grinding Process with Nanofluids Using Taguchi Analysis. Int. J. Adv. Manuf. Technol., 2012, 60 (1–4), 149–160. https://doi.org/10.1007/s00170-011-3599-5.

[9] Kumar, S.; Singh, D.; Kalsi, N. S. Experimental Investigations of Surface Roughness of Inconel 718 under Different Machining Conditions. Mater. Today, Proc., 2017, 4 (2), 1179–1185. https://doi.org/10.1016/j.matpr.2017.01.135.

[9] Gupta, M. K.; Sood, P. K.; Sharma, V. S. Optimization of Machining Parameters and Cutting Fluids during Nano-Fluid Based Minimum Quantity Lubrication Turning of Titanium Alloy by Using Evolutionary Techniques. J. Clean. Prod., 2016,135,1276–1288. https://doi.org/10.1016/j.jclepro.2016.06.184.

[10] Kishawy, H. A.; Hegab, H.; Deiab, I.; Eltaggaz, A. Sustainability Assessment during Machining Ti-6Al-4V with Nano-Additives-Based Minimum Quantity Lubrication. J. Manuf. Mater. Process., 2019, 3 (3). https://doi.org/10.3390/jmmp3030061.

[11] Sharma, A. K.; Tiwari, A. K.; Dixit, A. R.; Singh, R. K.; Singh, M. Novel Uses of Alumina/Graphene Hybrid Nanoparticle Additives for Improved Tribological Properties of Lubricant in Turning Operation. Tribol. Int., 2018, 119 (October2017),9–111.
https://doi.org/10.1016/j.triboint.2017.10.036.

[12] Paul, S., Singh, A. K., & Ghosh, A. (2016). Grinding of Ti-6Al-4V Under Small Quantity Cooling Lubrication Environment Using Alumina and MWCNT Nanofluids. Materials and Manufacturing Processes, 32(6), 608–615.
DOI:10.1080/10426914.2016.1257797

[13] Chakule, R. R.; Chaudhari, S. S.; Talmale, P. S. Evaluation of the Effects of Machining Parameters on MQL Based Surface Grinding Process Using Response Surface Methodology. J. Mech. Sci. Technol., 2017, 31 (8), 3907–3916. https://doi.org/10.1007/s12206-017-0736-6.

[14] Sharma, A. K.; Singh, R. K.; Dixit, A. R.; Tiwari, A. K.; Singh, M. An Investigation on Tool Flank Wear Using Alumina/MoS2 Hybrid Nanofluid in Turning Operation; Springer International Publishing, 2019; Vol. 1. https://doi.org/10.1007/978-3-319-99353-9_23.

[15] Sahu, N. K.; Andhare, A. B.; Raju, R. A. Evaluation of Performance of Nanofluid Using Multiwalled Carbon Nanotubes for Machining of Ti–6AL–4V. Mach. Sci. Technol.,2018,22(3),476–492.
https://doi.org/10.1080/10910344.2017.1365898.

[16] Singh, H.; Sharma, V. S.; Singh, S.; Dogra, M. Nanofluids Assisted Environmental Friendly Lubricating Strategies for the Surface Grinding of Titanium Alloy: Ti6Al4V-ELI. J. Manuf. Process., 2019, 39 (September2018), 241–249. https://doi.org/10.1016/j.jmapro.2019.02.004.

.