Performance Evaluation of Titanium Dioxide (TiO2) Nano Cutting Fluids in CNC Turning of Aluminium Alloy (AL319) via Minimum Quantity Lubricant (MQL) Technique

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Abstract: Aluminium alloy AL319 is a common alloy that has superior mechanical properties such as hardness and weldability. Nanofluids can be applied to various industrial widely in the aircraft, automotive industry and engineering problems, such as heat exchangers, cooling of electronic equipment, and chemical processes. This research objective focuses on evaluating the performance of Nano cutting fluid mixing titanium dioxide (TiO2) in CNC Turning using material AL319 Aluminium Alloy with MQL technique. The cutting performance is assessed in terms of surface roughness, cutting temperature, and tool wear was investigated. Machining parameters used for spindle speeds of 1000 to 1800 rpm and feed speeds of 0.10 to 0.20 mm / rev are used on CNC turning machines. MQL pressure is constant at 0.5 Mpa, and for parameters of TiO2 Nano liquid with concentrations of three volumes (0.5, 1.0, and 1.5%) was then compared with conventional CNC cutting liquid. Beforehand, TiO2 is diffused in CNC conventional coolant base by using the one-step method. Response surface method (RSM) via Face Centered Design (FCD) was used in designing the experimental use of the variance analysis (ANOVA) to determine which parameters are statistically important. The stability of TiO2 Nano cutting fluid is checked via visual sedimentation. The experiment concluded that the lowest cutting temperature of 28°C and surface roughness of 0.863 μm Ra when TiO2 Nano cutting fluid with 1.5% volume concentration is employed. The TiO2 Nano cutting fluids are recommended in future work to obtain more significant results. The experimental research reveals that the performance of TiO2 Nanofluid in terms of surface roughness, cutting temperature, and tool wear are found to be better compared to dry machining, wet, and MQL machining using conventional cutting fluid. Nanofluids can be considered as the future of heat transfer fluids in various heat transfer applications. They are expected to give better thermal performance than conventional fluids due to the presence of suspended nanoparticles which have high thermal conductivity.
1. Introduction

Turning is a machining process in which the workpiece rotating while the cutting tool moving along the axis. (Abbas et al., 2019). This process will generate heat and friction around the workpiece. As a solution to this problem, cutting fluid is used to decrease the heat generated. The conventional methods of enhancing the cooling rate have already reached their limits. The use of novel approaches is essential to achieve high-performance cooling and lubrication. There is very little difference in machining performance of the conventional cutting fluid under the MQL technique and under the process of wet machining (Sharma, Tiwari, Dixit, & Singh, 2017). However, the parameter used need to be considered, from the analysis it is noted that the most influential factor for the multi-objective function is feed rate followed by the cutting condition, depth of cut and cutting speed (Viswanathan, Ramesh, & Subburam, 2018). It was proved that the adoption of hybrid lubricating/cooling strategies is a viable alternative to the conventional ones, leading to a drastic reduction of the crater wear as well as good surface integrity given an optimized positioning of the lubricant/coolant nozzles (Sartori, Ghioatti, & Bruschi, 2017).

MQL is minimum quantity lubricant which had been used by many factory and machinist to minimize or reduce the used of coolant. It should be stated that MQL-nanofluid offered promising results through the three studied cases compared to dry and flood approaches. This is mainly attributed to the cooling capabilities of both flood and MQL-nanofluid techniques to reduce the severity of the high-heat generated in the cutting zone. It should be also stated that MQL-Nano-mist does not only offered a promising cooling property but also has a pure tribological effect on the performance of the cutting process (Abbas et al., 2019). Other than that, minimum quantity lubrication is an extensively accepted lubrication system owing to its improved heat removal in the machining areas (Naresh Babu, Anandan, Muthukrishnan, Arivalagar, & Dinesh Babu, 2019). Furthermore, Al2O3–MWCNT–based MQL noticeably reduced the surface roughness and main cutting force when compared with cryogenic CO2–based cooling (Jamil et al., 2019).

Nanofluids provide a potential way to fulfill this requirement. Nanofluid can be defined as a fluid containing nanometer-sized particles. This Nanofluid has high potential as a heat transfer. Because of its potential as heat transfer, it can increase tool life, improving surface roughness, reducing workpiece thermal deformation, improving the surface finish of machining. Titanium dioxide, also known as titanium (IV) oxide or titanium, is the naturally occurring oxide of titanium, chemical formula TiO2. TiO2 prepares as a nanofluid. It will be added to the coolant by using the one-step method. Cutting fluid is a type of coolant and lubricant designed specifically for metalworking processes such as stamping and machining. There are various kinds of cutting fluids, which include oils, oil-water, pastes, gels, aerosols (mists), and air or other gases. They may be made from petroleum distillates, animal fats, plant oils, water, and air, or other raw ingredients. The experimental study clearly reveals that the performance of TiO2 nanofluid in terms of surface roughness, tool wear, cutting force and chip morphology is found to be better compared to dry machining, wet/MQL machining with conventional cutting fluid (Sharma, Tiwari, Singh, & Dixit, 2016). The thermal conductivity, density, specific heat and viscosity of three different nanofluids are compared with each other and found that the addition of nanoparticles into base fluid enhanced its cooling ability without much affecting its viscosity (Sharma, Tiwari, & Dixit, 2016).

This study focuses on evaluates the performance of TiO2 Nano cutting fluid in CNC turning of Aluminum Alloy AL319 via the MQL technique. The cutting performance is surface roughness, cutting temperature, and tool wear was investigated versus feed rate and spindle speed. This study will prove the effectiveness of TiO2 Nanofluid concentration in the turning process through the combination of TiO2 Nano and coolant.
2. Methodology

2.1. Preparation of Nano Cutting Fluid
Titanium dioxide TiO2 Nanofluid dispersed into conventional coolant preparation. The most widely used for preparing Nanofluid is the one-step method. First, titanium dioxide TiO2 used in this method is produced as a wet liquid. Next, it will be measured the volume of TiO2 in 1.50% which is the higher volume concentration Vt% by using a measuring cylinder. Then, measured the volume of distilled water and the volume of coolant will be used according to the calculation. After that, mix distilled water and coolant by using a method of stirring for 30 minutes. Last, mix Nanofluid with that already distilled water and coolant liquid by using a method of stirring within thirty minutes. Lastly, the solution will be placed on a water bath ultra sonicator for 30 minutes to make sure it dissolves completely as shown in Figure 1 below.

![Figure 1. Sonication Process](image)

2.2. Experimental Setup
Figure 2 below shows how the test rig was designed and developed. The air pressure was blown to give pressure at the coolant and the coolant will go up along the tube straight to the tool through MQL for lowering the quantity of lubricant. The nanofluid from the MQL nozzle spray mist directly to the workpiece and a cutting tool to reduce the temperature and reduce the tool wear of the tool while improving the surface roughness of the workpiece.

![Figure 2. Setup of Test Rig](image)
2.3. Design of Experiment (DOE)
The design of the experiment (DOE) of this project consists of 3 input parameters were measured such as feed rate, depth of cut and cutting speed. From this experiment, 3 responses were analyzed that is temperature, tool wear and roughness surface. The temperature measured using infrared laser thermometer DT 8280. The roughness surfaces the tool that was used to measure are profilometer surface roughness tester SJ-210 and the tool wear were using a machine vision system. RSM method was used to running this experiment. Table 1 shows the design of the experiment by using different levels with different control factors such as spindle speed, feed rate, and concentration of Nanofluid. Spindle speed that uses at 1000, 1400, and 1800 rpm. The concentration of Nanofluid is 0.50, 1.00, and 1.50 Vt%. Feed rate 0.10, 0.15, 0.20 mm/rev.

Table 1. Design of Experiment Using Level

| Control Factor     | Symbol | Units | Level 1 | Level 2 | Level 3 |
|--------------------|--------|-------|---------|---------|---------|
| Spindle speed      | V      | RPM   | 1000    | 1400    | 1800    |
| Feed rate          | f      | mm/rev| 0.10    | 0.15    | 0.20    |
| Concentration np   | Vt%    |       | 0.50    | 1.00    | 1.50    |
| Nanofluid          |        |       |         |         |         |

2.4. Response Surface Methodology (RSM)
Based on the input parameter and response need to analyze, Table 2 have been designed by using RSM software base on the concentration of Nanofluid, feed rate and spindle speed. The RSM software gives 20 runs of the experiment that needed to be done for this project.

Table 2. Design Layout by RSM

| STD | RUN | BLOCK | Volume Concentration (Vt %) | Spindle speed (RPM) | Feed rate (mm/rev) |
|-----|-----|-------|---------------------------|--------------------|--------------------|
| 5   | 1   | Block 1 | 1.50                      | 1000               | 0.10               |
| 19  | 2   | Block 1 | 1.00                      | 1400               | 0.15               |
| 11  | 3   | Block 1 | 1.00                      | 1400               | 0.10               |
| 9   | 4   | Block 1 | 1.00                      | 1000               | 0.15               |
| 2   | 5   | Block 1 | 0.50                      | 1800               | 0.10               |
| 14  | 6   | Block 1 | 1.50                      | 1400               | 0.15               |
| 1   | 7   | Block 1 | 0.50                      | 1000               | 0.10               |
| 6   | 8   | Block 1 | 1.50                      | 1800               | 0.10               |
| 20  | 9   | Block 1 | 1.00                      | 1400               | 0.15               |
| 7   | 10  | Block 1 | 1.50                      | 1000               | 0.20               |
| 15  | 11  | Block 1 | 1.00                      | 1400               | 0.15               |
| 4   | 12  | Block 1 | 0.50                      | 1800               | 0.20               |
| 3   | 13  | Block 1 | 0.50                      | 1000               | 0.20               |
| 8   | 14  | Block 1 | 1.50                      | 1800               | 0.20               |
| 18  | 15  | Block 1 | 1.00                      | 1400               | 0.15               |
| 17  | 16  | Block 1 | 1.00                      | 1400               | 0.15               |
| 10  | 17  | Block 1 | 1.00                      | 1800               | 0.15               |
| 12  | 18  | Block 1 | 1.00                      | 1400               | 0.20               |
| 16  | 19  | Block 1 | 1.00                      | 1400               | 0.15               |
3. Results and Discussion

3.1. Stability Tests
Sonication is implemented using an ultra-sonicator instruction to render Nanofluid stable and reduce agglomerate thickness. Each volume concentration Nanofluid was generated in a volume of 100 ml and placed into a sonicator for 30 minutes. Then, all throughout the measuring cycle, the Nanofluids were very stable. The Nanofluid was prepared with exact measurement showed good stability for several days without any significant sedimentation as shown in Figure 3 and the formula for dilution of nanofluid is shown below.

![Figure 3. Stability of Nano Cutting Fluids.](image)

\[ \text{Formula } \Delta v = v_2 - v_1 = v_1 \left( \frac{v_1}{v_2} \right) \]

3.2. Machining Results
Based on the detailed result of the experiment that was run 20 times using the RSM method to get the value of the most precision value of surface roughness, cutting temperature, and tool wear. From the result, the lowest value surface roughness (Ra) for 0.50 volume concentration of TiO2 Nanofluid is 1.022 μm when using 1000 rpm and 0.10 feed rate (mm/rev) with the depth of cut 0.50 mm. The highest value surface roughness (Ra) for 0.50 volume concentration of TiO2 Nanofluid is 2.492 μm when using 1000 rpm and 0.20 feed rate (mm/rev) with a depth of cut 0.50 mm. For 1.00 volume concentration of TiO2 Nanofluid the lowest value surface roughness (Ra) is 0.901 μm when using 1400 rpm and 0.10 feed rate (mm/rev) with a depth of cut 0.50 mm. The highest value surface roughness (Ra) for 1.00 volume concentration of TiO2 Nanofluid is 2.268 μm when using 1400 rpm and 0.15 feed rate (mm/rev) with a depth of cut 0.50 mm. For 1.50 volume concentration of TiO2 Nanofluid the lowest value surface roughness (Ra) is 0.863 μm when using 1000 rpm and 0.10 feed rate (mm/rev) with a depth of cut 0.50 mm. The highest value surface roughness (Ra) for 1.50 volume concentration of TiO2 Nanofluid is 3.048 μm when using 1800 rpm and 0.20 feed rate (mm/rev) with a depth of cut 0.50 mm.

3.3. Cutting Temperature
Figure 4 below shown the comparison cutting temperature between three different concentrations 0.50, 1.00, 1.50. The higher value of Nanofluid concentration produces a lower cutting temperature. For the higher contain Nanofluids concentration 1.50 (Vt%), the cutting temperature recorded is 28 °C. while
for the 1.00 (Vt%) Nanofluids concentration the cutting temperature was measured is 29 °C. For the 0.50 (Vt%) Nanofluids concentration the cutting temperatures was measured at 30.5 °C and for the pure conventional coolant was give the higher cutting temperature is 32.3 °C. So, it justifies the higher Nanofluids concentration will give the lowest cutting temperature for this experiment. The results also showed the comparison cutting temperature between three feed rate 0.10, 0.15, 0.20. The higher value of feed rate produces a higher cutting temperature. For the higher contain Nanofluids concentration 1.50 (Vt%) which is produced for cutting temperature is 28, 28.5, 29.8 (°C), while for the 1.00 (Vt%) Nanofluids concentration the cutting temperature was measured is 29 °C, 29.5 °C, 30.5 °C. For the 0.50 (Vt%) Nanofluids concentration, the cutting temperature was measured 29.5 °C, 30.2 °C, 30.5 °C, and for true conventional coolant was give the higher cutting temperature is 32.3 °C, 32.8 °C, 33.1 °C. So, it justifies the lowest feed rate will give the lowest cutting temperature for this experiment.

![Graphs of Cutting Temperature](image)

**Figure 4. Graphs of Cutting Temperature**

### 3.4. Surface Roughness

Figure 5 below shows the comparison surface roughness between three different concentrations 0.50, 1.00, 1.50 (Vt %). The lower value is the best surface roughness produce by the higher contain nanofluids concentration 1.50 (Vt%) which is produced for Ra is 0.863 μm, while for the 1.00 (Vt%) nanofluids concentration the Ra was measured is 0.901 μm. For the 0.50 (Vt%) Nanofluids concentration the Ra was measured 1.022 μm and for the true conventional coolant was given the higher Ra is 1.886 μm. So, it justifies the higher Nanofluids concentration will give the lowest and the best Ra for this experiment. The experiment then compared to the pure MQL coolant and it proves that a higher concentration of Nanofluid was better the result of surface roughness. The comparative surface roughness between feed rate (mm/rev) is seen from the graph. The lowest feed rate value would yield the best surface roughness which is the lower surface roughness value. The average surface roughness for the lowest feed rate of 0.10, was 0.863 μm. And for the medium feed rate which was an average of 0.15 surface roughness 1.937 μm. Finally, the average surface roughness Ra was 1.833 μm for the highest feed rate of 0.20. This graph shows that feed rate plays important role in measuring surface roughness.
3.5. Tool Wear

Based on the result of tool wear, in Figure 6 the lowest result was recorded is around 0.0001 grams when using 1.5 volume concentration of Nanofluid and 1000 RPM of spindle speed. It safe to say that, the higher the volume concentration, the better the tool wear and for the spindle speed, the slower the speed the better the tool wear.
4. Conclusion
In this investigation, the aim was to assess the objective experiment in achieving and the result showed the containing a huge amount of volume concentration TiO2 nanofluid improve the surface quality and cutting temperature from 31℃ to 28℃ but it cannot justify the tool wear because of the factor that has been told. The following conclusion can be drawn to describe the performance of different concentrations of TiO2 at Al319 in CNC Milling. Recommendations for future experiments should use different techniques and environments, increase the concentration of Nanofluid to get a more accurate result.

i. TiO2 Nanofluids improved surface roughness quality and cutting temperature.

ii. By using a higher volume concentration of TiO2 nanofluid the minimum surface roughness and cutting temperature were obtained.

iii. The best volume concentration of TiO2 nanofluid is 1.50 will result in the best value of surface roughness is 0.863 μm and cutting temperature 28 ℃.

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