An Experimental Evaluation of SiO$_2$ nano cutting fluids in CNC Turning of Aluminium Alloy AL319 via MQL Technique.

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Abstract. The present study evaluate the performance of SiO$_2$ nano cutting fluid in CNC turning of AL319 Aluminium Alloy combined with MQL technique. The cutting performance namely surface roughness, cutting temperature and tool wear were investigated against feed rate and spindle speed. The spindle speed of 1000 to 1800 RPM and feed rate of 0.10 to 0.20 mm/rev were used as the input parameter. While the MQL nozzle pressure is kept constant at 0.5 MPa. The cutting performances of SiO$_2$ nano cutting fluid with three volume concentrations (0.5, 1.0 and 1.5%) were then compared to the conventional CNC cutting fluid. Beforehand, the suspended form of SiO$_2$ is dispersed in CNC conventional coolant base. One-step and dilutions methods were used in preparing nano cutting fluid. Response surface method (RSM) via Face centered design (FCD) was employed in designing the experimental work. The stability of SiO$_2$ Nano cutting fluid is observed via visual sedimentation. The experimental outcome depicts lowest cutting temperature of 28.4°C and surface roughness of 1.08902 Ra when SiO$_2$ nano cutting fluid with 1.5% volume concentration is employed. It can be concluded that the higher the SiO$_2$ Nano fluid volume concentration, the better the surface roughness quality and lowering the cutting temperature. While no significant result shown in tool wear due to short period of experimental cutting time and relative soft material coupled with coated insert carbide used. Longer cutting time with higher concentration of SiO$_2$ nano cutting fluid is recommended in future work in order to obtain significant result in tool wear.

1. Introduction

Coolant is one of alternative when come to reducing the temperature and provide proper lubrication any mechanical equipment or machinery, continuous movement of mechanical part between metal to metal generate excessive heat and can cause mechanical failure during operation. Many researcher and scientist develop various of coolant/lubrication to enhances the thermal performance during machining. For the past decade, nanofluid are used by dispersing nanoparticle into base coolant. The benefits of
nanofluid is amplification in term of thermal performance [1-3], viscosity, tribology [4, 5], and heat transfer coefficients compared to the base fluid. Nano sized particles (1-100 nm) suspended inside which are metal or metal oxide. The base fluid can be distilled water, ethylene glycol, lubricant or another type of lubrication.

Preparation nanofluid or nano-lubricant can be done by 2 methods, either one-step method or two-step method. Most commonly used to prepare nanofluid is two-step method because economical cost compares to one-step method, which nanoparticle are producing in a massive scale by-way-of-the two-step preparation. The first step is to create the nanomaterials dry powders by thermal decomposition and photochemical routines, salt reduction of transition metal methods metal vapour synthetization and electrochemical synthetization techniques, and ligand reduction. Meanwhile one-step preparation method is a process in which the nanoparticles are directly developed by physical vapour deposition (PVD) techniques or methods of fluid chemicals for synthetization nanofluid. Even though two-step method is economical, but nanoparticle have liability to aggregate due to high surface.

Nanoparticle Silicon oxide, SiO₂ are used in the making of nanofluid by using one step method which nanoparticle added into the base coolant. SiO₂ nanoparticle characteristics of high strength and hardness and inexpensive make SiO₂ nanoparticle widely used in turning, drilling, milling and grinding application [6].

MQL/NDM technique is the process sprayed the very small amount of lubricant/coolant mixed with air to aerosol at high pressure in the cutting zone by the help nozzle. MQL offers a safer, greener alternative to traditional fluid supply, allowing manufacturers to follow sustainability strategies and incorporate the capabilities of greener production. The MQL system incorporate of cutting fluid, compressor, fluid reservoir, air-oil mixing chamber, external pipes and nozzle. Main product used for machining with MQL system are fatty alcohols and synthetic esters (vegetable oil) [7]. Researcher [8] investigated the performance parameter of MQL grinding and found that MQL provide an extraordinary quality of lubrication which it turns can improve surface quality. This is supported by [9] whom studied the influence of the auxiliary wheel cleaning jet (WCJ) under MQL using aluminium oxide grinding wheel and obtained MQL + WCJ method showed outstanding performance compare to traditional MQL in term of cooling capacity in dissipate heat from grinding zone.

2. Methodology

The method of preparing the nanofluid is major aspect and it vital to be handled properly according to formulation. Solid nanofluid can contribute to numerous properties enhancement once apply to selected application and it can be achieved by proper preparation method. In this paper, one-step method were used to prepare single nanofluid which is SiO₂, the formulation for this single nanofluid need to be calculate using different volume concentration for different concentration of nanofluid as be done by following previous researcher. This nanofluid SiO₂ was create specially in the machining application.

\[
\Delta v = v_2 - v_1 = v_1(\phi_1 - \phi_2)
\]  

(1)

2.1. Preparation of Nano Cutting fluid

Synthesis of nanoparticle is the first step of good nanofluid. Nanoparticle were used in the preparation of nanofluids is SiO₂ nanoparticle suspended in water base with concentrations 25 wt% from US research nanomaterials Inc. SiO₂ nanoparticle were 50 and 22 nm, respectively. In this paper, nanofluid
in base fluid mixture of distilled water and base coolant with volume ratio of 95:5(W: BC). The characteristic of SiO₂ nanoparticle and water/base coolant mixture are presented in table 1. Method of preparation are the SiO₂ nanoparticle were dispersed into base fluid mix with base coolant for 30 minute using magnetic stirrer, then the water ultrasonic bath were used to assist the breakdown of the agglomeration between the nanoparticle from 30 minute. There sample were prepared by volume concentration 1.5%, 1% 0.5%. During time period of sonication time, after passing optimal time sonication process the sample will enter the phase which it causes drawback in term agglomeration and fouling emanate to rapid sedimentation.

Table 1: The Characteristic of SiO₂ Nanoparticle and Water/Base Coolant Mixture

| Characteristic     | SiO₂   | Water/BC |
|--------------------|--------|----------|
| Purity             | 99.99  | 99.5     |
| Colour             | Colourless | Colourless |
| Size (nm)          | 22     | -        |
| Concentration (wt%)| 25     | -        |
| Density (kg/m³)    | 2220   | -        |

2.2. Stability Evaluation

Stability evaluation is vital step to ensure the best performance of the nanofluid as done by previous researchers [11, 12]. Nanofluid which had be expose to sonication process will outgoing amplification of its stability and to mitigate the agglomeration size [13]. After sonication process, the sample will be left for sedimentation for 30 days and visual sedimentation where be observed in Fig. 1. The nanofluid is consider to be stable when the concentration or particle size of supernatant particles were kept constant throughout 30 days [14].

Figure 1. Visual sedimentation of SiO₂ Nano Cutting fluid
2.3. Experimental setup

The experiment was conducted using a Mori Seiki NL2500 CNC machine. The parameters of the turning are presented in Table 2. During data collection, Mitutoyo SJ-210-NATA Surface Mitutoyo SJ-210-NATA Surface The surface roughness of each workpiece was measured by using Mitutoyo SJ-210-NATA Surface. The Cutting temperature was measured by Non-Contact Laser Infrared Thermometer Gun (DT-8280) and Ziess Stemi 2000-C Microscope Profile Optical Microscope and computer were used to record and measure data for tool wear the experimental setup is shown in Fig. 2 while the experimental system is shown in Fig. 3.

![Experimental scheme for CNC Turning](image)

This experiment was conducted at CNC turning where experiment were setup as shown in the figure 3. Laser thermometer and nozzle MQL were setup and attached to the machine using magnet to make sure there is no vibration during measuring data process. The experiment use AL 319 aluminium alloy as the work piece. The MQL nozzle were setting at 0.5Mpa air pressure to give the best and minimum use of nano-cutting fluid. By using the formula (2), RPM of the spindle will change relative to the diameter metal cutting process. The actual diameter for the starting workpiece is 110mm, cutting speed of the aluminium is 400 mm/min referring to the material data sheet. Each 20mm of metal been remove, the spindle speed will increase 400 mm/min, incremental spindle speed change in proportion to level 1 to level 3. RSM is employed for design of experiment and data analysis as done by previous researcher [15].

\[
\text{Spindle Speed } (S) = \frac{(V*1000)}{(\pi*D)}
\]  

(2)
Figure 3. Experimental CNC Turning Setup

Table 2: Experimental Parameter of CNC Turning Machining

| 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 Nano fluid | Np    | Vol%  | 0.5     | 1.0     | 1.5     |

3. Results and Discussion

For the result of parameter which consists of temperature, surface roughness and tool wear will measure and record using the specific equipment and machine. The result will show the highest and lowest data of each parameter after running the experiment.

Table 3: Result of Experiment RSM

| STD | RUN | BLOCK | Volume Concentration (vt%) | Spindle speed (RPM) | Feed rate (mm/rev) | Temperature (C) | Surface roughness(Ra) | Tool wear (μm) |
|-----|-----|-------|----------------------------|---------------------|--------------------|------------------|-----------------------|----------------|
| 5   | 1   | Block 1 | 1.5                         | 1000                | 0.10               | 28               | 0.825                | 922.599        |
| 19  | 2   | Block 1 | 1.0                         | 1400                | 0.15               | 29.5             | 2.052                | 842.099        |
| 11  | 3   | Block 1 | 1.0                         | 1400                | 0.10               | 29.2             | 1.06                 | 1143.5         |
| 9   | 4   | Block 1 | 1.0                         | 1000                | 0.15               | 29.5             | 2.104                | 1191.49        |
| 2   | 5   | Block 1 | 0.5                         | 1800                | 0.10               | 30.1             | 1.346                | 1023.96        |
| 14  | 6   | Block 1 | 1.5                         | 1400                | 0.15               | 29.2             | 2.285                | 946.411        |
| 1   | 7   | Block 1 | 0.5                         | 1000                | 0.10               | 31               | 0.835                | 1058.7         |
| 6   | 8   | Block 1 | 1.5                         | 1800                | 0.10               | 29               | 1.376                | 997.012        |
3.1. Surface Roughness

Surface roughness was measured by using profilometer, Mitutoyo SJ-210 Surface Roughness Tester. From the graph shown the comparison surface roughness between three different concentrations 0.5, 1.0, 1.5 (vt%). The lower value is the best surface roughness produce by the higher contain nanofluids concentration 1.5 (vt%) which is produce for Ra is 0.0.825 µm. while for the 1.0 (vt%) nanofluids concentration the Ra was measured is 1.06 µm. For the 0.5 (vt%) nanofluids concentration the Ra was measured 1.346 µm and for the true conventional coolant was give the higher Ra is 1.886 µm. It justifies the higher nanofluids concentration will give the lowest and the best Ra for this experiment. The experiment them compared to the pure MQL coolant and it prove that the higher concentration of nanofluid will produce the better result of surface roughness such shown in Fig 4. Previous researcher [16] investigated the optimum uses of SiO₂ nano lubrication parameters in hard turning AISI4140 steel and obtaining Surface roughness enhance with 0.5%wt concentration in mineral oil, less air stream and a 30degree nozzle orientation angle.

From the table shown the comparison surface roughness between feed rate (mm/min). The lowest value of feed rate will produce best surface roughness which is the lower surface roughness Ra. For the lowest feed rate 0.1, the surface roughness Ra was average at 0.825(µm). Then for the medium feed rate which 0.15 the surface roughness Ra was average at 2.038 (µm). Lastly for the higher feed rate 0.2 and get the higher surface roughness Ra was average at 2.21 (µm). This graph shows that feed rate plays important role in measuring surface roughness.
3.2. Cutting Temperature

Cutting Temperature was measured by using Non-Contact Laser Infrared Thermometer Gun (DT8280) at distance 5 centimetres. This measurement can read a temperature with range (-50°C to 280°C). From the graph shown the comparison cutting temperature between three different concentrations 0.5, 1.0, 1.5 (vt%). The higher value of nanofluids concentration (vt%) produce the lower of cutting temperature. For the higher contain nanofluids concentration 1.5 (vt%) which is produce for cutting temperature is 29.2 (°C), while for the 1.0 (vt%) nanofluids concentration the cutting temperature was measured is 29.2 (°C). For the 0.5 (vt%) nanofluids concentration the cutting temperature was measured 31. (°C) and for the pure conventional coolant was give the higher cutting temperature is 32.5(°C). It justifies the higher nanofluids concentration will give the lowest cutting temperature for this experiment [17].

From the Figure 5 shown the comparison cutting temperature between three feed rate 0.1, 0.15, 0.2, feed rate (mm/min-1). The higher value of feed rate produces the higher of cutting temperature. For the higher contain nanofluids concentration 1.5 (vt%) which is produce for cutting temperature is 29.1, 29.5, 29.7 (°C), while for the 1.0 (vt%) nanofluids concentration the cutting temperature was measured is 30.2, 30.4, 30.7 (°C). For the 0.5 (vt%) nanofluids concentration the cutting temperature was measured 31.2, 31.5, 31.8 (°C) and for the 0.0 (vt%) nanofluids concentration or true conventional coolant was give the higher cutting temperature is 32.3, 32.8, 33.1 (°C). it vindicates the lowest feed rate will give the lowest cutting temperature for this experiment.
Figure 5. Cutting Temperature Between Feed Rate and Concentration of Nanofluid

3.3. Tool Wear

Figure 6. Lowest and highest tool wear

For the result of tool wear, Figure 7 the lowest result was recorded is 779.104um which is using 1.5 volume concentration of Nano fluid, 1400 RPM of spindle speed and 0.15 feed rate. The highest result is 1320.6um which is using 1.0 volume concentration of Nano fluid,1400 RPM of spindle speed and 0.15 feed rate.
Figure 7. Tool Wear Result Feed Rate Vs Spindle Speed

4. Conclusions

According to the experiment, the main objective of this project is to investigate was conducted to characterize the SiO₂ nano-cutting fluid to be use on CNC turning lathe machine and to study the SiO₂ nano-cutting fluid performance in Turning of Silicon Oxide (SiO₂) with MQL technique. In this investigation, the aim was to assess the objective experiment is achieving and the result showed the containing huge amount of volume concentration SiO₂ nanofluid improve the surface quality and cutting temperature but cannot justify the tool wear because of the factor that have been told. The following conclusion can be drawn to describe the performance of different concentration of SiO₂ at AL319 in CNC Milling.

- SiO₂ nanofluids improved surface roughness quality and cutting temperature.
- By using higher volume concentration of SiO₂ nanofluid the minimum surface roughness and cutting temperature was obtained.
- The best volume concentration of SiO₂ nanofluid is 1.5 will result the best value of surface roughness Ra=1.08902 μm and cutting temperature 28.395°C.

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