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AN EXPERIMENTAL EVALUATION OF SIO_2 NANO CUTTING FLUIDS IN CNC MILLING OF ALUMINIUM ALLOY AA6061-A6.

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ABSTRACT:

The present study investigates the performance of SiO_2 Nano cutting fluid in machining AL6061-T6 Aluminium Alloy using CNC Milling. The cutting performance namely surface roughness and cutting temperature were investigated against feed rate and spindle speed. The cutting performances of SiO_2 nano cutting fluid were then compared to the conventional CNC cutting fluid. Beforehand, the suspended form of SiO_2 is dispersed in CNC cutting fluid base. The nano fluid is prepared in three volume concentrations (0.5, 1.0 and 1.5%) by using one-step and dilution methods. The stability of SiO_2 Nano cutting fluid is observed via visual sedimentation. The result shows that SiO_2 nano cutting fluid with 1.5% volume concentration produce lowest surface roughness of 0.679 Ra and lowest cutting temperature of 29.3^{o}C. 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. Finally, viscosity test onto the SiO_2 Nano cutting fluid is recommended in future work in order to determine maximum volume concentrations allowed to be used in CNC milling machine.

1. INTRODUCTION

Nowadays, machining performs a significant role in the manufacturing industry. It is arguably the most useful manufacturing process in which the desired shape, size and surface finish are achieved through the removal of excess materials in the form of small chips. Heat generation and friction in machining zone affect tool life and surface quality negatively during metal cutting processes. Cutting fluids have been the general choice to reduce the surface friction of machining processes and dissipate the heat generated, improving the tool life and surface finish.

There are various types of cooling technique namely flood cooling, solid coolant and minimum quantity lubricant (MQL) are applied during machining to remove the heat generated in the cutting zone. For example, in the flood cooling method, conventional soluble oil is made to flood over the cutting area to dissipate the heat caused by the machining. The cutting fluid helps to improve the surface finish as well as to facilitate chip flushing. The major disadvantage of this method is that the coolant will never be allowed to penetrate properly into the actual chip-tool contact area, due to the high speed of the chip flowing at high cutting speeds. Moreover, the wastage of the coolant oil will be large as it is made to flood. On the other hand, minimum quantity lubrication (MQL) /near dry machining is a method, where a very small amount (ml/h instead of l/min) of lubricant flow is used. In MQL, the coolant medium is generally straight oil, but some applications have also utilized an emulsion or water (Weinert, Inasaki et al. 2004).

While, Nano fluid are a new class of fluids engineered by dispersing nanometer-sized materials (nanoparticles, nanofibers, nanotubes, nanowires, Nano rods, Nano sheet, or droplets) in base fluids. Nano fluid have been shown to have higher heat transfer rates and thermal conductivity, even at very low solid concentrations. The application of conventional cutting fluids creates some techno-environmental problems, such as environmental pollution, biological problems to operators and water pollution (Paul, Dhar et al. 2001). The unsuitability of the conventional liquid coolants leads to the selection of biodegradable cutting fluids, or elimination of the cutting fluids. Further, the cutting fluids also incur a major portion of the total manufacturing cost (Sreejith and Ngoi 2000). Machining with solid lubricants is one attempt to avoid the use of cutting fluids (Shaji and Radhakrishnan 2003).

An experimental investigation was conducted to compare the performance of conventional coolant by SiO_2 Nano cutting fluid and investigation was conducted to determine the best SiO_2 Nano cutting fluid concentration in CNC Milling of AL6061-T6 Aluminium Alloy. The material used for this experimental work is AL6061-T6 Aluminium Alloy with 2 Flutes HSS End Mill Ø6 mm by CNC Milling at volume concentration 0.5, 1.0 and 1.5 % SiO_2 Nano cutting fluid. The machining performance will be evaluated on surface roughness and cutting temperature.

2.1 MATERIAL AND METHODS

This section describes the methodology on the evaluation of CNC cutting performance onto AL6061-T6 Aluminium Alloy using Silicon dioxide (SiO_2) nano cutting fluid. The SiO_2 nano cutting fluid is prepared by using one-step and dilution methods. Meanwhile, the stability of the SiO_2 nano cutting fluid is done by visual sedimentation observation. The suspendend form of SiO_2 was procured US Research Nanomaterials, Inc. in weight concentrations of 25%. The conversion from weight to volume concentrations is determine by using equation (1). While equation (2) was used in dilution process to produce nano cutting fluid at lower volume concentration. to material Silicon dioxide (SiO_2) is a chemical compound that is an oxide of silicon with the chemical formula. Silica is most commonly found in nature as quartz, as well as in various living organisms. Silica is one of the most complex and most abundant families of materials, existing both as several minerals and being produced synthetically. Notable examples include fused quartz, crystal, fumed silica, silica gel, and aerogels. SiO_2 normally applications range from structural materials to microelectronics to components used in the food industry.

CNC milling is a cutting process in which material is removed from a block by a rotating tool. In CNC milling the cutting tool is moved in all three dimensions to achieve that desired part shape. In CNC milling the cutting tool usually rotates about an axis that is perpendicular to the table that holds the material to be cut. This milling machine are used because have a high precision and suitable RPM compare with conventional Milling Machine

There are many advantages to using CNC Machining. The process is more precise than conventional machining and can be repeated in exactly the same manner over and over again. Since of the precision possible with CNC machining, this process can produce complex shapes that would be almost impossible to achieve with conventional machining. CNC machine is used in the production of may complex three-dimensional shapes. It is because of these quality that CNC machine is used in jobs that need a high level of precision or very repetitive tasks. The machining experimental were carried out on a Deckel Maho DMU 50 Milling machine.

Table 3.1: Specification of DMU 50 Milling Machine.

Specification of DMU 50 Milling Machine	
Travel, X (long)	19.7 in
Travel, Y (Cross)	17.7 in
Travel, Z (Vertical)	15.7 in
Table Size	24.8 X 19.7
Spindle Speed	20 - 10,000 RPM
ATC Type	16 POS
CNC Control	SIEMENS 840D
Rotary Table	Integrated & Motor Swiwel Rotary W/HYD
Rapids	944 IPM
Spindle HP	12
Tool Holder Type	CAT 40
Tool Storage Capacity	16
Floor Space (in) : w X d	73 X 89

The material was selected in this experiment is AL6061-T6 Aluminium Alloy rectangular workpiece geometry 170 × 35 × 10 mm. AL6061-T6 Aluminium Alloy has good mechanical properties, exhibits good weld ability, and is very commonly extruded. It also is a precipitation hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. It is one of the most common alloys of aluminium for general-purpose use. There are AL6061-T6 Aluminium Alloy has shown in figure 3.4

Table 3.2: Typical composition of AL6061-T6 Aluminum Alloy.

Typical composition of AL6061-T6 Aluminum Alloy	
Aluminium	Balance
Magnesium	0.8-1.2
Silicon	0.4 – 0.8
Iron	Max. 0.7
Copper	0.15-0.40
Titanium	Max. 0.15
Manganese	Max. 0.15
Zinc	Max. 0.25
Chromium	0.04-0.35
Others	0.05

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CUTTING FLUIDS PREPARATION.

Silicon dioxide SiO2 Nano fluid dispersed into conventional coolant preparation. The most widely used for preparing Nano fluids is One-Step Method and there will be the method. Silicon dioxide SiO2 used in this method are first produced as wet liquid. After that, it will be measured the volume of SiO2 in 1.5% which is the higher volume concentration VT% by using measuring cylinder. Then, measured the volume of distilled water and the volume of coolant will be used according the calculation. Mix distilled water and coolant together by using a method of stirring. Mix Nanofluid with that already distilled water + coolant liquid by using a method of stirring within an hour. Lastly, the solution will be placed of water bath ultra sonicator for two hours to make sure its dissolve completely.

6. Lastly, the solution will be placed of water bath ultra sonicator for two hours to make sure its dissolve completely.

Table 3.3: Formula to preparation of nanofluid.

Volume Concentration (vt%)	Nanofluid (ml)	Water (ml)	Coolant (ml)	Total Nanofluid (ml)	Keep Nanofluid (ml)
1.5	230 (Pure Nanofluid)	1647	125	2002	1000
1.0	From 2002 use 1002	470	32	1503	1000
0.5	From 1503 use 503	470	32	1006	1006

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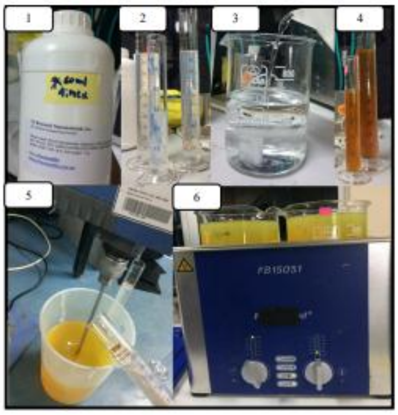


Figure 3.5: Step of SiO_2 Nanofluid Preparation.

The experiment as shows at figure 3.13 was is conducted by Deckel Maho DMU 50 CNC Milling Machine with AL6061-T6 Aluminium Alloy rectangular workpiece geometry 170 X 35 X 10 mm. The Cutting tools was used is HSS with 2 flutes and Ø6 mm. Then cutting fluids was used is conventional coolant and nanofluid enhancement conventional coolant. Infrared Thermometer was used during machining process estimated length is about 50 meter to measure the cutting temperature. The experiment was running at 2700, 3250 & 3800 rpm spindle speed and 324, 390 & 456 mm/min-1 .

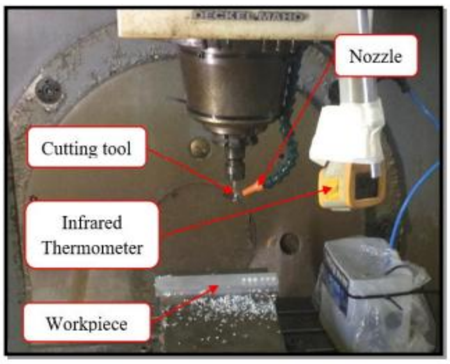


Figure 3.13: The experiment setup for this experiment.

The low and high levels were shown in table 3.4. 33 full factorial designs with three center point were used to determine significant factors and as screening process before pursuing to response surface methodology (RSM). The objective of RSM is to best the response based on the factor investigated. Table 3.5 shows completed design layout. After complete full factorial design, the RSM was employed. The response variables under investigate were surface roughness Ra and cutting temperature. Design Expert Version 7 was used in this experiment.

Table 3.4: Control Factor and experiment condition level.

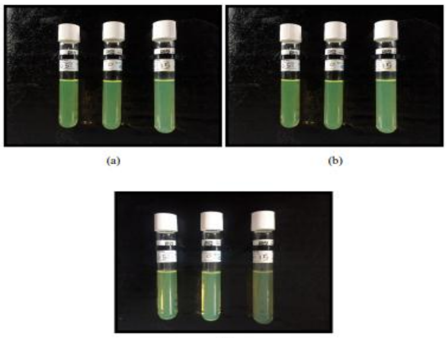
Symbol Variable Factors	Level		
	Level 1	Level 2	Level 3
A=Nanoparticle Concentration	0.5 %	1.0 %	1.5%
B=Spindle Speed (RPM)	2700	3250	3800
C=Feed Rate (mm/min^{-1})	324	390	456

Table 3.5: Completed design layout.

Std	Run	Block	Factor 1	Factor 2	Factor 3
			A=Nanoparticle	B=Spindle Speed	C=Feed Rate
			Volume Concentration	(RPM)	(mm/min^{-1})
17	1	Block 1	1.00	3250.00	390.00
10	2	Block 1	1.50	3250.00	390.00
11	3	Block 1	1.00	2700.00	390.00
5	4	Block 1	0.50	2700.00	456.00
7	5	Block 1	0.50	3800.00	456.00
12	6	Block 1	1.00	3800.00	390.00
4	7	Block 1	1.50	3800.00	324.00
9	8	Block 1	0.50	3250.00	390.00
18	9	Block 1	1.00	3250.00	390.00
13	10	Block 1	1.00	3250.00	324.00
19	11	Block 1	1.00	3250.00	390.00
2	12	Block 1	1.50	2700.00	324.00
8	13	Block 1	1.50	3800.00	456.00
20	14	Block 1	1.00	3250.00	390.00
14	15	Block 1	1.00	3250.00	456.00
1	16	Block 1	0.50	2700.00	324.00
6	17	Block 1	1.50	2700.00	456.00
15	18	Block 1	1.00	3250.00	390.00
3	19	Block 1	0.50	3800.00	324.00
16	20	Block 1	1.00	3250.00	390.00

STABILITY OF NANOFLUID.

Sonication is applied by using an ultra-sonicator an instruction to make stable nanofluid and reduce the size of agglomerates. Nanofluid were produced in a volume of 1000 ml for each volume concentration and put into a sonicator for 2 hours. Then, the nanofluids became very stable throughout the measuring process. The nanofluid was prepared as above without milling or using any surfactant/pH adjustment displayed good stability without any visible sedimentation for several days as shown in Figure 4.1 The mass of particles required to obtain a desired volume concentration can be estimated from Eq. (1).



(a) (b) (c)

Figure 4.1: SiO_2 Nanofluid sample based Belling X-10 150.
(a) Nanofluid sample after preparation.
(b) Nanofluid sample after a week. (c) Nanofluid sample after three weeks.

4.3 RESULT OF MACHINING.

Table 4.1: Result of surface roughness and cutting temperature.

Std	Run	Concentration (%vt)	Spindle Speed (rpm)	Feed Rate (mm/min^{-1})	Surface Roughness (μm)	Cutting Temperature (°c)
1	16	0.50	2700.00	324.00	2.28	30
2	12	1.50	2700.00	324.00	1.562	29.3
3	19	0.50	3800.00	324.00	1.316	30.5
4	7	1.50	3800.00	324.00	0.679	29.5
5	4	0.50	2700.00	456.00	2.809	29.5
6	17	1.50	2700.00	456.00	2.633	30.1
7	5	0.50	3800.00	456.00	2.245	29.7
8	13	1.50	3800.00	456.00	1.68	30.4
9	8	0.50	3250.00	390.00	1.962	30.3
10	2	1.50	3250.00	390.00	1.167	29.8
11	3	1.00	2700.00	390.00	2.428	29.5
12	6	1.00	3800.00	390.00	2.064	30.2
13	10	1.00	3250.00	324.00	1.492	29.5
14	15	1.00	3250.00	456.00	2.161	30.3
15	18	1.00	3250.00	390.00	1.692	30.5
16	20	1.00	3250.00	390.00	1.845	29.8
17	1	1.00	3250.00	390.00	1.894	29.4
18	9	1.00	3250.00	390.00	1.73	29.7
19	11	1.00	3250.00	390.00	1.692	29.9
20	14	1.00	3250.00	390.00	1.714	30.1

Surface roughness was measured by using profilometer, Mitutoyo SJ-210 Surface Roughness Tester. From the graph 4.2 shown the comparison surface roughness between four different concentrations 0.0, 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 0.706 µm. while for the 1.0 (vt%) nanofluids concentration the Ra was measured is 1.412 µm. For the 0.5 (vt%) nanofluids concentration the Ra was measured 2.201 µm and for the 0.0 (vt%) nanofluids concentration or true conventional coolant was give the higher Ra is 3.362 µm. So its justify the higher nanofluids concentration will give the more lowest and the best Ra for this experiment and the result was same pattern compare with result (Sayuti, Sarhan et al. 2014).

4.4 SURFACE ROUGHNESS.

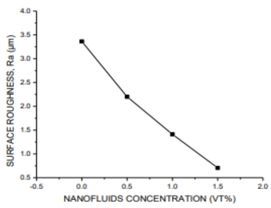


Figure 4.2: Surface roughness as opposed to nanofluids concentration.

From the graph 4.3 shown the comparison surface roughness between feed rate (mm/min-1). The lowest value of feed rate will produce best surface roughness which is the lower surface roughness Ra. For the lowest feed rate 324 (mm/min-1), the surface roughness Ra was average at 1.834 (µm). Then for the medium feed rate which is 390 (mm/min-1), the surface roughness Ra was average at 2.018 (µm). Lastly for the higher feed rate 456 (mm/min-1) and get the higher surface roughness Ra was average at 2.073 (µm).

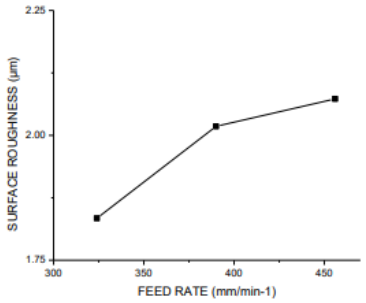


Figure 4.3: Surface roughness as opposed to feed rate.

From the graph 4.4 shown the comparison surface roughness between spindle speed 2700,3250,3800 (rpm). The higher value of spindle speed can produce best surface roughness which is the lower surface roughness Ra. For the nanofluids concentration 1.5 (vt%) which is produce the lower Ra 0.737,0.701,0.679 (µm). while for the 1.0 (vt%) nanofluids concentration the Ra was measured is 1.675,1.434,1.127 (µm). For the 0.5 (vt%) nanofluids concentration the Ra was measured 2.236,2.221,2.143 (µm) and for the 0.0 (vt%) nanofluids concentration or true conventional coolant was give the higher Ra is 3.434,3.372,3.279 (µm). So its substantiate the higher spindle speed will produce the lower surface roughness Ra for the different concentration although with conventional coolant.

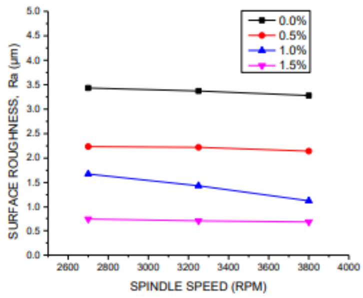


Figure 4.4: Surface roughness as opposed to spindle speed.

Table 4.4: Coefficient value for coded factor surface roughness.

Factor	Coefficient	df	Error	95% CI Low	95% CI High	VIF
Intercept	1.79	1	0.051	1.68	1.91	
A-Concentration	-0.29	1	0.047	-0.39	-0.18	1.00
B-Spindle Speed	-0.37	1	0.047	-0.48	-0.27	1.00
C-Feed Rate	0.42	1	0.047	0.31	0.53	1.00
AB	-0.038	1	0.053	-0.16	0.079	1.00
AC	0.077	1	0.053	-0.041	0.19	1.00
BC	0.041	1	0.053	-0.077	0.16	1.00
A^2	-0.27	1	0.090	-0.48	-0.074	1.82
B^2	0.41	1	0.090	0.21	0.61	1.82
C^2	-0.013	1	0.090	-0.21	0.19	1.82

Cutting Temperature was measured by using Non-Contact Laser Infrared Thermometer Gun (DT8280) at distance 50 meters. This measurement can read a temperature with range (-58 F to 536 F). From the graph 4.9 shown the comparison cutting temperature between four different concentrations 0.0, 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 29.4 (°C). while for the 1.0 (vt%) nanofluids concentration the cutting temperature was measured is 30.4 (°C). For the 0.5 (vt%) nanofluids concentration the cutting temperature was measured 31.5 (°C) and for the 0.0 (vt%) nanofluids concentration or true conventional coolant was give the higher cutting temperature is 32.7(°C). So its justify the higher nanofluids concentration will give the more lowest cutting temperature for this experiment and the result was same pattern compare with result (Sayuti, Sarhan, et al. 2014).

4.5 CUTTING TEMPERATURE.

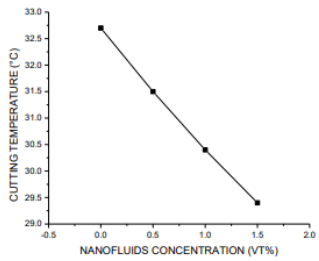


Figure 4.9: Cutting temperature as opposed to nanofluids concentration.

From the graph 4.10 shown the comparison cutting temperature between three feed rate 345, 390, 456 feed rate (mm/min-1). The most 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). So its justify the lowest feed rate will give the more lowest cutting temperature for this experiment.

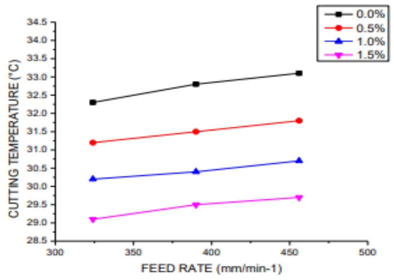


Figure 4.10: Cutting temperature as opposed to feed rate.

From the graph 4.11 shown the comparison cutting temperature between three spindle speed 2700,3250,3800 (rpm). The most higher value of spindle speed produces the higher of cutting temperature. For the higher contain nanofluids concentration 1.5 (vt%) which is produce the lowest cutting temperature opposed other concentrations for cutting temperature is 29.1, 29.5, 29.7 (°C) at. 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). So its justify the lowest feed rate will give the more lowest cutting temperature for this experiment.

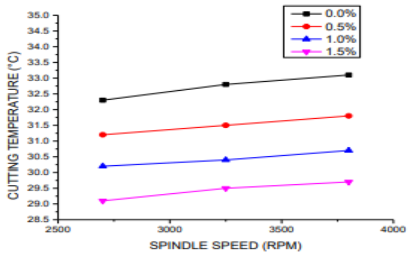


Figure 4.11: Cutting temperature as opposed to spindle speed.

Table 4.7: Coefficient value for coded factor Cutting Temperature.

	Coefficient		Standard	95% CI	95% CI	
Factor	Estimate	df	Error	Low	High	VIF
Intercept	29.90	1	0.065	29.76	30.04	
A-Concentration	-0.090	1	0.092	-0.29	0.11	1.00
B-Spindle Speed	0.019	1	0.092	-8.635E-003	0.39	1.00
C-Feed Rate	0.12	1	0.092	-0.079	0.32	1.00
AB	-0.025	1	0.10	-0.25	0.20	1.00
AC	-0.32	1	0.10	-0.15	0.60	1.00
BC	-0.025	1	0.10	-0.25	0.20	1.00

CONCLUSION.

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. The following conclusion can be drawn to describe the performance of different concentration of SiO2 at Al-6061-T6 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 wil result the best value of surface roughness Ra=0.679 µm and cutting temperature 29.3oC.

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