EXPERIMENTAL INVESTIGATION OF DRILLING PROCESS USING NANOFLUID AS COOLANT

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ABSTRACT: Nanofluid coolant is one of the new formulation of cutting fluids used in machining in order to obtain better surface finish of products. In this study, the effect of various coolants (nanofluid and pure deionized water) and cutting parameters (cutting speed and feed rate) to the machining performances of titanium alloy was investigated by using drilling process. A series of experiments were conducted using Design of Experiment (DOE) and the machining performances were measured in terms of surface roughness and cutting temperature. The results show that better surface finish and lower cutting temperature can be obtained by using carbon nanofiber nanofluid compared to that of pure deionized water. The significant factors that influence the surface roughness of titanium alloy are feed rate and coolant. Coolant also plays an important role to reduce the cutting temperature during the drilling process.

KEYWORDS: *Drilling; Titanium Alloy; Nanofluid; Surface Roughness; Cutting Temperature*

1.0 INTRODUCTION

Drilling operation is known as the most common machining process where the process is involved in making of cylindrical holes in metallic and non-metallic materials. The tool is rotated and also moved in the axial direction. It can be done by a rotating tool that normally has two or four helical cutting edges [1].

The drilling operation of titanium alloy is widely used in airplane industries and medical application owing to outstanding properties of titanium alloy such as light weight, corrosion resistance and biocompatibility [2]. However, due to its high hardness, the machinability of this material is quite low [3]. Furthermore, during the drilling process, high temperatures are generated due to friction between the drill tool and workpiece [4], causing the process becomes inefficient in terms of drill tool life and quality of drilled hole.

In order to control the temperature and wash away the chips produced in the cutting zone, a number of researchers attempted various cooling methods such as cryogenic cooling [5], minimum quantity lubrication (MQL) [6] and etc. Recently, the use of nanofluids as coolant in machining operations has become a new research focus, due to its superior lubrication and heat dissipation characteristic [7]. Nanofluids are defined as suspension of nanoparticles in the base fluid. Although this method can enhance the machining efficiency to certain extend, however, to our best knowledge, extensive research on the drilling process using nanofluid as coolant is still scarce, particularly on the use of carbon nanofibers (CNF) as nanoparticles.

Therefore, the present study intends to fill the gap in this area by focusing on the investigation of CNF nanofluid in drilling of titanium alloy. The machining performances such as surface roughness and cutting temperature were investigated under different drilling parameters (cutting speed, feed rate and types of coolant) using full factorial design.

2.0 METHODOLOGY

2.1 Machining

The experiment was performed using a 3-axis HAAS VOP-C CNC milling machine. The workpiece for this experiment was titanium alloy with the dimension of 50 mm width, 50 mm length and 5 mm thickness. The cutting tool used was high speed steel (HSS) with diameter of 7.5 mm. Deionized water was used as conventional coolant while for nanofluid, carbon nanofibers mixed with deionized water and gum arabic were used. The experiment setup is shown in Figure 1. The drilling process parameters were set at different levels for all the experiments as stated in Table 1. The number of experiments and combination of parameters were determined by using 2 level of full factorial design. SJ-301 surface roughness tester was used to measure the surface roughness and cutting temperature was measured using Fluke Ti400 9Hz Thermal Imager respectively and the data was analysed using ANOVA.

Table 1: Machining conditions

Factors	Level 1	Level 2
Cutting Speed (m/min)	15	25
Feed rate (mm/rev)	0.05	0.10
Types of coolants	Deionized water	Nanofluid

2.2 Formulation of Nanofluid

In order to prepare the nanofluid, the same method as explained in [8] was used. In this experiment, 0.02 g/L CNF nanofluid was used. The nanofluid preparation was started from weighing the deionized water (DI), surfactant, and CNF. Ultrasonic homogenizer (Model Labsonic type P series) was used to dissolve the 0.1 g of gum arabic (GA) into one litre of DI water to stabilize the CNF suspension. Then, another 0.1 g of CNF was dispersed into the mixture. The sonication process to disperse the CNF with mixture of DI water and GA surfactant was done at frequency of 60 amplitudes and 0.5 cycles.

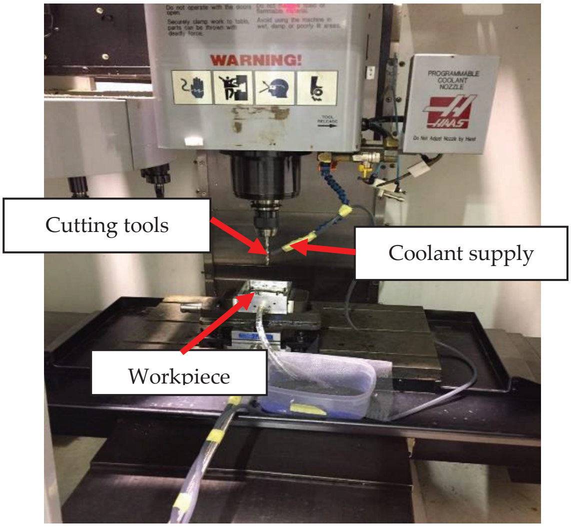

Figure 1: Experimental setup

3.0 RESULTS AND DISCUSSION

3.1 Surface Roughness

The quality of machined surface was determined by surface roughness, arithmetic surface roughness (Ra) value and AVOVA was used to analyse the data, as shown in Table 2.

The significant factors that affect the surface roughness can be identified when the P-value is less than 0.05. Based on the result from the ANOVA in Table 2, it shows that the significant factors are feed rate, coolant, interaction between cutting speed and coolant, and interaction between feed rate and coolant which denoted by B, C, AC and BC respectively. From the ANOVA, 7.95 of F-value shows the model is significant. There is only 0.06% chance that a "Model F-Value" could occur due to noise. The final equation in terms of coded factors can be determined using Equation (1) to predict the surface roughness value.

Table 2: ANOVA for surface roughness

Source	Sum of Squares	Degree of Freedom	Mean Square	F value	Prob>F
Model	0.69	4	0.17	7.95	0.0006
B - Feed rate	0.25	1	0.25	11.47	0.0031
C - Coolant	0.21	1	0.21	9.50	0.0061
AC	0.14	1	0.14	6.26	0.0217
BC	0.10	1	0.10	4.59	0.0453
Residual	0.35	19	0.022		
Lack of Fit	0.15	3	0.052	3.18	0.0527
Pure Error	0.26	16	0.016		
Correlation Total	1.11	23			

Final equation in terms of coded factors such as

$$Ra = 0.64 - 0.10 * \text{Feed Rate} + 0.09 * \text{Coolant} - 0.08 * \text{Cutting Speed} * \text{Coolant} - 0.07 * \text{Feed Rate} * \text{Coolant} \quad (1)$$

Based on the result, the model graphs also can be generated to analyze the interaction between parameters. Figure 2 shows the effect of coolant on surface roughness. It is clearly seen that by using nanofluid, better surface finish can be obtained compared to that of conventional coolant (deionized water). This result is consistent with the findings of Sharma et al. [9], in which the nanoparticles will reduce the frictional forces between drill bit-workpiece interfaces and cause the temperature generated dropped. Thus, the tool wear can be prevented, and leading to a better surface quality.

Figure 3 illustrates the effect of cutting speed on surface roughness by using different coolants. It is clearly seen from this figure, by using deionized water, the surface roughness reduces as the cutting speed increases. As known from Sharif et al. [10], higher heat is developed when the cutting speed increases, thus softening the workpiece material and improves the surface finish. However, when the cutting speed increases, the surface roughness also increases by using nanofluid. This might be due to the nanoparticles are difficult to enter to the small machining zone at higher cutting speed and causing the effect of nanofluid as coolant was insignificant.

Figure 4 depicts the interaction between feed rate and coolant on the surface roughness. It is clearly seen that, when the feed rate increases, the surface roughness decreases by using nanofluid and deionized water. However, this finding is contradicted with the results of previous research [11]. According to Samy and Kumaran [11], at higher feed rate, the chips that are formed improves the rubbing action between drill bit-workpiece interfaces, thus increased the surface roughness of the drill hole.

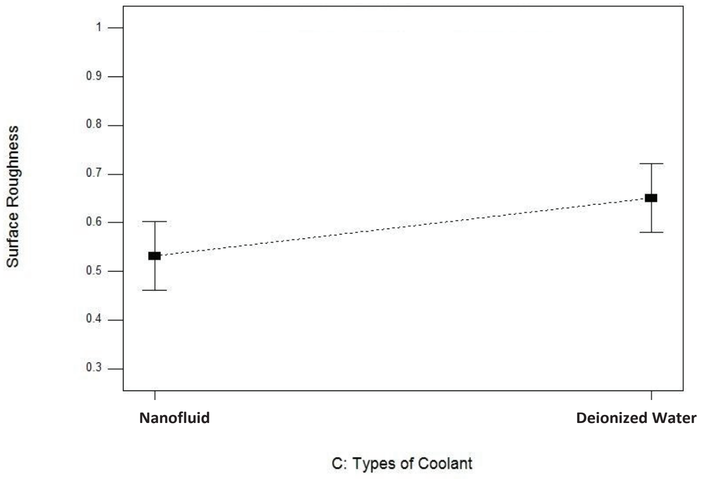

Figure 2: Effect of coolants on surface roughness

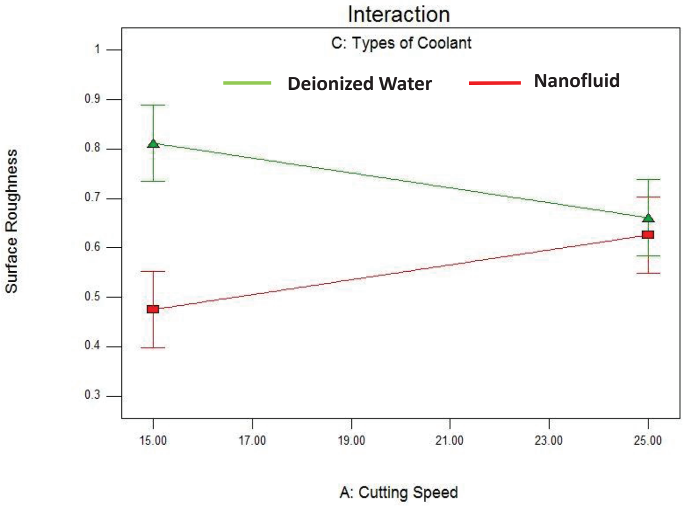

Figure 3: Effect of cutting speed on surface roughness by using different coolants

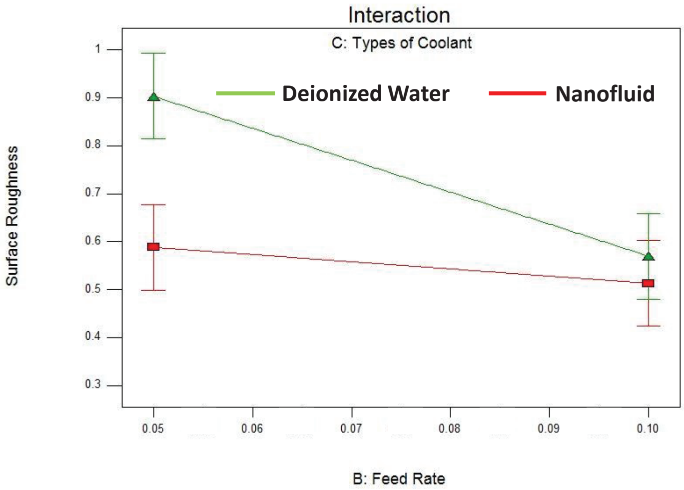

Figure 4: Effect of feed rate on surface roughness by using different coolants

3.2 Cutting Temperature

In this experiment, Thermal Imager was used to determine the cutting temperature. Through the variation in cutting temperature with respect to cutting speed and feed rate, the cooling ability of cutting temperature can be determined. Table 3 shows the analysis of cutting temperature using ANOVA.

Table 3: ANOVA for cutting temperature

Source	Sum of Squares	Degree of Freedom	Mean Square	F value	Prob>F
Model	2481.77	2	1240.88	23.78	< 0.0001
C - Coolant	2162.39	1	2162.39	41.45	< 0.0001
BC	319.38	1	319.38	6.12	0.0220
Residual	1095.67	21	52.17		
Lack of Fit	579.84	5	115.97	3.60	0.1734
Pure Error	515.82	16	32.24		
Correlation Total	3577.43	23			

From the ANOVA table (Table 3), 23.78 of F-value indicates that the model is significant and 0.01% chance that “Model F-Value” could occur due to noise. The models of coolant and interaction between feed rate and coolant which denoted by C and BC are significant model terms, whereby the “Prob > F” value is less than 0.0500. From this ANOVA analysis, the final equation in terms of coded factors can be determined using Equation (2) to predict the cutting temperature value.

Final equation in terms of coded factors such as

$$\text{Cutting Temperature} = 48.86 + 9.49 * \text{Coolant} + 3.65 * \text{Feed Rate} * \text{Coolant} \tag{2}$$

Figure 5 shows the effect of coolant on cutting temperature. As shown in Figure 5, nanofluid produced lower cutting temperature during the drilling process compared to that of conventional coolant, which is deionized water. This is due to the inclusion of nanoparticles increase heat carrying capacity of cutting fluid and result in lower temperature at the machining zone [6]. Furthermore, the thermal conductivity of CNF nanofluid is higher than the one of deionized water, which may help to dissipate the heat at the drilling zone.

The interaction between feed rate and coolant on cutting temperature is demonstrated in Figure 6. As shown in Figure 6, when the feed rate increases, the cutting temperature reduces by using nanofluid. As known from Sorrentino et al. [12], workpiece-tool contact time was reduced when the feed rate increased, that consequently reduced the thermal energy developed by the friction, and thus temperature reduced at the cutting zone. However, by using deionized water, the cutting temperature increases as the feed rate increases. This might be due to the insignificant effect of deionized water to act as coolant in this case.

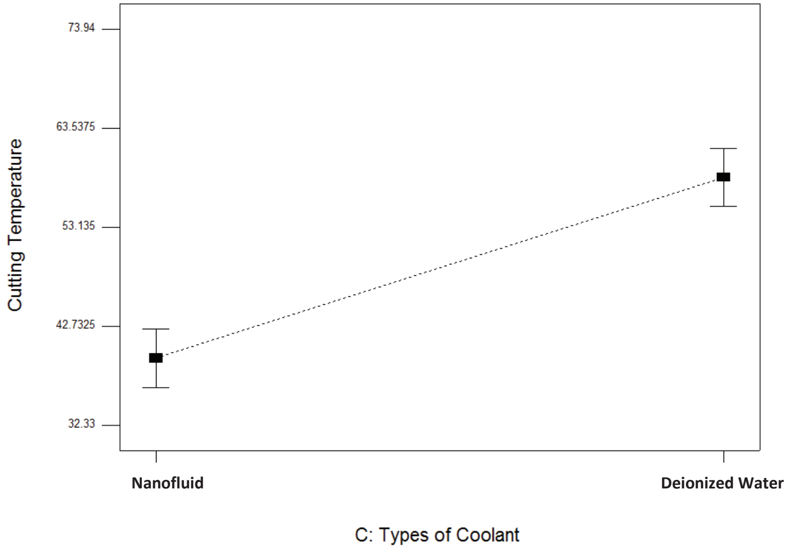

Figure 5: Effect of coolant on cutting temperature

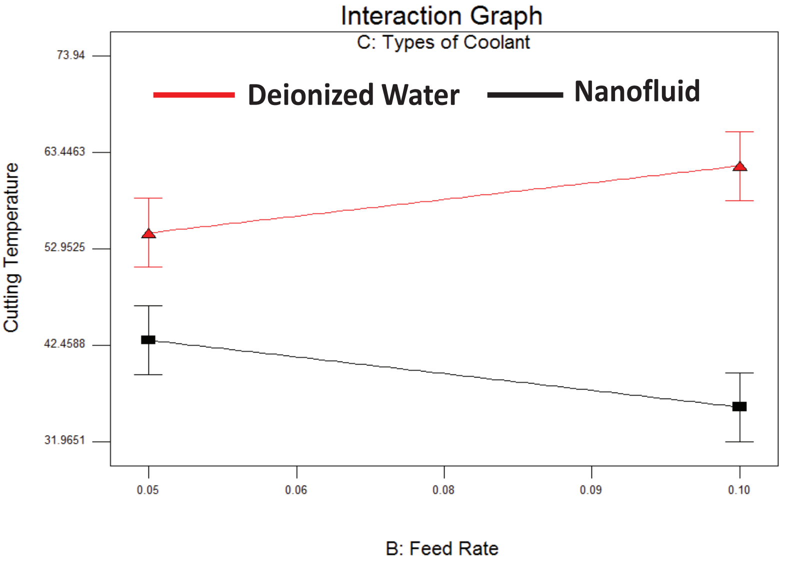

Figure 6: Effect of interaction between feed rate and coolant on cutting temperature

4.0 CONCLUSION

The conclusions from this study can be summarized as below:

i. Lower surface roughness and cutting temperature can be obtained using CNF nanofluid compared to pure deionized water.

ii. By using CNF nanofluid, low cutting speed and feed rate produce the lowest surface roughness. Cutting temperature also reduces significantly with the increase of feed rate.

iii. Based on the Full Factorial Design, the most significant factor that effects the surface roughness during the machining are feed rate and coolant. Meanwhile, for the cutting temperature, coolant is significant factor to achieve lower value of cutting temperature.

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REFERENCES

[1] G. Gangadhar, D.S. Venkateswarlu and C. Rajesh, "Experimental approach of CNC drilling operation for mild steel using taguchi design," *International Journal of Modern Engineering Research*, vol. 4, no. 10, pp. 75-81, 2014.

[2] T. Matsumura and S. Tamura, "Cutting simulation of titanium alloy drilling with energy analysis and FEM," *Procedia CIRP,* vol. 31, pp. 252-257, 2015.

[3] Z. Rysava, S. Bruschi, S. Carmignato, F. Medeossi, E. Savio and F. Zanini, "Micro-drilling and threading of the Ti6Al4V titanium alloy produced through additive manufacturing," *Procedia CIRP*, vol. 46, pp. 583-586, 2016.

[4] B. Tasdelen, T. Wikblom and S. Ekered, "Studies on minimum quantity lubrication (MQL) and air cooling at drilling," *Journal of Materials Processing Technology*, vol. 200, no. 1-3, pp. 339-346, 2008.

[5] L.S. Ahmed and M.P. Kumar, "Cryogenic drilling of Ti-6AL-4V alloy under liquid nitrogen cooling," *Materials and Manufacturing Processes*, vol. 31, no. 7, pp. 951-959, 2016.

[6] M. Perçin, K. Aslantas, I. Ucun, Y. Kaynak and A. Çicek, "Micro-drilling of Ti-6Al-4V alloy: The effects of cooling/lubricating," *Precision Engineering*, vol. 45, pp. 450-462, 2016.

[7] P.J. Liew, A. Shaaroni, N.A.C. Sidik and J. Yan, "An overview of current status of cutting fluids and cooling techniques of turning hard steel," *International Journal of Heat and Mass Transfer*, vol. 114, pp. 380-394, 2017.

[8] P.J. Liew, A. Shaaroni, J. Razak, M.S. Kasim and M.A. Sulaiman, "Optimization of cutting condition in the turning of AISI D2 steel by using carbon nanofiber nanofluid," *International Journal of Applied Engineering Research*, vol. 12, no. 10, pp. 2243-2252, 2017.

[9] P. Sharma, B.S. Sidhu and J. Sharma, "Investigation of effects of nanofluids on turning of AISI D2 steel using minimum quantity lubrication," *Journal of Cleaner Production*, vol. 108, pp. 72–79, 2015.

[10] S. Sharif, E.A. Rahim and H. Sasahara, "Machinability of titanium alloys in drilling," in *Titanium Alloys-Towards Achieving Enhanced Properties for Diversified Applications*, A.K.M. Nurul Amin, Ed. Osaka: InTech, 2012, pp.117-138.

[11] G.S. Samy and S.T. Kumaran, "Measurement and analysis of temperature, thrust force and surface roughness in drilling of AA (6351)-B4C composite," *Measurement*, vol. 103, pp.1-9, 2017.

[12] L. Sorrentino, S. Turchetta and C. Bellini, "In process monitoring of cutting temperature during the drilling of FRP laminate," *Composite Structures*, vol. 168, pp. 549–561, 2017.