INVESTIGATION OF EFFECTS OF CARBON NANOFIBER NANOFLUID IN DRILLING OF AISI 304 STAINLESS STEEL

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ABSTRACT: This paper presents the experimental study of the effects of carbon nanofiber (CNF) nanofluid in drilling of AISI 304 stainless steel. The drilling performance was assessed based on the surface roughness inside the holes, hole dimensional accuracy and burr formation using four different CNF nanofluid concentrations. The machining performance of CNF nanofluid also compared with the base fluid (deionized water) only. The experimental results show that the CNF nanofluid not only improve the surface finish and hole accuracy, but also reduce the burr formation at the circumference of the drilled hole.

KEYWORDS: *Drilling; Nanofluid; Hole surface roughness; Hole accuracy; Burr formation*

1.0 INTRODUCTION

Drilling process is known as the most common machining process to create cylindrical hole in any types of materials [1]. During the drilling of metals, heats are generated due to friction between the drill bit and workpiece, causing the process becomes inefficient in terms of tool life, material removal rate and workpiece surface quality [2]. This problem is more pronounced when drilling process is used to machine hardened and difficult-to-cut materials such as stainless steel. Therefore, cutting fluids is considered as the most important elements during this operation. The main purpose of cutting fluids is to cool the workpiece, reduce friction, and wash away the chips produced during the process [3-6]. Besides, cutting fluids also act as corrosion protection for machine and workpiece and minimize the cutting forces during the process thus saving the energy [7]. However, despite of it advantages, cutting fluids are also having their weaknesses. According to Astakhov [8], sometimes, the cost of cutting fluid is more expensive that the cost related to tool. In addition, most of the cutting fluids will possess the health hazard to the operator. Dispose of the used for cutting fluid is also a major challenge [3, 7].

As an alternative to cutting fluids, various cooling methods have been carried out, such as minimum quantity lubrication (MQL) [9] and emulsion [10]. With the recent advancements in material technology, the use of nanofluids has become significant in the regime of cooling [11]. For instance, Sarhan et al. [12] used the mixture of nano SiO2 and ordinary mineral oil as a lubricant in milling process. Results from their experiment show a noticeable reduction in the cutting force, power, and specific energy requirements by using nanoparticle lubrication as compared to the ordinary mineral oil. Rahmati et al. [13] also found that the inclusion of MoS2 nanoparticles in lubricant improved the machined surface quality due to the rolling, filling, and polishing actions at the machining zone. Prabhu and Vinayagam [14] concluded that the surface quality was enhanced from microlevel to nanolevel by using CNT nanofluid in grinding. Other researchers, Nam et al. [15] investigated the effect of nanofluids (Nano-diamond in vegetable oil and nanodiamond in paraffin oil) with MQL in micro-drilling process of aluminum 6061 workpiece. According to Murshed et al. [16], nanofluids, which engineered by dispersing nanometer-sized solid particles in conventional heat transfer fluids, have been found provided higher thermal conductivity compared to their base fluids.

A close examination on the available literatures, it is surprisingly that only few researches have been done on the drilling process by using nanofluid. Therefore, the aim of this study is to investigate the performance of drilled hole (surface roughness, dimensional accuracy and burr formation) using carbon nanofiber nanofluid on AISI 304 stainless steel.

2.0 EXPERIMENTAL

2.1 Formulation of Nanofluids

This investigation has been carried out using 150 nm~200 nm diameter CNF with deionized water (DI) as the base fluid. Firstly, Poly vinyl pyrrolidone (PVP) surfactant was dissolved in DI water to improve the stability of suspension using ultrasonic homogenizer at 50 amplitudes for 15 minutes. Then the CNF was dispersed into the solution for another 40 minutes. Before running the drilling process, the nanofluid was put into ultrasonic bath for 30 minutes to avoid agglomeration and sedimentation. Four different concentrations were prepared by changing the volume fraction percentages of nanofluid for this investigation to compare with base fluid.

2.2 Machining

AISI 304 stainless steel having 10 mm thickness was used as the workpiece material. Drill bit used was HSS which having 7.5 mm diameter. Experiments were carried out on conventional drilling machine at constant cutting speed which is at 120 rpm. The workpiece was drilled penetrate through the workpiece thickness. The experiments were repeated three times for each nanofluid concentration. The details of machining condition are shown in Table 1. During the drilling process, the nanofluid is delivered to the drilling zone continuously by directly drop using the dropper. The volume used for each experiment is 3.8ml.

Table 1: Machining conditions

Machine	Conventional drilling machine
Machining operation	Drilling
Workpiece material (mm)	AISI 304 stainless steel 75x75x10
Tool (mm)	HSS drill bit (∅ 7.5)
Drilling depth (mm)	10
Cutting speed (rpm)	120
Concentration of CNF nanofluid (%)	0, 0.25, 0.5, 0.75, 1.0

2.3 Machining Performance

To investigate the quality of the drilled hole and effectiveness of CNF nanofluid as lubricant in drilling process, surface roughness (Ra), dimension accuracy and burr formation are measured and studied. Portable surface roughness tester was used for the measurement of surface roughness inside drilled hole. The measurement was taken at seven different points and the average was taken as an arithmetic surface roughness.

The dimensional accuracy of the hole diameter and roundness error was evaluated by Coordinate Measuring Machine (CMM) at various location. The hole diameter at the entrance and exit were measured and compared. The total deviation of the hole diameters at the entrance and exit was used for the measurement of the accuracy. Entrance burr width was measured using an optical microscope at five positions around the hole and the average was calculated in order to minimize the inaccuracy of the measurement.

3.0 RESULTS AND DISCUSSION

3.1 Surface Roughness

Figure 1 shows the graph of surface roughness value when drilling AISI 304 with different concentration of CNF. It can be seen that without CNF (DI water only), the roughness value is the highest, which is 4.56 μm. However, there is a decreasing value of surface roughness when the concentration of CNF is increased and the optimum value is found at the 0.75% CNF concentration. From this graph, it is clear that the holes machined using CNF nanofluids are having more tendency to give better surface finish as compared to holes machined using base fluid. During machining, there are temperatures rises which is caused by friction occurred between tool and workpiece.

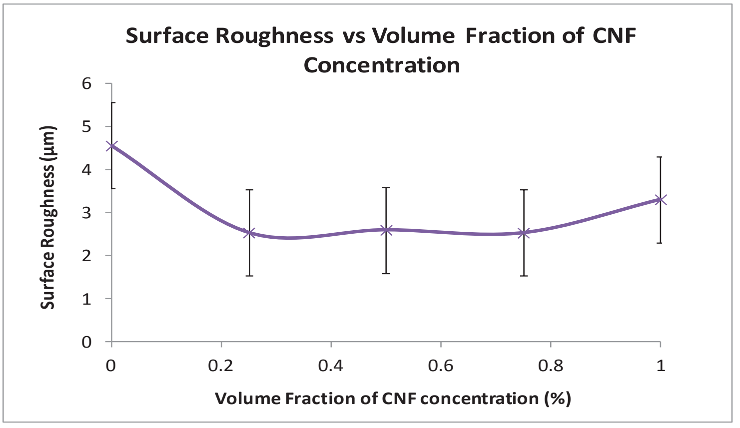

Figure 1: Surface roughness values at different percentage of CNF concentration

According to Krishna et al. [17], the increasing of temperatures highly influences the surface quality of the machined workpiece. Thus, with CNF nanofluid, it may help to give better cooling and lubrication during machining. This might be due to the CNF fill in the gap between the tool and the workpiece and thus reduce the temperature by traping the heat produced in the cutting zone. Besides that, thanks to its shape, the CNF particles might roll over the workpiece surface during machining and thus make a polishing effect. Therefore, a better surface quality can be produced.

It is also noticed that from the graph, there is slightly increasing value of surface roughness at 1% concentration of CNF. The surface roughness values obtained is 3.31 µm. According to Nam et al. [15], increasing volumetric concentration of nanoparticles in fluids can give impact to surface roughness which resulted in poor surface finishing. By increasing CNF concentration, the number of nanoparticles in the fluid will increase as well. When higher quantities of nanoparticles were used, CNFs may entangle with each other and caused the drilling process unstable. This may also cause the chips produced trap in the gap between the tool and workpiece and lead to the poor surface finish when it rolled together. This is supported by Rahmati et al. [13] whereby at higher concentration, these nanoparticles were sheared off by other incoming nanoparticles and more ploughed off particles remained on the thin exfoliated film and thus resulting higher surface roughness. Therefore, in this case, 1% concentration of CNF provided inferior surface roughness compared to 0.75%.

3.2 Hole Accuracy

Figure 2 shows the graph of hole diameter deviation at different percentage of CNF concentration for each repetition of experiment. Diameter deviation was calculated based on the different size of the top and bottom hole diameter. Based on the graph, it can be seen that the highest diameter deviation is at the 0.5 % CNF concentration. By using only DI water, the hole diameter deviation is higher compared to the other three concentrations with the average of 0.10 μm. The used of nanofluid might reduce the cutting force during the drilling process. This is consistent with that reported by Sarhan et al.[12] and Sayuti et al. [18] where they indicated that with the inclusion of nanoparticles in fluids, it can help to produce a thin protective film on machined surface. The nano particles will roll together to each other and tool chip interface thus it will decrease the coefficient of friction and the cutting force. Therefore, higher dimensional accuracy can be obtained with CNF nanofluid.

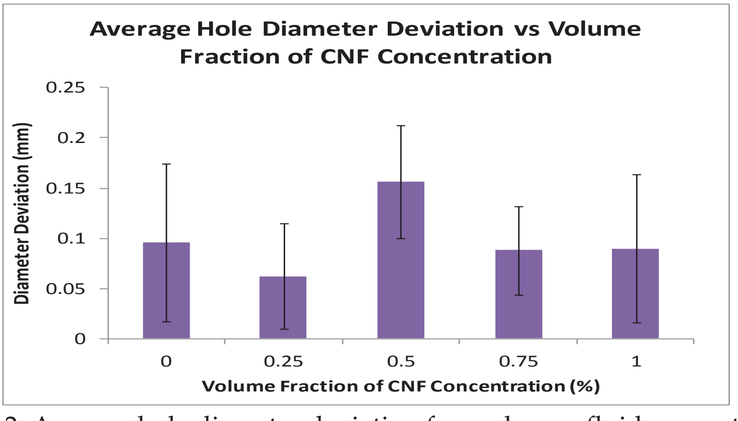

Figure 2: Average hole diameter deviation for each nanofluid concentration

3.3 Burr Formation

Figure 3 shows the burr formation at different concentrations of CNF which is 0%, 0.25%, 0.50%, 0.75% and 1% respectively. Based on the result, thicker burr is produced by using base fluid compared to CNF nanofluid especially at 0.25%, 0.50% and 0.75% percentage of CNF concentration.

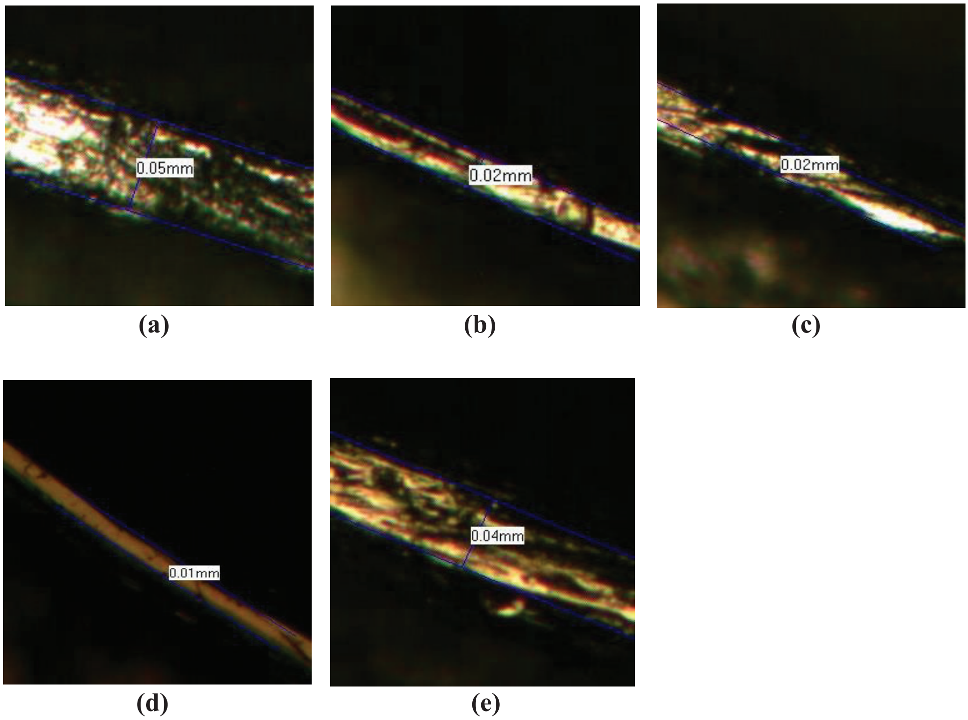

Figure 3: Burr formation at different concentration of CNF for (a) 0%, (b) 0.25%, (c) 0.5%, (d) 0.75% and (e) 1%

Generally, with the presence of CNF, chips and burr around the circumference of the drilled hole mostly are removed. This observation is similar to the result gained by Nam et al. [15]. The nanoparticles in the fluids can effectively avoid chips from being adhered to the drilled hole. This might be due to the encounter of the CNF particles with the undesirable projections of material as a result of plastic deformation that will form burr and thus wear it down. Moreover, as the present of CNF can reduce the friction by act as the thin protective film, it might also increase the tool wear therefore, less burr is form. This is supported Costa et al. [19] where he stated that the sharp drills produce relatively small burr, while worn drills produce opposite effect. This is because when lower thrust force applied, less workpiece material was subject to plastic deformation, resulting in smaller burr at the hole entrance. Besides, the ball bearing effect of nanofluid significantly played an important role to eliminate burrs and chips during drilling operation.

However, from this investigation it is noticed that when 1% percentage of CNF was used during drilling process, the formation of thicker burr is observed. This might be due to the impact of increased viscosity in nanofluid whereas it can disturb the drilling process.

4.0 CONCLUSION

This study is focused on the investigation of drilling process on AISI 304 stainless steel using CNF nanofluid. The percentage of CNF concentration was varied to investigate their effects on the drilling performance such as surface roughness, dimensional accuracy and burr formation. Besides, the comparison between base fluid (deionized water only) and CNF nanofluid also has been carried out. The following conclusions can be drawn from the results obtained through this entire investigation:

i. Better surface quality can be obtained using CNF nanofluid compared to deionized water only. The optimum surface finish was achieved at the 0.75% CNF concentration.
ii. With the suitable amount of CNF in DI water, the dimensional accuracy of drilled hole (diameter deviation of the entrance and exit hole) is higher compared to DI water only.
iii. The burr formation at the circumference of the drilled hole can be significantly reduced when applying CNF nanofluid.

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