MILLING OF TITANIUM ALLOY USING HEXAGONAL BORON NITRIDE (hBN) NANOFLUID AS A COOLANT

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ABSTRACT: Titanium has been used for many areas, such as aircraft turbine blade, fuel tanks, marine hardware and surgical implant. Due to its high hardness and high temperature when machining, the conventional method such as dry machining leads to rough surface roughness, high cutting force and short tool life. This study aims to evaluate the effect of different concentrations of hexagonal boron nitride (hBN) nanofluid on the cutting force, tool wear and surface roughness of titanium alloy using milling process. In this research, three different concentrations, namely 0.02, 0.06 and 0.1 wt% of hBN nanofluid were used, and their performance was compared with that of pure deionised (DI) water. The nanofluid was prepared by mixing the hBN nanoparticles with DI water and polyvinylpyrrolidone K30 as surfactant. The experimental results indicate that the machining performance of titanium alloy is better by using hBN nanofluid than by using pure DI water. Cutting force, tool wear and surface roughness are approximately reduced by 16.1%, 63.9% and 33.3% respectively by using 0.1wt% of hBN nanofluid compared to pure deionised water.

KEYWORDS: *Hexagonal Boron Nitride; Nanofluid; Coolant; Milling; Titanium Alloy*

1.0 INTRODUCTION

Titanium alloy Ti-6A1-4V is one of the hard materials that difficult to machine [1]. Titanium alloy has been used for many areas, such as aircraft turbine blade, fuel tanks and marine hardware [2]. Titanium alloy has also been used for surgical implant and others biomedical application. The usage of titanium alloy is rapidly increasing nowadays due to the outstanding properties, such as high tensile and compressive strengths and low density but high fatigue resistance in air and water [3].

Milling is one of the processes that used to produce different profiles and curves on titanium alloy. As the milling process started, force fluctuates on the workpiece and produces stress on the cutting zone. The stress continuously accumulates in the cutting zone and generates heat. Without any heat dissipated, the chemical reaction between cutting tool and chips will occur and this phenomenon leads to the failure of insert in a short time due to its high temperature. Thus, a cooling technique should be introduced to decrease the temperature of the insert, lubricate the insert and remove the chip optimally [4-6].

Dry machining, wet machining, minimum quantity lubricant (MQL) and cryogenic cooling are common cooling techniques in milling operation. Dry machining is carried out without the assistance of cutting fluids [7]. This technique is popular and useful for manufacturing ductile metal products because of its low cost, environmental sustainability and capability to increase tool life. In the meantime, wet machining is efficient in reducing heat during machining operation of hard materials. This technique can smoothen the operation and can thus decrease the cutting force [8]. MQL has been widely used in various industries. MQL is usually used for high-speed machining, such as turning, face milling and boring, because it is more economical than when used in low-speed machining. MQL technique can improve tool life, and reduce cutting force, surface roughness and machining zone temperature [9]. Cryogenic cooling commonly uses liquid nitrogen as the cooling medium [10] and this method is useful because it can decrease the cutting temperature significantly.

Nanofluid is recently being widely used in machining for cooling [11-15]. It is also known as colloidal dispersion of various nanoparticles in a base cutting fluid and being used for machining operation such as grinding, drilling, milling and turning [16-17]. This method can enhance the machining efficiency to a certain extent. Hexagonal boron nitride (hBN) is a very stable dielectric ceramic material that exhibits versatile properties, for instance good chemical inertness and exceptional high thermal conductivity. It is commonly used as heat transfer enhancement and lubricant [18-22]. However, to the best of our knowledge, extensive research on the milling of titanium alloy using hBN nanofluid as coolant is scarcely found in the previous studies.

Therefore, this paper aims to examine the influence of different concentrations of hBN nanofluid on the cutting force, tool wear and surface roughness of titanium alloy using milling process. Comparison between hBN nanofluid and conventional cutting fluid (pure deionised (DI) water) in terms of machining performance was performed experimentally.

2.0 METHODOLOGY

2.1 Equipment and Materials

Milling process was conducted with a HAAS VOP-C 3-axis CNC machine. The cutting tools used for end milling was coated carbide insert, and titanium alloy was selected as the workpiece in this research. For the preparation of nanofluid, the liquids used were DI water as base fluid, hBN as nanoparticles and polyvinylpyrrolidone (PVP) K30 as surfactant to disperse the nanoparticles. Tables 1 and 2 list the chemical composition of the titanium alloy and hBN, respectively.

Table 1: Chemical composition of Ti-6Al-4V [23]

Element	Composition (wt%)
Titanium (Ti)	89.464
Aluminum (Al)	6.08
Vanadium (V)	4.02
Iron (Fe)	0.22
Oxygen (O)	0.18
Carbon (C)	0.02
Nitrogen (N)	0.01
Hydrogen (H)	0.0053

Table 2: Chemical composition of hBN using energy dispersive X-ray [24]

Composition	Composition (wt %)
O	46.75
Ca	24.42
C	12.53
Mg	10.11
Sb	4.05
Si	2.13

2.2 Experimental Conditions

Pure DI water and three different concentrations of 0.02, 0.06 and 0.1 wt% of hBN nanofluid were prepared. Ultrasonic homogeniser was used to mix the solutions. The frequency was set at 50 amplitudes and 0.5 cyles. The weight for hBN nanoparticles and PVP K30 must be the same depending on the concentration needed. Equation (1) shows the formula for the nanofluid preparation.

$$Concentration\ of\ nanofluid\ (wt\%) = \frac{Weight\ of\ solute\,(g)}{Weight\ of\ solution\,(g)} \times 100\% \quad (1)$$

where

Weight of solute = Weight of hBN + Weight of surfactant.
Weight of solution = Weight of base fluid.

Next, DI water and PVP K30 were mixed together for 15 min. After 15 min, hBN was added into the mixture and the mixing process continued for another 75 min. The nanofluid preparation took approximately 90 min. During the ultrasonic process, the beaker was immersed in a basin of cold water to decrease the water temperature. After mixing for 15 min, the water in the basin were changed to a new cold water before the process continue for another 75 min. This process was done to avoid disturbing on dispersion of the nanoparticles in the base fluids as the temperature has significantly effect on the viscosity [25]. After mixing process was completed, the milling process was started under constant cutting speed, feed rate, and cut depth. The milling experiments were carried out in the miniaturized machine tool system which is shown in Figure 1. Coated carbide insert (RDET0803M0EN-G Sumitomo) and tool holder 20 mm diameter with 2 cutting edges (RSX08020ES Sumitomo) were used in the machining. Table 3 presents the selected parameters.

Table 3: Machining parameters

Machining Parameters	Details
Feed rate, f (mm/rev)	0.10
Cutting speed, V_c (m/min)	90
Depth of cut, d (mm)	2
Concentration of hBN nanofluid (wt%)	0.02, 0.06, 0.1
Flow rate of nanofluid (ml/h)	150

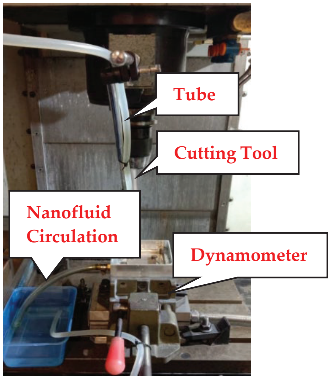

Figure 1: Experiment setup

2.3 Measurement and Analysis

After milling process, the surface roughness of the titanium alloy was measured using surface roughness tester (Mitutoyo SJ-301). Kistler 5697 dynamometer was used to measure the cutting force during the machining process, and tool wear (flank wear) was measured using Meiji stereo microscope.

3.0 RESULTS AND DISCUSSION

3.1 Cutting Force

Figure 2 shows the effect of different concentrations of hBN nanofluid on the cutting force. The graph shows that the cutting force is the highest when hBN is excluded. This finding is in agreement with that of Sayuti et al. [26]. The high cutting force occurs because of the high impact of the cutting tool toward the material due to the absence of nanoparticles. Thus, the cooling effect can be increased with the presence of nanoparticles [27]. When the concentration of hBN increases, the cutting force decreases. The reason is that the hBN particles in the nanofluid act as lubricant that reduces the cutting force. The particles of the nanofluids show better properties of ductility and flexibility, so that it can be crushed by the high extrusion force in machining and thus a firm physical lubrication film can be immediately shaped in the machining zone [28-29].

The effective film layer act to reduce the friction between the contact surfaces and decrease the cutting force values. The hBN nanoparticles reduced the friction by rolling between the tool-chip contact interface by means of their spherical shape, and thus converted sliding friction to rolling friction, which was notably effective in achieving a low cutting force [30]. Nanoparticles with good heat dissipation also will help to retain the hardness of the cutting tools for a longer time [31]. As a result, the time before the cutting tool wears will be long, which in turn reduces the cutting force.

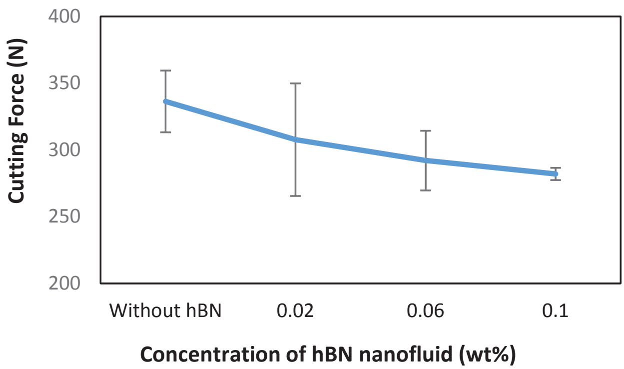

Figure 2: Effect of different concentrations of hBN nanofluid on the cutting force

3.2 Tool Wear

Figure 3 shows the effect toward tool wear when milling the titanium alloy using different concentrations of hBN nanofluid. Without hBN, tool wear becomes high. The high tool wear occurs because of the high friction due to the absence of nanoparticles that act as lubricant. This result is proven by Gariani et al. [32], who found that tool life is short when dry machining is used because high friction occurs. Thus, the absence of hBN nanoparticles in the DI water increases the force exerted to the material and therefore increases the tool wear. The tool wear decreases as the concentration of hBN increases. The reason is that the hBN nanofluid reduces the friction between the insert and the workpiece. Huang et al. [33] argued that wetting and penetration of lubricant droplets must be increased to lower the adhesion and friction of the workpiece on the machining zone. Ultimately, the tool life can be improved.

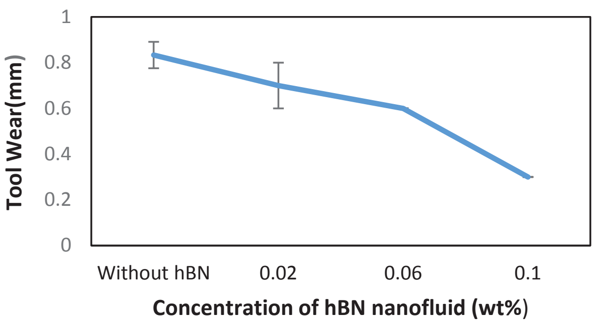

Figure 3: Effect of different concentrations of hBN nanofluid on the tool wear

3.3 Surface Roughness

Figure 4 shows the effect of different concentrations of hBN nanofluid on the surface roughness. The graph shows that the surface roughness is high when pure DI water (without hBN) is used. However, the surface roughness decreases when the concentration of hBN nanofluid increases. To some extent, hBN nanoparticles effectively played the role of ball bearings where the sliding friction was changed into rolling friction between the friction pair, resulting in reducing the contact area between the frictional surfaces [34]. After all, the impact of both "ball bearing effect" and "polishing effect" consequently smoothing the rough friction contact surfaces. Therefore, the increases in hBN nanofluid concentrations smoothens the material surface.

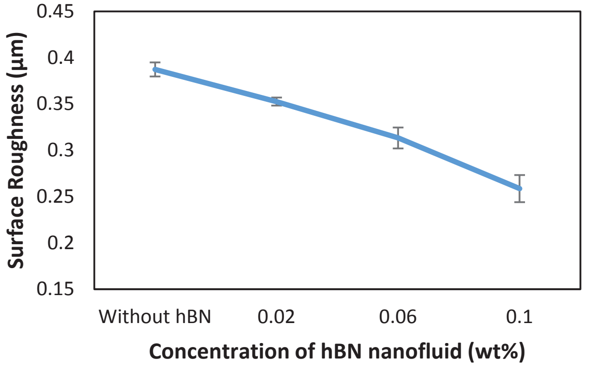

Figure 4: Effect of different concentrations of hBN nanofluid on the surface roughness

4.0 CONCLUSION

This study focused on the effect of different concentrations of hBN nanofluid on cutting force, tool wear and surface roughness of the titanium alloy using milling process. Pure DI water (without hBN) and different concentrations of hBN nanofluid of 0.02, 0.06 and 0.10 wt% were used during the experiment.

The significant outcomes of the study are summarised in the following points.

i. Pure DI water (without hBN nanoparticles) produces the highest cutting force, tool wear and surface roughness.
ii. Surface roughness, tool wear and cutting force significantly decrease with the increases of hBN nanoparticle concentration.

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