Performance of Castor Oil and Neem Oil as Metal Cutting Fluids in Drilling Inconel 718 Using MQL Technique on Tool Wear and Surface Roughness

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Abstract. Inconel 718 is hard to cut material due to its high hardness, high strength at elevated temperatures, low thermal diffusivity and affinity to react with tool materials. The high temperature during machining results in aggressive tool wear and poor hole quality. Therefore, the application of metal cutting fluids (MCF) as a lubricating and cooling agent is very significant in the drilling of nickel-based superalloys such as Inconel 718. The present study embraces these issues by evaluating the performance of non-edible vegetable oils such as castor and neem oil under minimal quantity lubrication (MQL) conditions towards the tool wear and surface roughness. The drilling experiments were carried out using coated (TiAlN) carbide drill with diameter of 6 mm at different cutting speeds of 10 and 20 m/min and a constant feed of 0.015 mm/rev. The results of this study showed that castor oil significantly outperformed the neem oil in drilling performance regarding tool wear and surface roughness.

1. Introduction

Inconel 718 is a precipitation-hardenable nickel-chromium alloy comprising high amounts of iron, niobium and molybdenum with lower amounts of aluminum and titanium. The alloy commonly being used in safety-critical industries (such as aerospace, medical, nuclear) due to high working temperature, excellent wear resistance, corrosion and creep resistance [1]. However, the low thermal conductivity of Inconel 718 may induce severe tool wear, large built-up edge (BUE) formation, chipping and cracking during the machining of this nickel-based alloy and perceived as challenging issues for manufacturers [2].

Therefore, metal cutting fluid (MCF) as a coolant and lubricant are the alternatives technology to increase the efficiency of machining operations such as reduced the cutting force and cutting temperature, minimized tool wear, better surface finishing and prolong tool life [3, 4]. However, due to the problems regarded the environment, health and machining cost, it is recommended to limit the usage of MCF whenever necessary. Thus, minimal quantity lubrication (MQL), which sprays a small quantity of cutting fluid (almost 10 – 100 ml/h) to the cutting region is an ideal solution for aforementioned problems [5].

Besides that, vegetable oils are also suggested in MQL application owing to its higher biodegradability and reduced waste treatment costs [6]. In fact, non-edible oils are assured as a sustainable feedstock for MCF since most of the non-edible plants could be cultivated on wastelands,
do not compete with food crops for restricted lands, comparatively cheap and offer similar or even better yields as the edible oils [7]. Hence, the machinability of different non-edible vegetable oils via MQL method was analyzed in this present study in order to reduce the tool wear and surface roughness of Inconel 718 during the drilling process.

2. Material and Methods

2.1. Workpiece material and cutting tools
The workpiece material used in this study was Inconel 718 with a chemical composition of 53.8% Ni, 18.1% Cr, 5.5% Nb, 2.9% Mo, 1% Ti, 0.55% Al, 0.25% C, 0.04% Si, 0.06% Mn and balance Fe (weight percent). At first, the drilling samples were cut using a wire electrical discharge machine, AQ537L Sodick to produce the rectangular plate with a final dimension of 94 mm length x 68 mm width x 10 mm thick. TiAlN coated tungsten carbide twist drills of a diameter of 6 mm have been selected as a cutting tool due to its superior properties [8]. TiAlN is a wear-resistant coating due to its high-temperature corrosion and oxidation resistance resulting in excellent chemical stability. Hence, it is an effective coating material in machining heat-resistant material such as Inconel 718.

2.2. Experimental Setup
The drilling experiments were conducted using three-axis CNC milling machine (Akira Seiki Performa) under the MQL technique with different cutting speeds and a constant feed rate. Non-edible vegetable oils such as castor and neem oil have been selected as lubricating oil. The tool wear growth was measured using a Stereo Microscopy System XST60 with the image processing software as shown in Figure 1. The flank wear of each drilling hole was analyzed until either of the following requirements reached. i. Maximum flank wear, $V_{\text{max}} \geq 0.15$ mm; ii. Chipping $\geq 0.15$ mm; iii. Fracture or catastrophic failure. The surface roughness value ($R_a$) of the drilled holes were recorded using an Accretech Handysurf E-35 equipped with a portable stylus as indicated in figure 2. The $R_a$ values of the drilling surface were observed at four different positions, 0°, 90°, 180° and 270° for each hole and the average of $R_a$ values were calculated.

![Figure 1](image1.jpg)  
Figure 1. (a) Experimental setup for tool wear measurement; (b) Cutting tool position to measure flank wear.
3. Results and Discussion

3.1. Tool Wear

The average flank wear versus the number of holes drilled for the different cutting speeds using castor and neem oil are shown in figure 3. According to Xavior [9], flank wear found on the tool face is the most typical wear when machining Inconel 718. As drilling progresses, the flank wear on the main cutting edge of the carbide tool was measured for each drilled hole under different cutting fluids. Based on figure 3, the lower cutting speed, 10 m/min accomplished the highest number of holes drilled compared to the higher cutting speed, 20 m/min for castor and neem oil. The number of holes that can be drilled at 10 m/min for castor and neem oil are 14 and 11 holes whereas, at the cutting speed of 20 m/min are 7 and 5 holes respectively. This is in line with the conclusion drawn by previous study, carbide tool faced higher flank wear at high cutting speed [9].

![Figure 3. Maximum flank wear under MQL condition using castor and neem oil.](image-url)
This is likely due to the tool gets worn out at a rapid rate during high cutting speeds, with severe tool failure patterns nearly up to tool life criterion [10]. In addition, the castor oil was performed better than neem oil in different cutting conditions. As seen in figure 3, the number of holes drilled using castor oil exceeding the number of holes drilled using neem oil at lower and higher cutting speeds. This is due to the higher viscosity of castor oil as compared to neem oil [11] and therefore, high viscous oil generated lower cutting forces, lower workpiece temperature and better progression of flank wear [12].

3.2. Surface Roughness
Figure 4 illustrated the average surface roughness of the drilled holes under MQL condition using castor and neem oil. It can be observed that the surface roughness value of Inconel 718 using castor oil showed a decreasing trend of 1.653 μm and 1.455 μm respectively for 10 m/min and 20 m/min. A similar trend is performed for the Inconel 718 by using neem oil. As reported by previous researchers [1-3] surface roughness decreased at higher cutting speed. This is because there could be a thermal softening of material at high speed and there is a potential that surface flaws can be wiped out [10]. Also, it was found that the lower surface roughness values obtained when using castor oil compared to neem oil for all cutting speeds. The high content of ricinoleic acids in castor oil provides good lubrication properties thus enhancing the surface finish of the workpiece [15]. Therefore, it can be concluded that a better surface finish achieved when using castor oil as a MCF at a higher cutting speed.

Figure 4. Average surface roughness versus cutting speed using different non-edible vegetable oils, castor and neem oil.

4. Conclusion
The performance evaluation of castor oil and neem oil as MCF in drilling Inconel 718 was investigated regarded the tool wear and surface roughness. The following conclusion are drawn:

i. The tool wear rate increased at a higher cutting speed. Castor oil shows better performance than neem oil due to the increased number of holes drilled at both cutting speed once the tool life reached the criteria.

ii. The surface roughness is reduced at high cutting speed owing to the thermal softening material and the possibility that surface flaws can be wiped out.
iii. Castor oil outperformed the neem oil with respect to tool wear and surface roughness within all cutting speed.

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