Effect of using different types of Non-Edible Vegetable Oils as Metal Cutting Fluids in Drilling Inconel 718 on Tool Wear and Surface Roughness

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Abstract. Inconel 718, a thermal-resistant nickel-based alloy, is used extensively in the aircraft industry. Due to the high toughness and work hardening properties, the use of metal cutting fluids (MCF) in machining operations is very significant. The application of the MCF to the cutting zone can minimize heat generation and reduce wear rate at the cutting edge. Surface roughness is often considered as a quality indicator for the finished or semi-finished product. This research evaluates the performance of non-edible vegetable oils which are castor and rice bran oil towards the tool wear and surface roughness. The drilling experiments were conducted using coated (TiAlN) carbide drill at various cutting speeds of 10 and 20 m/min and a constant feed of 0.015 mm/rev. The results of this research reveal castor oil outperformed rice bran oil in reducing tool wear and improved surface roughness.

1. Introduction
Inconel 718 has good mechanical and chemical properties at elevated temperatures and is commonly used in aerospace, ocean, and chemical industries [1]. However, Inconel 718 is classified as one of the hard to cut materials due to the high temperature properties, work hardening, and inclusion of abrasive carbide particles in microstructure resulting in poor surface finish, severe tool wear, higher cutting forces, cutting temperatures, and vibrations [2].

The poor machinability of Inconel 718 leads to the application of metal cutting fluids (MCF) to reduce the high temperature during the cutting process. An estimated 85% of MCF used worldwide are petroleum-based oils [3]. The use of petroleum-based oils produced many negative effects on the environment. The major negative effects are related to improper use, lead to the contamination of surface water and groundwater, air pollution, soil contamination, and at the same time, affected agricultural products and food contamination [4].

Previous researchers [5,6,7] stated that the use of non-edible vegetable oils via minimal quantity lubrication (MQL) during the drilling process showed significant improvement in the machining process. The application of non-edible vegetable oils ensures good lubricity, excellent anti-wear properties, high viscosity, improve tool life, and low emission of metal traces to the atmosphere [8]. However, its role as a cutting fluid via MQL, particularly during the drilling of Inconel 718, is still limited. The purpose of this research is to analyze the impact of different non-edible vegetable oils on the tool wear and surface roughness of Inconel 718 during the drilling process.
2. Experimental Procedure
The drilling experiments were conducted on a three-axis CNC milling machine (see Figure 1) under various cutting speeds and a constant feed. The rectangular plate of Inconel 718 was clamped with a specific design jig to support and locate the workpiece in the desired position. Drilling experiments were carried out by using castor and rice bran oil. In order to ensure the comparability between the different types of cutting fluids, a set of parameters (cutting speed 10 and 20 m/min, feed rate 0.015 mm/rev) were used for both cutting fluids [9]. The tool wear were measured by using a Stereo Microscopy System XST60 with the image processing software whereas the surface roughness were recorded using an Accretech Handysurf E-35 equipped with a portable stylus. The measurements were recorded at four positions (0º, 90º, 180º, 270º) within each hole, parallel to the drill feed direction. The machining parameters is shown in Table 1.

![Experimental setup](image)

**Figure 1.** Experimental setup.

| Table 1. Equipment Parameters for Machining and Analysis. |
|----------------------------------------------------------|
| **Equipment**                                         | **Descriptions**                        |
| Machine tool:  |
| CNC Milling Machine                              | Akira-Seiki Performa SR3                |
| Analysis Equipment:  |
| Microscope                                       | Stereo Microscopy System XST60          |
| Surface Texture Measuring Instrument              | Accretech Handysurf E-35                |
| Work Specimen:         |
| Material                                        | Inconel 718 (94 mm x 68 mm x 10 mm)     |
| Cutting Tool:         |
| Material and coating                              | Tungsten carbide (WC-Co) and TiAlN      |
| Type of drill bit                                  | Twist drill (Ø 6 mm)                    |
| Point and helix angle                              | 140º and 30º                            |
| Cutting Fluids:                                   | Castor and rice bran oil                |
| Cutting Parameters:  |
| Cutting speeds and feed                           | 10, 20 m/min and 0.015 mm/rev           |
3. Results and Discussion

3.1 Tool Wear

Figure 2 shows the maximum flank wear versus the number of holes drilled at different cutting speeds using castor and rice bran oil. The tool wear were measured along the main cutting edge of the coated (TiAlN) carbide drill after each drilled hole until it reaches the tool life criterion of maximum flank wear, \( V_{b\text{max}} \geq 0.15 \, \text{mm} \). As reported by previous researchers [10,11], the major failure mode of the worn drills in drilling Inconel 718 is flank wear. From Figure 2, the lowest cutting speed of 10 m/min obtains a high number of holes drilled in comparison to 20 m/min. The number of holes that can be drilled at 10 m/min for castor and rice bran oil are 14 and 7 holes whereas, at the cutting speed of 20 m/min, 7 and 3 holes respectively. Since the Inconel 718 is difficult to cut material, greater heat is produced when machining at 20 m/min compared to 10 m/min cutting speed. Due to the low thermal conductivity of the material, more heat is transmitted to the cutting tool, contribute to the main cause of tool wear [12].

Figure 3 depicted the tool wear pattern of the coated (TiAlN) carbide drill for castor and rice bran oil under MQL technique. The four factors leading to the tool failure were flank wear, brittle fracture (chipping, flaking, cracking), coating delamination, and tool fracture [13]. From the images observed during the experiment, the cutting tool has reached tool life criteria at all cutting speeds. Overall, castor oil outperformed the rice bran oil due to the high viscosity [14] and hence, produce excellent lubricating properties to reduce tool wear.

![Figure 2. Maximum flank wear under MQL condition for coated (TiAlN) carbide drill using castor and rice bran oil.](image-url)
Castor Oil | Rice Bran Oil

| Hole: 14 | Hole: 7 |
| Cutting speed: 10 m/min | Cutting speed: 10 m/min |

| Hole: 7 | Hole: 3 |
| Cutting speed: 20 m/min | Cutting speed: 20 m/min |

**Figure 3.** Tool wear pattern under different cutting speeds and constant feed of 0.02 mm/rev using coated (TiAIN) coated carbide drill.

3.2. Surface Roughness

Figure 4 shows the average surface roughness versus cutting speeds using different cutting fluids, castor and rice bran oil. It has been observed that the surface roughness value of the castor oil shows a decreasing trend of 1.594 µm to 1.455 µm at 10 m/min and 20 m/min respectively. Nanavati [15] had investigated the influence of cutting speed, feed rate, cutting depth, and tool geometry on surface roughness and notice that to minimize the surface roughness, a high cutting speed and low feed are necessary. However, the surface roughness of rice bran oil was directly proportional to the cutting speed. Rice bran oil produce low surface roughness at a lower cutting speed. This is probably due to the lower viscosity of rice bran oil compared to castor oil, thus producing a better coolant effect with the lower cutting temperature at lower cutting speed, 10 m/min [16]. Therefore, it can be concluded that a better surface finish achieved when using castor oil as a metal cutting fluid at a higher cutting speed.
Figure 4. Average surface roughness versus cutting speed using different non-edible vegetable oils, castor, and rice bran oil.

4. Conclusions
In this study, the use of coated (TiAlN) carbide drill when drilling Inconel 718 was analyzed at various cutting speeds using castor and rice bran oil. Conclusions have been drawn as follows:

i. The tool wear rate increased at a higher cutting speed. Castor oil obtain more number of holes drilled compare to the rice bran oil at both cutting speed once the tool life criteria were achieved.

ii. The lowest surface roughness was recorded when using castor oil compared to rice bran oil at high cutting speed.

iii. Castor oil offers better results than rice bran oil in reducing tool wear and surface roughness at high cutting speed due to the high viscosity to obtain good lubricating properties.

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