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EXPERIMENTAL INVESTIGATION OF VEGETABLE OIL-BASED CUTTING FLUIDS ON TANGENTIAL AND RADIAL CUTTING FORCES DURING TURNING OF ALUMINIUM ALLOY

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Abstract

This study evaluates the influence of different vegetable oil-based cutting fluids on the machining performance of AlSi10Mg aluminium alloy during turning operations. Cylindrical workpieces measuring 200 mm in length and 25 mm in diameter were machined under different combinations of spindle speed, feed rate, and depth of cut. Five vegetable oils, namely castor, neem, punnai, rain tree, and sunflower oils, were compared with dry machining and conventional cutting fluid conditions. Machining performance was assessed by examining the variation in tangential cutting force (Fz) and radial cutting force (Fy). The experimental results showed that dry machining consistently produced higher cutting forces, whereas conventional cutting fluid recorded the lowest values across the investigated conditions. Among the vegetable-based lubricants, punnai oil demonstrated the most favourable performance. At the reported spindle speed of 420 rpm, punnai oil reduced the tangential force by 23.75%, 22.14%, 12.22%, and 9.29% compared with dry machining across the four cutting conditions. Similarly, at 250 rpm, the radial force was reduced by 18.75%, 20.00%, 11.58%, and 15.00%, respectively. Sunflower oil also exhibited comparatively favourable performance, followed by castor oil. The reduction in cutting forces may be associated with improved lubrication at the tool–chip and tool–workpiece interfaces. The findings suggest that punnai oil has potential as an alternative lubricant for machining AlSi10Mg aluminium alloy, although further investigation of tool wear, surface integrity, and lubricant stability is required to establish its broader industrial applicability.

Keywords: AlSi10Mg aluminium alloy, Vegetable-based cutting fluids, Punnai oil, Turning operation, Tangential cutting force, Radial cutting force, Sustainable machining.

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1. INTRODUCTION

Of all these variables, the cutting fluid is probably the most versatile, since it acts directly in the tool-chip region and tool-workpiece interface, affecting surface integrity, chip formation, temperature, and friction. A wrong choice of fluid will negate the effectiveness of a well-functioning process, whereas a good choice will extend tool life, minimize energy consumption, and provide what the design requires without the need for additional finishing operations (Mandal et al., 2023). For many years, mineral oil-based cutting fluids were the main cutting fluids used in the industry. However, two issues hinder its use. The first is an environmental issue. Petroleum-based cutting fluids degrade very slowly, are toxic to microorganisms and aquatic life when diluted, and require special handling for disposal, leading to additional regulatory and economic costs. Second, while more hygienic, the fine mist produced when equipment is submerged tends to contaminate the respiratory zone, and epidemiological studies have shown that chronic exposure is associated with respiratory diseases and certain skin diseases. All these factors have led researchers, employers, and regulators to look for a biotechnology-based alternative that has a less negative impact on the environment while still getting the job done. Ekengwu et al. (2025) investigated the lubricity potential of Neem oil lubricant and Tiger nut oil lubricant when used singly and in combination for turning mild steel. Their findings indicated that neem oil has a lower cutting temperature and surface roughness than mineral oil as the base oil they used. Based on those comparisons, the 80:20 blend of neem to tiger nut oil appeared to provide the best overall results, rather than any one individual indicator. They

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said that the improvement was due to the presence of oleic acid and linoleic acid in neem oil, which provides molecules to adhere more strongly to the metal surface, and therefore, reasonably stable boundary film remains at the tool–chip interface. Mandal et al. ran turning trials with sunflower, soybean, coconut oil emulsions and then compared all of this with a baseline of the traditional mineral cutting oil. Based on their reports, the oil which gave the lowest surface roughness for the three oils was soybean oil and the oil which was most effective for lowering cutting zone temperature was coconut oil. Guo et al. explored the lubrication performance of castor oil containing soybean oil for MQL but they did it in a case of grinding a nickel-based alloy. The mixture was significantly superior to either castor or soybean alone. It reduced both the grinding forces and the rough surfaces. The reason they explained is that the castor oil has a higher viscosity and stronger film forming property, primarily due to the ricinoleic acid chain. So, soybean oil is said to be more thermally stable with these hot contact conditions that occur during grinding. Jeevan and Jayaram, went through the tribological data and the machining performance over a broad range of vegetable oil cutting fluids. They looked at castor, neem, linseed, jatropha, and a few others, across both turning and grinding. Their conclusion was that vegetable oils usually lower tool wear, decrease cutting forces and, also reduce surface roughness compared with dry machining, and quite often even outperform mineral oil. Yuan et al. studied a mixture of castor oil and ethanol and passed this mixture through MQL in a steel turning process. They found 36% improvement in the surface finish and 53% reduction in the tool wear as compared to dry machining. In MQL grinding, Wang et al. investigated some vegetable oils at the wheel-workpiece interface and pointed out that castor oil was the best lubricant. The friction coefficient was reduced by 50.1 percent and the specific grinding energy was reduced by 49.4 percent compared to the normal flood grinding. In this paper, five oils are tested under the same conditions, on the same AlSi10Mg specimens and with the same tool during turning. Moreover, surface roughness (Ra, Rz) under varying feed rates and depths of cut using each oil were compared.

2. MATERIALS AND METHODS

AlSi10Mg aluminium alloy was used as the workpiece material throughout. Specimens were cylindrical rods, each 200 mm long and 25 mm in diameter, procured from Fenfe Metallurgical, Materials Research Centre, Ramanagar, Bangalore. This alloy does respond to changes in cutting fluid and machining parameters in a manner that is evident in both surface roughness and tool wear measurements just what an experiment designed to compare fluid conditions requires. Four of the six cutting fluids were purchased as commercial oils from local suppliers. Castor oil and sunflower oil were procured at Rs. 150 each. Neem oil cost Rs. 230, and Punnai oil derived from Calophyllum inophyllum seeds was obtained at Rs. 450. The sixth fluid was an industrial soluble cutting fluid concentrate of the type commonly used in production machine shops, purchased separately and diluted with water at the manufacturer's recommended ratio of 1:10 to 1:20 by volume. This conventionally produced fluid served as the reference condition against which all five vegetable oil emulsions were compared.

Table 1: Design of experiments-machining parameter combinations

Exp. Run	Spindle Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	400	0.10	0.4
2	200	0.10	0.4
3	200	0.10	0.2
4	400	0.10	0.2
5	400	0.15	0.4
6	200	0.15	0.4
7	200	0.15	0.2
8	400	0.15	0.2

3. RESULTS AND DISCUSSION

Cutting force is a direct measure of friction at the tool-chip and tool-workpiece interfaces (Gunasekaran et al., 2021; Kumar et al., 2022; Thanigaivelan et al., 2018). When a fluid establishes an effective boundary film, it reduces the friction coefficient and lowers the force the machine must apply to maintain the cut. Less force also means less heat generated at source, which slows the wear mechanisms that act on the tool. Each run was recorded with three components: Fz, the tangential force in the direction of cut and the dominant energy-carrying component, Fy, the radial force pushing the tool away from the workpiece and Fx, the axial force in the feed direction. The results of Fz and Fy were discussed.

The figure 1 illustrates the variation in the measured parameter under seven lubrication conditions: dry, castor oil, neem oil, punnai oil, rain tree oil, sunflower oil, and conventional cutting fluid, at a constant speed of 420 rpm. The results are presented for four experimental conditions, represented as 1, 2, 3, and 4.

Under the first experimental condition, dry machining recorded the highest value of 8.0, whereas conventional cutting fluid exhibited the lowest value of 5.9. Among the vegetable-based oils, punnai oil showed the lowest value of 6.1, followed by sunflower oil (6.3), castor oil (6.5), neem oil (7.0), and rain tree oil (7.3). A similar trend was observed under the second condition, where dry machining produced the maximum value of 28.0. Conventional cutting fluid recorded the lowest value of 21.2, followed by punnai oil (21.8) and sunflower oil (22.0). Rain tree oil exhibited the highest value among the vegetable oils at 23.5.

For the third experimental condition, the measured values were comparatively lower, ranging from 7.5 to 9.0. Dry machining again exhibited the maximum value of 9.0,

while conventional cutting fluid recorded the minimum value of 7.5. Among the vegetable oils, punnai oil performed better, recording a value of 7.9, followed by sunflower oil (8.0), castor oil (8.2), neem oil (8.7), and rain tree oil (8.9).

Under the fourth experimental condition, dry machining produced the highest value of 14.0, whereas conventional cutting fluid exhibited the lowest value of 12.1. Among the vegetable oils, punnai oil recorded the minimum value of 12.7, followed by sunflower oil (12.9), castor oil (13.1), neem oil (13.6), and rain tree oil (13.9). Overall, the results indicate that dry machining consistently produces the highest measured values, whereas conventional cutting fluid records the lowest values across all four experimental conditions. Among the vegetable-based lubricants, punnai oil consistently demonstrates the lowest values, followed by sunflower oil, suggesting their potential as alternatives to conventional cutting fluids. The differences may be associated with the lubrication and cooling characteristics of the oils, although further experimental evidence is required to establish the underlying mechanisms.

The findings suggest that punnai oil offers the most favourable performance among the investigated vegetable oils when lower values of the measured parameter are desirable.

Figure 2 presents the variation in radial cutting force (Fy) under dry machining and different lubrication conditions at a constant spindle speed of 250 rpm. The lubricants considered include castor oil, neem oil, punnai oil, rain tree oil, sunflower oil, and conventional cutting fluid. The results show noticeable differences in radial force across the four cutting conditions, highlighting the influence of lubrication on machining performance.

Under cutting condition 1, dry machining recorded the highest radial force of 8.0 N, whereas conventional cutting fluid produced the lowest value of 6.2 N. Among the vegetable-based lubricants, punnai oil exhibited the lowest radial force of 6.5 N, followed by sunflower oil (6.7 N), castor oil (6.8 N), neem oil (7.0 N), and rain tree oil (7.2 N). Under cutting condition 2, the radial force increased to 10.0 N during dry machining. Conventional cutting fluid reduced the force to 7.8 N, while punnai oil recorded 8.0 N, corresponding to a 20.0% reduction compared with dry machining.

Under cutting condition 3, dry machining generated a radial force of 9.5 N, whereas conventional cutting fluid recorded 8.0 N. Among the vegetable oils, punnai oil again demonstrated the lowest radial force of 8.4 N, followed by sunflower oil (8.6 N) and castor oil (8.8 N). Cutting condition 4 exhibited the highest radial forces among the four conditions, with dry machining reaching 16.0 N. Conventional cutting fluid recorded the lowest value of 13.1 N, while punnai oil achieved 13.6 N, representing a 15.0% reduction compared with dry machining. The remaining vegetable oils produced comparatively higher radial forces, with rain tree oil recording the highest value among them at 14.8 N.

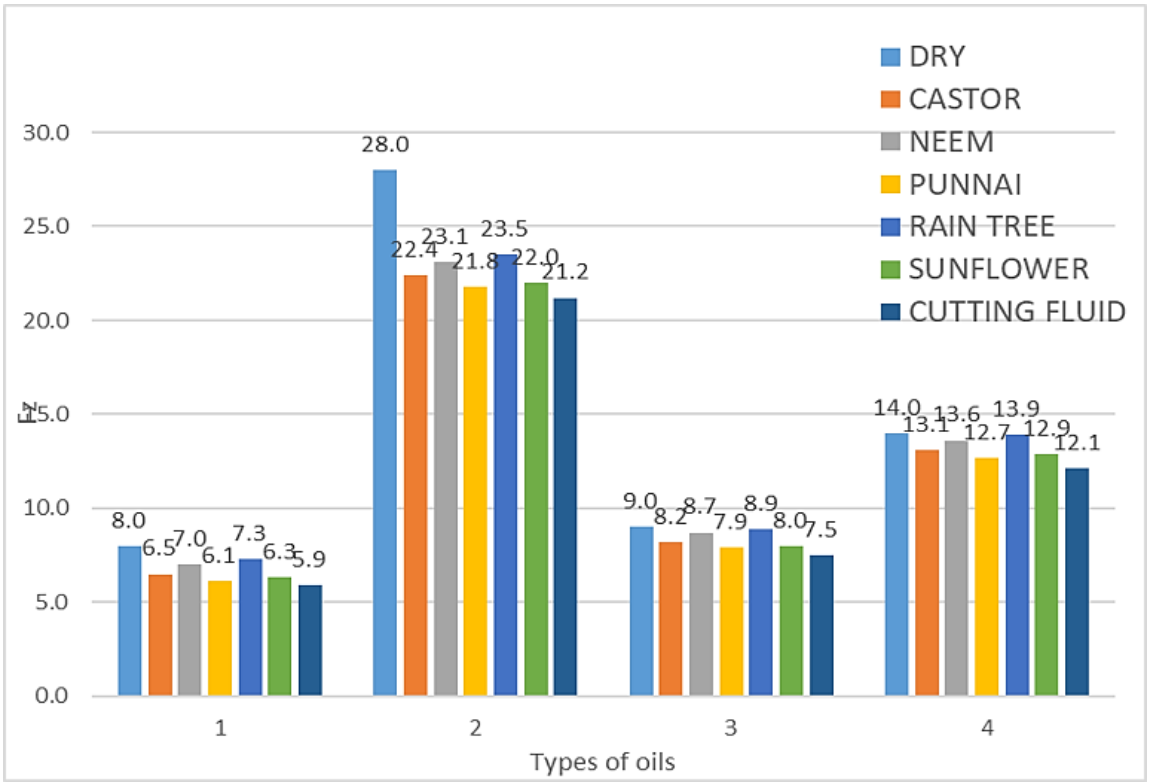


Figure 1: Tangential force Fz comparison across all cutting conditions

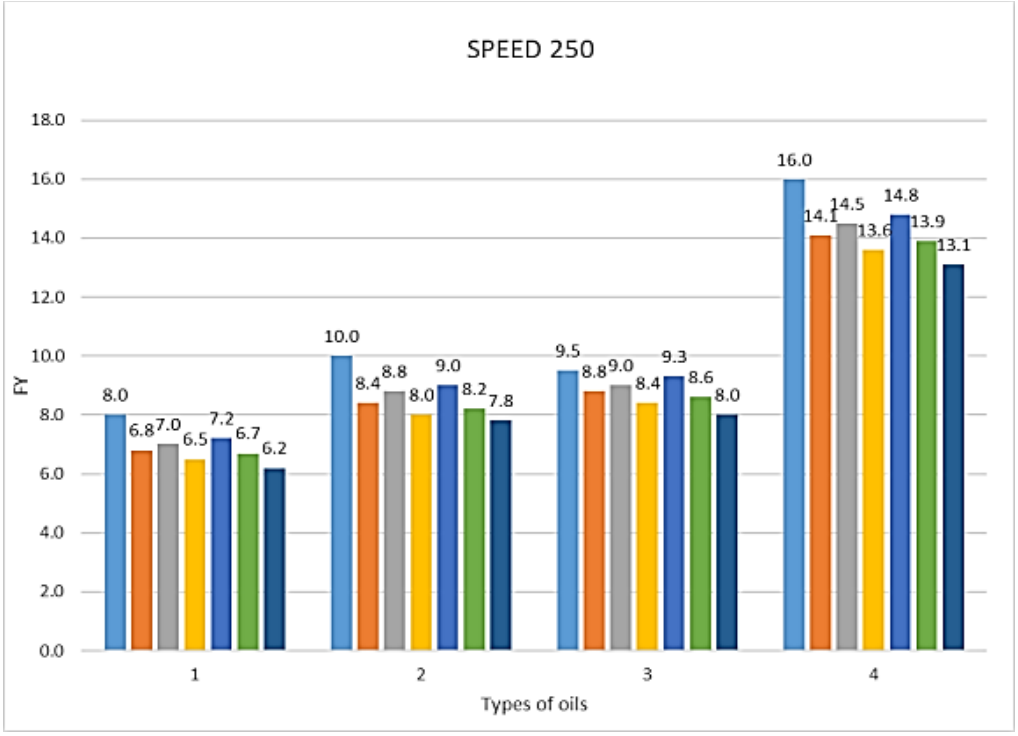


Figure 2: Tangential force Fy comparison across all cutting conditions

Overall, conventional cutting fluid consistently exhibited the lowest radial force under all four cutting conditions. However, punnai oil demonstrated the best performance among the vegetable-based lubricants, reducing radial force by approximately 18.75%, 20.00%, 11.58%, and 15.00% compared with dry machining under cutting conditions 1, 2, 3, and 4, respectively. The reduction in radial force may be attributed to the formation of a lubricating film at the tool–workpiece interface, which could reduce friction and resistance during machining. However, additional experimental investigations are required to confirm this mechanism.

The findings indicate that punnai oil has considerable potential as an alternative to conventional cutting fluids for reducing radial cutting force under the investigated machining conditions. Its consistently lower radial force compared with other vegetable oils suggests favourable lubrication performance at a spindle speed of 250 rpm.

4. CONCLUSIONS

The present study investigated the influence of different vegetable oil-based cutting fluids on the machining behaviour of AlSi10Mg aluminium alloy under various turning conditions. Five vegetable oils, namely castor, neem, punnai, rain tree, and sunflower oils, were evaluated alongside dry machining and conventional cutting fluid. The performance of these lubricants was examined primarily through tangential and radial cutting force measurements. Based on the experimental observations, the following conclusions were drawn:

1. Dry machining consistently produced the highest tangential and radial cutting forces under the investigated conditions. In contrast, conventional cutting fluid exhibited the lowest force values, indicating its superior performance in reducing cutting resistance.
2. Among the vegetable-based lubricants, punnai oil demonstrated the best overall performance, consistently recording the lowest cutting forces across all four experimental conditions in both force comparisons. Sunflower oil exhibited the second-best performance among the vegetable oils, followed by castor oil.
3. At the reported spindle speed of 420 rpm, punnai oil reduced the tangential cutting force by 23.75%, 22.14%, 12.22%, and 9.29% compared with dry machining under cutting conditions 1, 2, 3, and 4, respectively. These reductions indicate its effectiveness in lowering cutting resistance across the evaluated machining conditions.
4. At a spindle speed of 250 rpm, punnai oil reduced radial cutting force by 18.75%, 20.00%, 11.58%, and 15.00% compared with dry machining under the four cutting conditions. The lowest radial forces among all lubrication conditions were obtained using conventional cutting fluid, although the values recorded with punnai oil were relatively close.
5. The reduction in cutting forces observed with vegetable oils may be associated with their ability to provide lubrication at the cutting interface. The comparatively favourable performance of punnai oil suggests that its lubricating characteristics may help

reduce frictional resistance during machining. However, detailed tribological investigations are necessary to verify this explanation.

Overall, the study demonstrates that punnai oil is the most promising vegetable-based lubricant among the investigated alternatives for reducing cutting forces during the turning of AlSi10Mg aluminium alloy. Future research should examine the influence of lubricant concentration, cutting temperature, tool wear, and surface finish to determine the practical suitability of punnai oil for industrial machining applications.

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CONFLICT OF INTEREST

There is no conflict of interest among the authors.

DATA AVAILABILITY

Corresponding authors is will provide the data on request

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