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RESEARCH ARTICLE

EVALUATING THE PERFORMANCE OF DIFFERENT TYPES OF CUTTING FLUID IN THE MACHINING OF ALUMINIUM-MANGANESE ALLOY IN TURNING OPERATION

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ABSTRACT

The research aimed to evaluate the performance of neem seed oil as a cutting fluid in orthogonal machining of aluminium-manganese alloy 3003, carbide cutting tool insert was used as a cutting tool under different machining parameters of spindle speed, feed rate and depth of cut with different types of cutting fluids (neem seed oil and soluble oil) as well as dry machining. The results were obtained in terms of the average surface roughness of the machined workpiece and flank wear under different cutting parameters (spindle speed, feed rate and depth of cut). The results indicated that the neem seed oil cutting fluid reduced the surface roughness by 39% and 22% as compared to dry turning and soluble oil cutting respectively. It was established from the results that the neem seed oil cutting fluid reduced the flank wear by 72% and 56% as compared to dry turning and soluble oil cutting respectively. Based on the study, it can be concluded that neem seed oil cutting fluid facilitates a better surface finish and substantial reduction in tool wear when compared with dry and soluble oil machining.

Key Words: Cutting fluid, Surface roughness, Flank wear, Dry machining, Neem.

INTRODUCTION

The fact that cutting fluid contains oil poses a huge concern to health and environment aspect. The chemical based coolants used nowadays are harmful to the operator, environmentally unfriendly, costly and potentially toxic. Due to the many problems regarding to the health and environmental issues, the vegetable oil and soybean oil have been tested in machining and good result obtained, however, the cost of making those oils is quite expensive and are edible which limits their use as cutting fluid. In reducing the cost of production, cheaper natural source needs to be developed which is not edible such as the neem seed oil. The use of vegetable oil from non-edible sources (neem seed oil) is to prevent the diversion of food and edible crops like groundnut oil, palm kernel oil and palm oil to cutting fluid which will invariably lead to food insecurity.

Neem seed oil is from non-edible plants which grow on their own in the Northern part of Nigeria but never days stress are given for cultivation of trees which not only provides us with vegetation, but it also provides employment to tribal, poor people and finally with different products which is superior to mineral oil being biodegradable, cheaper and eco-friendly. Adhvaryu and Erhan (2005) (Adhvaryu and Erhan, 2005) discovered that non-edible oil seeds mainly contain lipid protein, protein portion and carbohydrates and finding its way into lubricants for industrial applications. It seems that it is the suitable replacements of the conventional coolants. The fatty acid composition of neem seed oil shows higher level of unsaturated fatty acids especially linoleic acid, oleic acid and saturated fatty acids.

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These were found to have high palmitic acid and stearic acid. Masjuki *et al.* (1999) (Masjuki *et al.,* 1999) claimed that the triglyceride structure of the vegetable oils provides desirable qualities of boundary lubrication; a high natural viscosity and viscosity index (the strong intermolecular interactions are resilient to temperature changes) and structural stability over reasonably operating temperature ranges. Al-3XXX wrought alloys are widely used for architectural applications, cooking utensils, bodies of beverage cans, packaging, chemical equipment, pressure vessels and heat exchangers (Avner, 1974; Aman and Hari, 2005; Xavior and Adithan, 2009; Belluco and De Chiffre, 2001; Khan *et al.,* 2009; Peace, 1993). The 3003 alloy is one of the most popular alloys in this group, which has good formability, very good resistance to corrosion, and good weldability (Avner, 1974).

Surface finish is one of the most significant technical requirements of the customer. A reasonably good surface finish is desired to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product. Aman and Hari (2005) (Aman and Hari, 2005) said that the challenge of modern machining industries is focused mainly on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. Xavior and Adithan (2009) (Xavior and Adithan, 2009) studied the performance of coconut oil during the machining of AISI 304 material with carbide tool. They found that coconut oil reduced the tool wear and improved the surface finish with respect to mineral oil. Belluco and De Chiffre (2001) (Belluco and De Chiffre, 2001) used three vegetable based cutting oils including additives and a straight cutting fluid for performance study in turning, reaming and tapping operations.

Results indicated that vegetable based cutting oils were superior to mineral oil. Khan *et al.* (2009) (Khan *et al.,* 2009) reported the effects of MQL by vegetable oil based cutting fluid on the turning performance of low alloy steel AISI 9310 as compared to completely dry and wet machining in terms of chip-tool interface temperature, chip formation, tool wear and surface roughness. The chip-tool interface temperature was measured by tool-work thermocouple technique during turning of AISI 9310 steels. The results showed that chip-tool interface temperature were reduced by MQL and wet machining as compared to dry machining under different cutting conditions with uncoated carbide inserts. In this research work, evaluating the performance of cutting fluids from neem seed oil and commercial cutting fluid were used on surface roughness and flank wear during turning of aluminium manganese alloy with carbide tools.

MATERIALS AND METHODS

Material

The workpiece selected for this research was commercially available aluminium-manganese alloy. Table-1 shows the chemical composition of the workpiece material in percentage by weight which was analysed at National Geosciences Research Laboratory (NGRL), Kaduna, Nigeria. The workpiece diameter and length were 45mm and 350mm respectively. A centre hole was drilled on the face of the work piece to allow supporting at the tailstock. A pre-cut with a 1mm depth of cut was performed on each workpiece prior to actual turning; the size of the workpiece is maintained at 44mm. This was done in order to remove the rust layer or hardened top layer from the outside surface and to minimize any effect of inhomogeneity on the experimental result.

The fatty acid profile of Neem seed oil is given in Table 2. The fatty acid composition showed higher level of unsaturated fatty acids, especially linoleic acid, oleic acid and saturated fatty acids which were found to have high palmitic acid and stearic acid. Masjuki *et al.* (1999) (Masjuki *et al.,* 1999) said that the triglyceride structure of the vegetable oils provides desirable qualities of boundary lubrication; a high natural viscosity and viscosity index (the strong intermolecular interactions are resilient to temperature changes) and structural stability over reasonably operating temperature ranges.

Experiments

The machining was carried out using a XL400 lathe machine having fixed feed rate and depth of cut. The cutting conditions are shown in the Table 3. In this experiment, the surface roughness of the machined samples was measured using an ISR 16 surface roughness tester. At the surface roughness measurements, cut-off length for the measurement was set at 0.8mm and stylus was inserted and the start-up button was pushed to take the surface roughness [Ra] reading. These measurements were repeated three times, on three different points on the work piece, and the average values of the readings were recorded. The tool wears were measured using a digital vernier calliper. The flank wears were measured from the distance between the top of the cutting edge and the bottom of the area where flank wear occurs. Carbide turning tools were replaced when the width of the flank wear area reaches some predefined limit. Peace, G. S. (1993) (Peace, 1993) explained that the 1993 international standard (ISO 3685) stipulates that a flank wear width of 0.76 mm for rough turning and 0.38 mm for finish turning. The flank wears were formed by continuous rubbing of the work material with cutting edges. All the tests were conducted under dry, neem seed oil and soluble oil cutting fluid conditions.

Table 1. Chemical composition of workpiece in percentage by weight

Chemical composition Wt%	Al	Ca	Ti	Cr	Mn	Fe	Cu	Te	Hf
	93.4%	0.1%	0.79%	0.94%	2.03%	1.52%	0.06%	0.92%	0.1%

Source: National Geosciences Research Laboratory (NGRL), Kaduna, Nigeria

Table 2. Fatty acid profile of neem seed oil

Fatty acid	% composition
Unsaturated fractions:	
Oleic acid (C18:1)	56.98
Linoleic acid (C18:2)	3.69
Linolenic acid (C18:3)	0.28
Erucic acid (C22:1)	0.09
Palmitoleic acid (C16:1)	1.88
Saturated fractions:	
Palmitic acid (C16:0)	15.55
Stearic acid (C18:0)	21.11
Arachidic acid (C20:0)	0.18
Behenic acid (C22:0)	0.11
Lignoceric acid (C24:0)	0.71
Total	100%

Source: National Research Institute for Chemical Technology, Zaria, Nigeria

Table 3. Cutting parameters and level

Level Number	Spindle speed, N (rev/min)	Feed rate, f (mm/rev)	Depth of cut, d (mm)
-1	200	0.5	1.0
0	350	0.75	1.5
1	500	1.0	2.0

It should be noted that three different conditions were experimented:

Firstly, readings were taken in dry condition for three different spindle speeds (200, 350, 500rpm) while keeping feed rate at 0.75mm/rev and depth of cut at 1.5mm. The same steps were also performed for both neem seed oil and soluble oil cutting fluids. The next step was performed by keeping both the depth of cut (1.5mm) and spindle speed (350rpm) constant while varying the feed rate (0.5, 0.75, 1.0mm/rev) in dry operation. Lastly, readings were taken in dry condition for three different depths of cut (1.0, 1.5, 2.0mm) while keeping spindle speed at 350rpm and feed rate at 0.75mm/rev. These steps were repeated using soluble oil and neem seed oil cutting fluids.

Cutting tool

Uncoated carbide inserts tool SNMG 120408-QM H13A (ISO designation) were clamped onto a tool holder with a designation of DBSNR 2020K 12 (ISO designation) for turning operation.

Machining parameters and their levels

The cutting parameters are shown in Table 3. Three levels of spindle speed, three levels of feed rate and three levels of depth of cut were used.

RESULTS AND DISCUSSION

The result obtained shows the performance of two cutting fluids and dry machining in terms of surface roughness and flank wear.

The soluble oil cutting fluid reduced the surface roughness by 24% as compared to dry turning. It was also observed that the deviation of surface roughness is highest in case of neem seed oil cutting fluid and lowest for dry machining. This was perhaps due to the high lubricating effect of neem seed oil cutting fluid. Figure 2 shows the effect of varying feed rate on surface roughness keeping spindle speed (350rpm) and depth of cut (1.5mm) constant. The result shows that neem seed oil is most effective at reducing the surface roughness when compared to the use of soluble oil and dry turning. The average surface roughness increases with increase in feed rate from 0.5 to 1.0mm/rev. The best surface quality was obtained using neem seed oil cutting fluid compared with soluble oil cutting fluid. The neem seed oil cutting fluid reduced the surface roughness by 28% and 18% as compared to dry turning and soluble oil cutting fluid respectively. The soluble oil cutting fluid reduced the surface roughness by 12% as compared to dry turning. It is also observed that deviation of surface roughness is the lowest in case of neem oil based cutting fluid and highest for machining without any cutting fluid (dry).

Similar results are obtained with variation of depth of cut while keeping the other two cutting parameters constant which can be seen from Figure 3. In this case surface quality is much better using neem seed oil cutting fluid when compared to the other two cutting conditions. For the two cutting conditions namely dry machining and machining with soluble oil cutting fluid, roughness is linearly increasing with increasing rate of depth of cut but using neem seed oil as cutting fluid, surface quality slightly deteriorates with increasing rate of depth of cut. The neem seed oil cutting fluid reduced the surface roughness by 23% and 15% as compared to dry turning and soluble oil cutting fluid respectively.

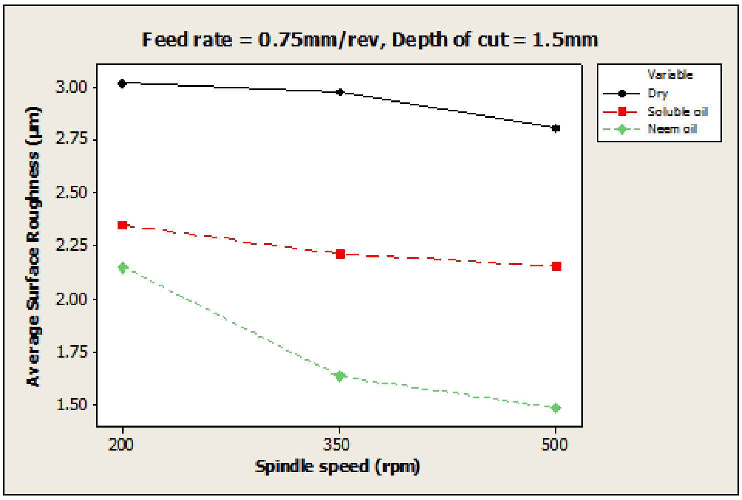

Figure 1. Effect of spindle speed on surface roughness (f = 0.75mm/rev, d = 1.5mm)

Average Surface Roughness

Figure 1 shows the effect of spindle speed on the average surface roughness keeping the other two cutting parameters constant (feed rate = 0.75mm/rev and depth of cut = 1.5mm). It was observed that the average surface roughness decreases with the increase in spindle speed from 200 to 500rpm. However, the best surface quality was obtained using neem seed oil as cutting fluid and the lowest surface quality occurred in dry condition. The neem seed oil cutting fluid reduced the surface roughness by 39% and 22% as compared to dry turning and soluble oil cutting fluid respectively.

The soluble oil cutting fluid reduced the surface roughness by 10% as compared to dry turning. The application of neem seed oil as cutting fluid gave good surface quality because of its good lubricating properties.

Flank Wear

Figure 4 shows the effect of spindle speed on flank wear for a feed rate of 0.75mm/rev and depth of cut of 1.5mm. Figure 4 shows that the increase in spindle speed increases the flank wear under the same machining conditions.

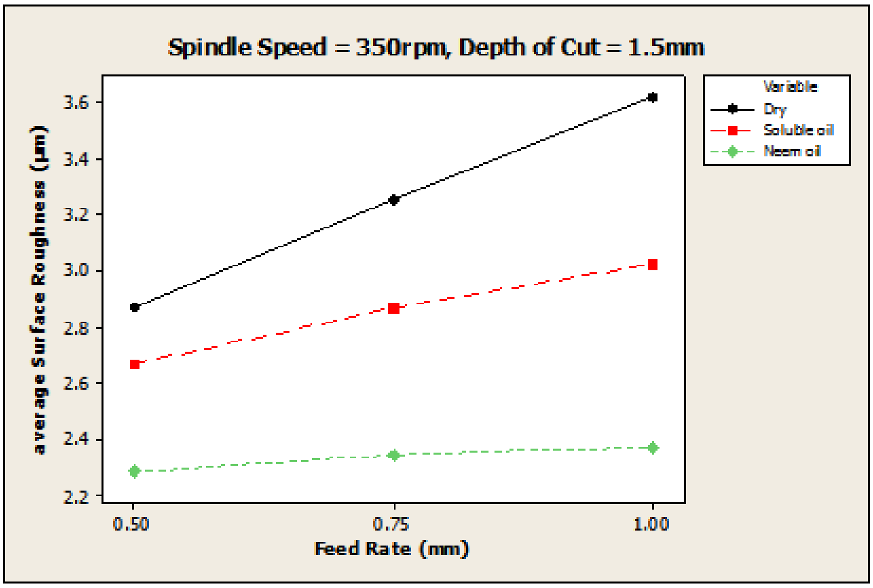

Figure 2. Effect of feed rate on surface roughness (N = 350rpm, d = 1.5mm)

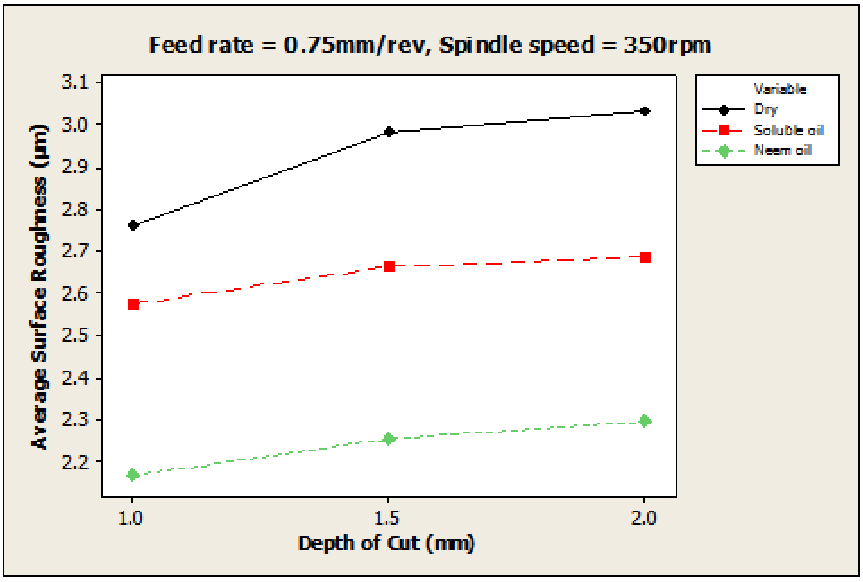

Figure 3. Effect of depth of cut on surface roughness (f = 0.75mm/rev, N = 350rpm)

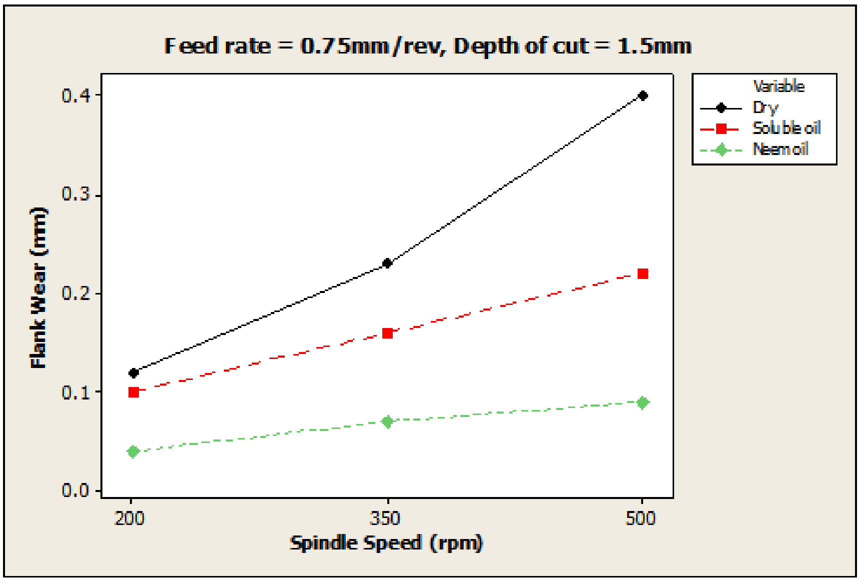

Figure 4. Effect of spindle speed on flank wear (f = 0.75mm/rev, d = 1.5mm)

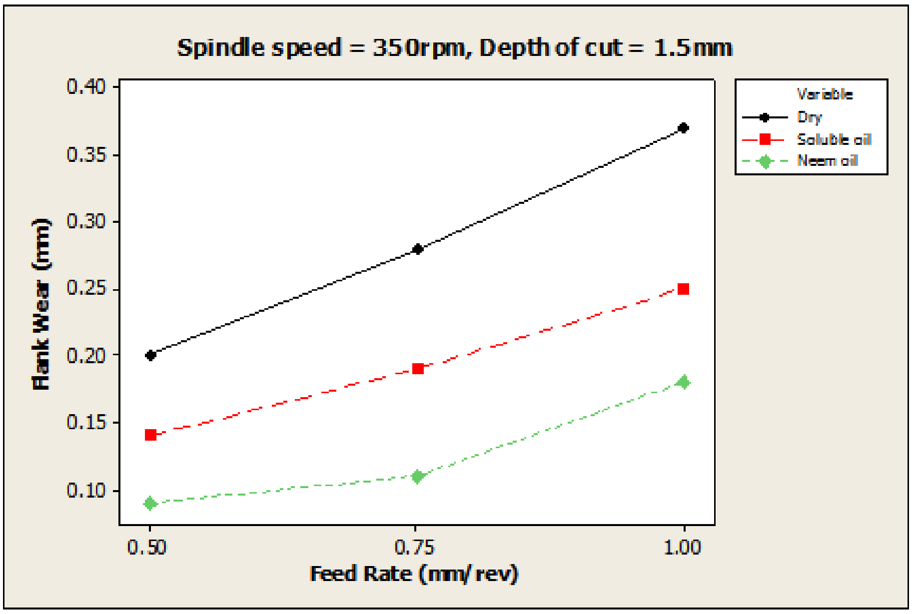

Figure 5. Effect of feed rate on flank wear (N = 350rpm, d = 1.5mm)

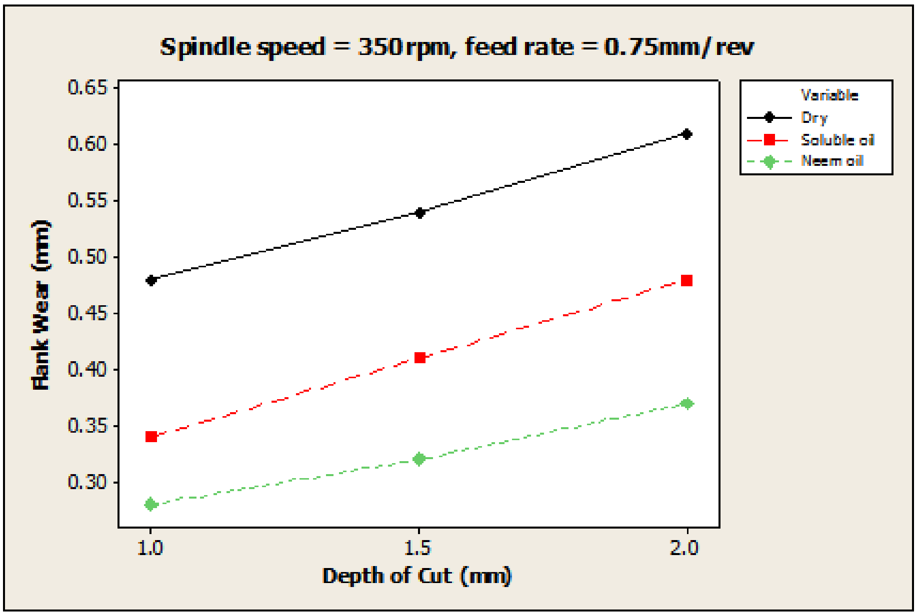

Figure 6. Effect of depth of cut on flank wear (N = 350rpm, f = 0.75 mm/rev)

For low spindle speed of 200rpm, it was observed that the flank wear of dry machining and soluble oil coolant was almost the same. However it was observed that the highest flank wear was obtained for dry machining, whereas the lowest flank wear was obtained for neem seed oil coolant. The neem seed oil coolant reduced the flank wear by 72% and 56% as compared to dry turning and soluble oil cutting fluid respectively. The soluble oil coolant reduced the flank wear 36% as compared to dry turning. At higher spindle speeds, the material passes away within a short interval of time, which facilitates the machining interface to become an adiabatic system. Increase in temperature softens the cutting tool and causes more tool wear.

Figure 5 shows that an increase in the feed rate increases the flank wear. A rise in the feed rate increases the friction between workpiece and hikes heat generation which causes greater flank wear. It was seen that in dry machining, the effect of feed rate on flank wear was highest among all.

With the application of cutting fluid, the rate of flank wear was reduced while the lowest flank wear was obtained using neem seed oil. The neem oil coolant reduced the flank wear by 55% and 34% as compared to dry turning and soluble oil coolant respectively. The soluble oil coolant reduced the flank wear by 32% as compared to dry turning. Overall, the results suggested that neem seed oil exhibited comparable performance with soluble oil in terms of flank wear rate. This can be attributed to the ability of neem seed oil in reducing the temperature at the tool-workpiece interface thus the flank wear rate was reduced. Neem seed oil has higher viscosity index than soluble oil. The higher viscosity index of neem seed oil can be explained due to the fact that neem seed oil contains palmatic acid (CH3(CH2)14COOH) which consists of triglyceride structures that provide desirable lubricant and maintain stronger intermolecular interactions with increasing temperature (Masjuki *et al.,* 1999).

In addition, the fatty acid in neem seed oil contains a thicker molecular layer of lube oils. These factors could contribute to the better lubricating hence could reduce the tool wear rate.

From figure 6, it is shown that the flank wear increases with the increase in depth of cut at constant spindle speed of 350rpm and feed rate of 0.75mm/rev. It was observed that the highest flank wear was obtained for dry machining, whereas the lowest flank wear was obtained for neem seed oil. Between the two coolants (neem seed oil and soluble oil), the flank wear is less in case of neem seed oil coolant at increased depth of cut. The neem seed oil coolant reduced the flank wear by 77% and 69% as compared to dry turning and soluble oil coolant respectively. The soluble oil coolant reduced the flank wear by 24% as compared to dry turning.

Conclusion

- The minimum surface roughness and best surface quality was obtained using neem seed oil as cutting fluid as compared to soluble oil cutting fluid in turning operation.
- The least surface roughness was achieved at spindle speed of 500 rpm using neem seed oil. It was the most effective in reducing surface roughness as spindle speed increased.
- Neem seed oil had the best surface quality at feed rates lower than 0.5 mm/rev and depth of cuts lower than 1.5mm, while the highest surface roughness was observed at feed rate of 1.0 mm/rev and depth of cut 2.0mm using dry turning.
- Lower flank wear values were obtained with soluble oil and the least flank wear was achieved at spindle speed of 200 rpm using Neem oil. Neem seed oil generated the highest reduction in flank wear when machining Al-Mn alloy at a spindle speed of 200rpm, a feed rate of 0.5 mm/rev and a depth of cut of 1.0mm
- An increase in the spindle speed decreased the surface roughness value.
- An increase in the feed rate and depth of cut increased the surface roughness value.
- An increase in the spindle speed increased the flank wear value.
- An increase in the feed rate and depth of cut increased the flank wear value.
- The significant contribution of neem seed oil in machining of the aluminium-manganese alloy 3003 by carbide insert undertaken has offered the reduction of flank wear which would enable remarkable improvement in tool life and allow higher spindle speeds, feed rates and depths of cut. Such significant reduction was due to its high lubricating property.

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