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Performance evaluation of non-edible oils blends as cutting fluid in turning operation of mild steel

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Abstract

Cutting fluids play a crucial role in machining processes by providing cooling to the cutting tool and workpiece surface, lubricating the tool-workpiece interface, and removing chips from the cutting zone. The main objective of using cutting fluids is to reduce temperature and minimize frictional wear through effective cooling and lubrication. As a result, mineral, vegetable, and animal oils have emerged for cutting fluid. Though, mineral oil-based cutting fluid also presents significant concerns regarding environmental impact, health hazards, and the challenges of recycling and disposal. Compared to mineral oils, vegetable oils exhibit favourable characteristics such as a higher viscosity index, flash point, lubricity, and lower evaporative losses. Vegetable oils can be classified as edible or non-edible, and several studies have demonstrated the effective utilization of edible vegetable oils as environmentally friendly cutting fluids in machining operations. However, the current scenario poses limitations on harnessing edible oils for lubricant production due to the increasing global demand and limited availability. In this study, the focus was on using non-edible vegetable oils, specifically Neem and Karanja oils, as cutting fluids in different ratio blends for turning mild steel. The objective was to assess the effect of these blends on surface roughness. To conduct the experiments, employed the Taguchi L_9 orthogonal array experimental design plan.

Keywords: Eco-friendly cutting fluids, Karanja oil, neem oil, surface roughness, turning operation.

1. Introduction

In the competitive landscape of today's manufacturing industry, the success of a production unit relies on its ability to manufacture high-quality products at economical rates. However, the frequent replacement of tools on the shop floor due to wear significantly increases the overall cost of the product. Therefore, reducing tool wear is a critical aspect of machining research (Shaw, 2005). Tool wear is commonly attributed to friction in the machining zone. The high temperatures and cutting forces resulting from friction intensify tool wear and decrease tool lifespan

(Shaw, 2005). To mitigate friction, cutting fluids are extensively employed in the industry (Byers, 2006). Cutting fluids act as lubricants and coolants during the machining process. Various types of cutting fluids are available in the market, including straight oils, water-miscible oils (WMO), semi-synthetic fluids, and synthetic fluids.

1.1 Vegetable oils derived from non-edible sources used as cutting fluids during turning operations.

The utilization of non-edible vegetable oils as cutting fluids provides numerous benefits, primarily due to their minimal impact on the food chain, which is a significant concern associated with edible oils. Jatropha and Pongamia oils exemplify readily accessible and biodegradable non-edible vegetable oils. In a conducted research study, Jatropha and Pongamia oils were treated with epoxidation to improve their oxidative stability before being applied as straight-cutting fluids. The performance of these modified oils was subsequently assessed and compared to commercially available cutting fluids that are mineral oil-based [1]. In the turning process, an AA 6061 workpiece was machined using a High-Speed Steel (HSS) tool, with variations in feed rate (FR), depth of cut (DOC), and cutting velocity (VC). Through experimentation, it was determined that lower values of DOC and FR, along with higher cutting speeds, were found to be optimal, as indicated in Table 1. By utilizing Jatropha oil as the cutting fluid, a remarkable surface roughness (Ra) as low as 0.7 µm was achieved, while Pongamia oil yielded a value of up to 0.8 µm. Conversely, when mineral oils were employed, the Ra value exceeded 1 µm. Not only did cutting fluids derived from vegetable oils result in lower Ra values, but they also led to reduced cutting forces. The minimum cutting force recorded for mineral oil stood at 465 N, whereas, when Jatropha oil was used, it decreased to 235 N. Additionally, Pongamia oil exhibited the lowest cutting force, with a minimum value of 100 N. It is important to note that Jatropha oil possesses high viscosity in its crude state, which hampers its flowability. To enhance its performance as a cutting fluid, researchers employed the trans-esterification process and supplemented Jatropha oil with 0.05% by weight of boron nitride [2]. An experimental study was conducted using a CNC lathe machine to machine AISI 1045 specimens, employing three different cutting fluids: a commercial cutting fluid, Jatropha oil, and modified Jatropha oil. The Minimum Quantity Lubrication (MQL) technique was utilized to deliver the cutting fluid to the hot zone, while the turning operation was carried out under constant cutting conditions specified in Table 1. When the modified Jatropha oil, enhanced with 0.05% boron nitride, was used, the cutting force was reduced to 375 N. In comparison, the cutting force was 425 N for simple Jatropha oil and 475 N for the commercial cutting oil. Similarly, a reduction in the cutting zone temperature was observed, with maximum temperature values of 235°C, 225°C, and 215°C for the commercial oil, Jatropha oil, and boron nitride-enhanced Jatropha oil, respectively. This research highlights the favorable characteristics of non-edible oils that can be utilized as cutting fluids following specific chemical modifications. Another experimental study has also examined the effectiveness of Jatropha oil-based cutting fluids [3]. A cutting fluid was prepared by creating an emulsion of Jatropha oil and water in a ratio of 1:9. The emulsion was formulated using specific emulsifier and additives, which are detailed in Table 1. To enhance the properties of Jatropha oil, anti-corrosive and anti-oxidation additives were incorporated. The turning operation took place on a lathe machine, utilizing a Tungsten Carbide tool. The cutting velocity (VC), depth of cut (DOC), and feed rate (FR) were varied according to the values provided in Table 1. The performance evaluation of the cutting fluid considered the output parameters of tool wear and surface roughness (Ra). The results revealed that the Jatropha-based cutting fluid achieved a minimum Ra value of 0.56 µm, whereas the mineral oil exhibited a higher Ra value of 1.40 µm, clearly demonstrating the superior performance of Jatropha oil in terms of surface quality. Regarding tool wear, the Jatropha oil had a minimum wear value of 0.09 µm, slightly higher than the 0.07 µm observed for mineral oil. Although mineral oil displayed slightly better performance in terms of tool wear, the Jatropha emulsion excelled when considering factors such as surface quality and biodegradability. To surpass the inherent limitations of nanoparticles and enhance their properties, it is feasible to introduce nanoparticles of diverse materials into the base fluid. This mixture of nanoparticles in a liquid is referred to as a hybrid nanofluid. By combining the physical and chemical properties of multiple nanofluids, a hybrid nanofluid offers improved characteristics [4, 5]. In a research study, Carbon Nano Tubes (CNT) and Molybdenum Di Sulfide (MoS2) nanoparticles were added in a weight percentage (wt.%) ranging from 0.5% to 3%, with a hybrid ratio of 1:2, the incorporation of nanoparticles into Sesame oil can result in a hybrid nanofluid. The cutting parameters were maintained at a constant level, while the evaluation focused on parameters such as surface roughness (Ra), tool wear, cutting force, and temperature [6]. To create hybrid nanofluids, the formulated vegetable oil was emulsified using Sodium Dodecyl Sulfate. The performance of hybrid nanofluids as cutting fluids was evaluated and compared to the conventional cutting situation. Turning operations were carried out on AISI 1040 Steel using a lathe machine with constant cutting parameters specified in Table 1. The performance evaluation focused on cutting force, tool wear, surface roughness (Ra), and temperature to determine the optimal cutting environment. The results indicated that the best performance, in terms of reducing cutting force and Ra, was achieved with a 2 wt.% concentration of the hybrid nanofluid. Compared to dry cutting and conventional cutting fluid, the cutting force was reduced by 32% and 27.3%, respectively. Additionally, Ra values were reduced by 28.5% and 18.3%, respectively. Regarding cutting temperature and tool wear, superior performance was observed with a 3 wt.% concentration of the hybrid nano cutting fluid. Specifically, the cutting temperature was lowered by 43.4% compared to dry cutting, and by 28% compared to the conventional cutting fluid. Furthermore, tool wear was reduced by 81.3% and 75%. Based on these findings, it can be concluded that other hybrid nano cutting fluids present themselves as viable alternatives to conventional cutting fluids. Research has been conducted using neem oil, a non-edible vegetable oil with anti-bacterial properties, as a cutting fluid. The performance of neem oil as a cutting fluid was compared with commercial cutting oils, with a focus on the criterion of temperature reduction [7]. The oils, including Neem oil, were utilized as cutting fluids during the turning process of Mild Steel at different cutting velocities (VC) and feed rates (FR) as indicated in Table 1. The optimal values of VC and FR, which resulted in lower cutting zone temperatures, were also mentioned in Table 1. The research findings revealed that Neem oil effectively reduced the cutting zone temperature by as much as 39.53 °C. In comparison, soluble oils and straight oils achieved cutting zone temperatures of 40.51 °C and 43.21 °C, respectively. Undoubtedly, Neem oil stands out as an exceptional option for a biodegradable cutting fluid due to its capacity to reduce cutting forces, non-edible nature, and antibacterial properties. Likewise, Jojoba oil, another non-edible oil, is renowned for its superior oxidative stability compared to various other vegetable oils. In a specific study, a nano-cutting fluid based on Jojoba oil was utilized to evaluate its performance relative to commercial mineral oil during the turning process of Ti-6Al-4V alloy [8]. In the study, mineral oil named LRT 30 was utilized, and cutting fluids were used in their pure form and with the addition of MoS2 nanoparticles. Constant values for feed rate (FR) and cutting velocity (VC) specified in Table 1 were maintained. The machining processes were carried out without any lubrication, employing the Minimum Quantity Lubrication (MQL) technique with pure LRT 30 and Jojoba oil, as well as MQL with MoS2-enhanced nanofluids. Nanofluids were prepared for both oils by incorporating MoS2 nanoparticles at different concentrations (0.1%, 0.5%, and 0.9% by weight). To ensure proper mixing, an emulsifier called lauryl sodium sulfate was added at a concentration of 0.1% by weight and stirred magnetically. A lathe machine equipped with a carbide tool coated with PVD (Physical Vapor Deposition) was utilized for the turning operation. The research findings indicated that a concentration of 0.1% by weight of MoS2 in both mineral oil and Jojoba oil produced the most favourable results for all the output parameters. The dry cutting process required a maximum cutting force of 112 N, while Jojoba oil demonstrated a minimum cutting force of 73.62 N, compared to LRT 30 nanofluid (76.4 N). In a similar manner, Jojoba nanofluid demonstrated a minimum surface roughness (Ra) value of 0.1358 µm, outperforming the LRT 30 nanofluid (0.1407 µm) and dry cutting (0.2289 µm). Tool wear exhibited a similar pattern, with Jojoba nanofluid showing a minimum wear of 0.1 mm, while the nano mineral oil exhibited wear of 0.14 mm, and dry cutting had a wear value of 0.19 mm. The high viscosity index and long-chain fatty acid structure of Jojoba oil contribute to its effectiveness and superior performance as a cutting fluid. Additionally, at a concentration of 0.1%, a higher concentration of MoS2 particles in the nanofluid enhances thermal conductivity. In a previous research, a natural and biodegradable Gingelly oil, known for its sticky nature and better lubrication and heat transfer properties, was nominated as a cutting fluid. Its efficiency was equated in mineral oil-based cutting fluid and dry cutting [9].

Table 1. Turning operations performed with cutting fluids derived from non-edible vegetable oil [23].

Sr. No.	Vegetable Oil	Additives Used	Workpiece Material	Cutting Parameters	Optimized Cutting Parameters	Investigated Parameters	Remarks	Reference
1	Jatropha oil, Pongamia oil	No Additive	AA6061	DOC = (0.5, 1, 1.5) mm FR = (0.1, 0.175, 0.250) mm/rev VC = (800, 1270, 1600) rpm	VC = 1600 rpm DOC = 0.5 mm FR = 0.1 mm/rev	Ra, Cutting Force	Epoxidation of vegetable oils can improve their oxidative stability, making them suitable for use as cutting fluids.	[1]
2	Jatropha oil	Boron Nitride	AISI 1045	FR = 0.08 mm/min VC = 350 m/min	Cutting parameters were kept constant.	Cutting Force, Temperature	Non-edible oils possess many desirable characteristics that make suitable for application as	[2]

							cutting fluids similar to edible oils.	
3	Jatropha oil	Emulsifier, Anticorrosive agent (banana plant juice), Antioxidant, Biocide		VC = (500, 630, 800, 1250) rpm FR = (0.52, 0.65, 0.82, 1) mm/rev DOC = (0.3, 0.65, 1, 1.24) mm	VC = 1250 rpm DOC = 1 mm FR = 1 mm/rev	Ra, Tool Wear	Special attention was to the selection of additives that are biodegradable in nature, for instance Banana plant juice has been utilized as an anti-corrosive agent.	[3]
4	Sesame oil	Sodium Dodecyl Sulfate	AISI 1040 Steel	FR = 0.161 mm/rev DOC = 0.5 mm VC = 80 m/min	Cutting parameters were constant.	Ra, Tool Wear, Cutting Force, Temperature	Increasing the concentration of nanoparticles in fluids has a direct effect on specific heat and thermal conductivity. Hence, the proper concentration of nanoparticles in fluids plays an important role.	[6]
5	Neem oil	No Additive	Mild Steel	DOC = 6 mm FR = (1, 0.8, 0.6, 0.4, 0.2) mm/rev VC = (58, 85, 125, 180, 260, 540) rpm	VC = 58 rpm FR = 1 mm/rev	Temperature	Neem oil is effective in reducing the temperature in the cutting zone and possesses antibacterial properties, making it a favorable choice as a cutting fluid.	[7]
6	Jojoba oil	Nano MoS2 Particles	Ti-6Al-4V Alloy	FR = 0.16 mm/rev VC = 80 m/min DOC = 0.4 mm	Cutting parameters were constant.	Ra, Cutting Force	The acceptable concentration of nanoparticles in cutting fluids expands their performance.	[8]
7	Gingelly oil	No Additive	AISI 1014	FR = 0.6 mm/rev VC = 328 m/min DOC = (0.25, 0.5) mm	Cutting parameters were constant.	Ra, Cutting Force	Gingelly oil is an excellent alternative as a cutting fluid due to its better lubricating properties.	[9]

Different blends of Neem and Karanja oils cutting fluids were used in the study by Jyothi, P. et. al [10] for drilling operation. The feed rate (FR), depth of cut (DOC), and cutting speed (VC) were kept constant, as shown in Table 4. The blend of 50% Karanja oil and 50% Neem oil demonstrating the best performance for cutting fluids is noteworthy. The evaluation based on chip formation, surface finish, and cutting forces provides valuable insights into the effectiveness of different cutting fluid formulations. The surface roughness (Ra) values also varied depending on the cutting fluid used. Dry cutting had a Ra value of 4.1 µm, mineral oil-based cutting fluid had a Ra value of 3.5 µm, and the 50% blend of Karanja and Neem oil had the lowest Ra value of 1.25 µm, indicating a smoother surface finish. Neem oil performed exceptionally well when blended with other oils. The study conducted by M Susmitha et al. evaluating the influence of non-edible vegetable-based oils as cutting fluids on a CNC machine using SAE 20W40 oil, Honge oil, Neem oil, and different blends of Neem and Honge oil on chip formation, surface roughness, and cutting forces during drilling operations on mild steel provides valuable insights into the performance of different oil blends.

2. Materials and Methods

2.1. Materials

2.1.1. Cutting Fluids

In the present work, the turning of mild steel was performed using blends of Neem and Karanja vegetable-based non-edible oils as cutting fluids. The performance of these oils was compared with different ratio blends of these oils.

The specific compositions of the oil blends were as follows:

1. Blend of Neem and Karanja (50% Neem - 50% Karanja)
2. Blend of Neem and Karanja (33.3% Neem – 66.7% Karanja)
3. Blend of Neem and Karanja (66.7% Neem – 33.3% Karanja)

These oils were used as cutting fluids during the turning process on mild steel. The surface finish was evaluated and compared among the different blend ratio cutting fluids.

The study aimed to assess the ratio of the effectiveness of the vegetable-based non-edible oils-based cutting fluids blend in different ratios.

2.1.2 Workpiece material

The workpiece used in the research study, was made of mild steel with a diameter of 50 mm and a length of 200 mm.

2.1.3. Cutting Tool

In this study, a high-speed steel (HSS) tool bit was utilized. The tool bit had the following geometry:

1) Nose radius: 0.5 mm
2) Back rake angle: 6˚
3) Side rake angle: 10˚
4) End cutting edge angle: 12˚

5) Side cutting edge angle: 12°

These geometric parameters play a crucial role in determining the cutting performance and efficiency of the tool during the machining process. The specific geometry of the tool bit is chosen based on the machining requirements and the material being machined.

2.2. Method

2.2.1. Experimental Design

Table 2: Turning process parameters and their levels.

Symbol	Process parameters	Units	Levels		
			1	2	3
v	Cutting speed	rpm	300	550	900
f	Feed rate	mm/rev	0.10	0.15	0.20
d	Depth of cut	mm	0.4	0.6	0.8
CT	Cutting Fluid		1	2	3

The Taguchi method is a technique in experimental design that aims to optimize product or process quality by reducing the number of experiments required and identifying significant factors more efficiently. It employs orthogonal arrays to minimize the impact of uncontrollable factors. The method focuses on parameter design, which involves determining the best parameter settings to achieve the desired quality with minimal variation. By using this approach, the Taguchi method helps streamline experimentation and improve the quality of products or processes. The selection of control factors is a critical step when applying the Taguchi method for experimental design. It is essential to include as many factors as possible initially to identify non-significant variables. To address this need, Taguchi utilizes a standard orthogonal array, which allows for the efficient accommodation of multiple factors in the experiment.

Within the Taguchi method, the signal-to-noise (S/N) ratio serves as the chosen quality characteristic. Instead of using standard deviation, the S/N ratio provides a quantifiable measurement. It enables the assessment of various parameter settings and a higher S/N ratio signifies superior performance.

In this study, the experimental setup was based on the Taguchi method using the design of experiments (DOE), took into account four variables: cutting speed, feed rate, depth of cut, and cutting fluids. Each variables had three levels, as shown in Table 2. To conduct the experiment, Taguchi specified the use of an L_9 orthogonal array, which is suitable for a four-factor-three-level experiment. The analysis was performed at a 95% confidence level.

Table 3: Physical properties of cutting fluids used [11]

S. No.	Types of cutting fluid	Specific Heat (KJ/Kg.K)	Flash Point (^{0}C)	Fire Point (^{0}C)	Dynamic Viscosity (N-s/m^2)	Adhesiveness (g/m^2)
1.	50% Neem 50% Kranja	1.6999	256	290	0.01648	359
2.	33.3% Neem 66.7% Kranja	1.6703	228	256	0.0135	257
3.	33.3% Kranja 66.7% Neem	1.6789	228	264	0.011271	367

Based on the provided information and the evaluation of different parameters, among the testing options, it was observed that the blend of 50% Neem and 50% Karanja oil performed the best as cutting fluid.

Here are the reasons for selecting the 50% Neem and 50% Karanja blend as the best cutting fluid:

a) Flash and Fire Points: The blend has high flash and fire points of 256 °C and 290 °C respectively. This indicates that it is less likely to catch fire or ignite at high temperatures, making it a safer option.

b) Viscosity: The dynamic viscosity of the 50% Neem and 50% Karanja blend is 0.01648 N-s/m². This viscosity value indicates that it strikes a balance between being low enough to reduce friction effectively and not requiring excessive energy to move. This optimal viscosity helps in reducing friction during machining.

c) Adhesiveness: The blend of 50% Neem and 50% Karanja has an optimum adhesiveness value of 359 g/m2. This indicates that it possesses the right level of stickiness to adhere to the surface of the workpiece and the cutting tool during machining. It maintains a lubricating layer that reduces friction between the surfaces while facilitating easy separation.

Considering these factors, the blend of 50% Neem and 50% Karanja demonstrate favourable characteristics in terms of flash and fire points, viscosity, and adhesiveness, making it the best cutting fluid option for machining applications.

3. Experimental setup

3.1. Turning Conditions

In the machining experiment, a manually operated centre lathe was used to perform turning on the workpiece using a High-Speed Steel (HSS) cutting tool. Each experimental run had a fixed cutting time of 15 minutes, and a fresh cutting tool was used for each run. The cutting fluid was applied using the conventional flood method.

The evaluation of the machining performance focused on the surface roughness of the workpiece. The portable surface roughness tester was used to measure the surface roughness (Ra) after each experimental run. Three measurements of Ra were taken at different points on the workpiece, and the average of these three readings was used for further analysis.

The surface roughness, Ra, was chosen as the output parameter for evaluation. To analyze the data, the corresponding signal-to-noise (S/N) ratio was calculated based on the average surface roughness readings. In this case, since smaller values of Ra are desired for better surface quality, the "smaller the better" characteristic was used for the S/N ratio calculation.

By using the S/N ratio as the evaluation metric, the Taguchi method allows for determining the optimal parameter settings that minimize surface roughness and improve the surface quality of the machined workpiece.

Fig: 1 Experimental Setup

4. Results and Discussion

4.1. Surface roughness of the machined surface

It is observed that the surface roughness measurements of the machined parts varied depending on the cutting fluid used. The surface roughness is measured in terms of µm (micrometers), where a lower value indicates a smoother surface.

Table 4: Experimental plan, results, and their calculated S/N ratios.

Exp. runs	Controllable process parameters				Experimental results	S/N ratios of results
					Surface roughness R_a (μm)	
	v	f	d	CT	Average R_a (μm)	R_a (dB)
1	1	1	1	1	1.858	-5.38091
2	1	2	2	2	1.891	-5.53383
3	1	3	3	3	2.209	-6.88391
4	2	1	2	3	1.559	-3.85692
5	2	2	3	1	1.319	-2.40490
6	2	3	1	2	1.758	-4.90038
7	3	1	3	2	1.317	-2.39172
8	3	2	1	3	1.667	-4.43871
9	3	3	2	1	1.568	-3.90692

4.1.1 Effect of process parameter on surface roughness *(Ra)*

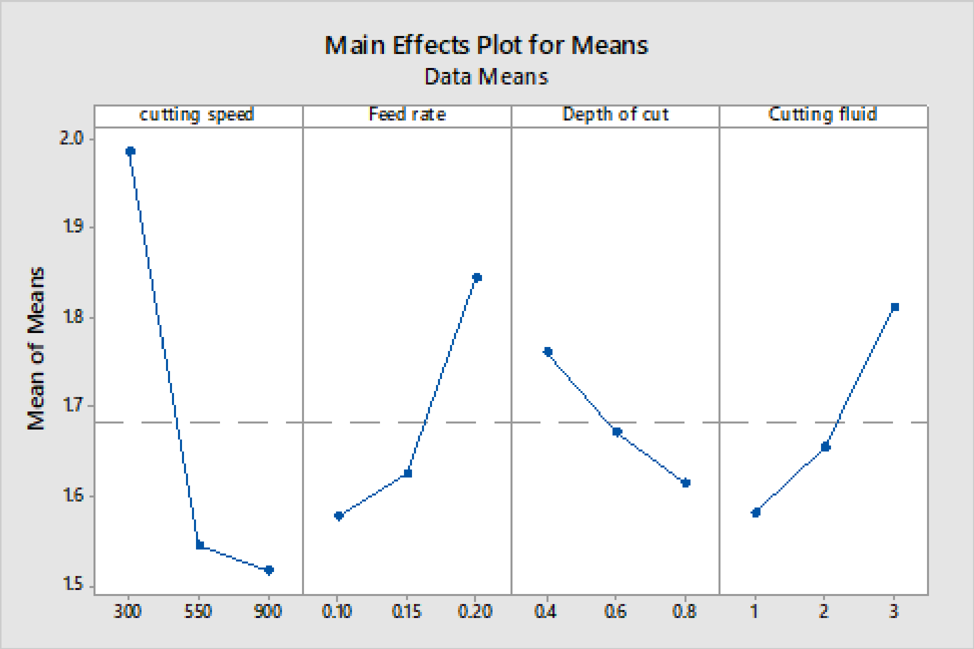


Fig. 2: Main effect plot for means for *Ra* value.

Figure 2 demonstrates the impact of different process parameters on surface roughness. The findings reveal that rise in cutting speed leads to a decrease in the Ra value. It can be attributed to the heightened friction between the tool and workpiece at higher cutting speeds, which generates elevated cutting temperatures in the machining zone. These increased temperatures cause thermal softening of the workpiece and a reduction in smeared materials on the machined surface, ultimately resulting in a smoother surface with lower roughness, this observation aligns with existing literature [12]. On the other hand, an increase in feed rate results in an increase in the Ra value. This is because the workpiece offers greater resistance to the tool, leading to the formation of a larger built-up edge (BUE) on the tool flank face and a deteriorated surface, consequently raising the Ra value. Furthermore, a rise in the depth of cut also leads to decreasing trend in the Ra value.

The type of cutting fluid used also has a significant influence on the Ra value. As depicted in Figure 4, a blend of 50% Neem and 50% Karanja yields lower Ra values compared to 33.3% Neem 66.7% Kranja blend and 33.3% Kranja 66.7% Neem blend, respectively. This can be attributed to the lower cutting zone temperatures achieved when a blend of 50% Neem and 50% Karanja is used in the machining zone.

4.2 Selection of optimum process parameters for *Ra*

Table 5: Mean S/N ratio response table for surface roughness *(Ra)*

Symbol	Process parameters	Mean S/N Ratio				
		Level 1	Level 2	Level 3	Max-Min	Rank
v	Cutting speed(rpm)	-5.933	-3.721	**-3.579**	2.354	1
f	Feed rate(mm/rev)	**-3.877**	-4.126	-5.230	1.354	2
d	Depth of cut(mm)	-4.907	-4.433	**-3.894**	1.013	4
CT	Coolant type	**-3.898**	-4.275	-5.060	1.162	3

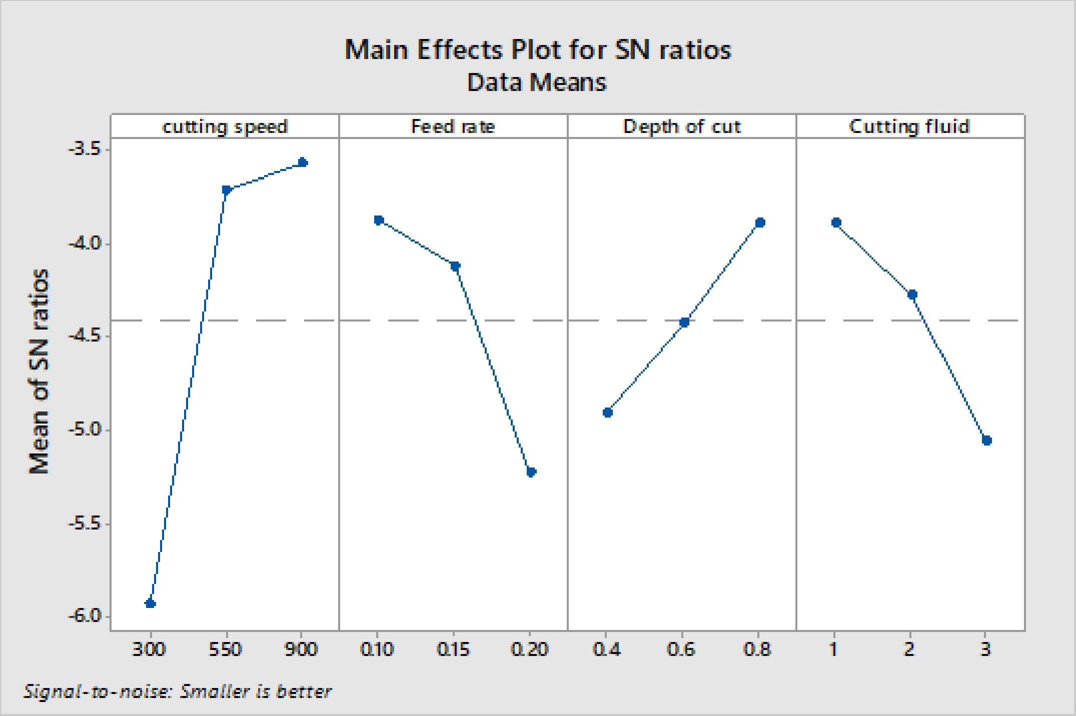


Fig. 3: Mean S/N ratio of surface roughness

Table 5 presents the signal-to-noise (S/N) ratio (dB) for the surface roughness. Since a smaller value is desired for the surface roughness response, the performance of the three different percentage blend cutting fluids was evaluated using the Taguchi optimization process. This process focuses on achieving a smaller-the-better characteristic for the surface roughness through the S/N ratio. To facilitate the analysis and computation of the ratios, statistical analysis software (Minitab-18) was utilized, which is commonly used in engineering applications.

The main effect plots shown in Figure 3 depict the relationship between the surface roughness and the machining parameters at different levels based on the S/N ratio values. The plots indicate that the optimal machining parameters for minimizing the surface roughness were achieved with a cutting speed of 900 rpm (level 3), a feed rate of 0.10 mm/rev (level 1), a depth of cut of 0.8 mm (level 3), and a cutting fluid type 1 (level 1). Consequently, the use of a cutting fluid type 1 resulted in the optimal parameters for attaining a better surface finish on the workpiece. The optimal combination is denoted as *v3-f1-d3-CT1* for surface roughness.

4.3 Confirmation Test

Table 6: Confirmation test results for optimization of surface roughness *(Ra).*

	Initial process-parameter	Optimal process-parameters	
		Prediction	Experiment
Level	v_2-f_2-d_2-CT_2	v_3-f_1-d_3-CT_1	v_3-f_1-d_3-CT_1
Surface roughness (µm)	1.45	1.24	1.22
S/N ratio (dB)	-3.321	-2.013	-1.999
Improvement in S/N ratio (dB)	1.322		
Percentage reduction of surface roughness	18.85%		

Confirmation tests were conducted to validate the predicted optimum cutting conditions obtained through the Taguchi method. The predicted signal-to-noise (S/N) ratio was used to estimate and verify the response at the predicted optimum cutting conditions. The confirmation experiments were performed using the Taguchi predicted optimum cutting conditions, and the results for Ra (surface roughness) are presented in Table 5.

The optimized cutting conditions predicted by the Taguchi method resulted in improved performance characteristics, specifically in reducing the surface roughness (Ra). The S/N ratios of the predicted and optimal cutting conditions were found to be very close for Ra, with an improvement of 1.322 dB at the optimal cutting conditions compared to the initial parameter settings mentioned in Table 6. Confirmation experiments further validated that the Taguchi-predicted optimum cutting conditions yielded favorable results compared to the initial parameter conditions. The surface roughness (Ra) achieved at the Taguchi-predicted optimum cutting conditions showed a reduction of 18.85% compared to the initial parameter conditions. As a result, the Taguchi-predicted optimum cutting conditions were considered optimal for achieving low Ra in the machining of Mild Steel under the given conditions. These findings indicate that the Taguchi optimization method significantly improved the machinability characteristics of Mild Steel by considering the provided process parameters.

4.4 Test for Ra in different experimental, predicted parameters for different cutting fluids.

Table 7: Test results for Surface Roughness *(Ra)*

S. No.	*v*	*f*	*d*	1 (µm)	2 (µm)	3 (µm)
1	300	0.10	0.4	1.858 *	1.931	2.088
2	300	0.15	0.6	1.817	1.891 *	2.047
3	300	0.20	0.8	1.979	2.052	2.209 *
4	550	0.10	0.6	1.329	1.402	1.559 *
5	550	0.15	0.8	1.319 *	1.392	1.549
6	550	0.20	0.4	1.684	1.758 *	1.914
7	900	0.10	0.8	1.243	1.317 *	1.473
8	900	0.15	0.4	1.437	1.510	1.667 *
9	900	0.20	0.6	1.568 *	1.641	1.798
Mean Value				1.581	1.654	1.811

Note: * This symbol indicates Experimental Values and all remaining values are predicted using the Minitab Software tool (Taguchi L_9 orthogonal array).

4.5 ANOVA Analysis of Experimental Results for R_a

Table 8: ANOVA for Surface Roughness *(Ra)*

Source	DOF	Sum of squares	Mean squares	% contribution
v	2	0.414620	0.207310	63.64
f	2	0.121668	0.060834	18.68
d	2	0.032444	0.016222	4.98
CT	2	0.082767	0.041383	12.70
Total	8	0.651499		100.00

Table 8 presents the results of the analysis of variance (ANOVA), which was conducted to determine the contribution of each parameter to the surface roughness. The percentage contributions of each input parameter to the surface roughness are as follows: cutting speed (63.64%), feed rate (18.68%), depth of cut (4.98%), and cutting fluid (12.70%). These results indicate that the cutting speed has the highest significance on the surface roughness, followed by the feed rate, cutting fluid, and depth of cut. Therefore, ANOVA analysis concluded that *Ra* was significantly affected by cutting speed.

4.6 Modeling

Table 9: Results for the developed models

Run	Experimental	Fits	Residuals	Error %
	R_a (µm)	R_a (µm)	R_a (µm)	R_a
3	2.209	2.06695	0.142054	6.43
7	1.317	1.24330	0.073705	5.59
8	1.667	1.63780	0.0292049	1.75
9	1.568	1.46830	0.0997049	6.35

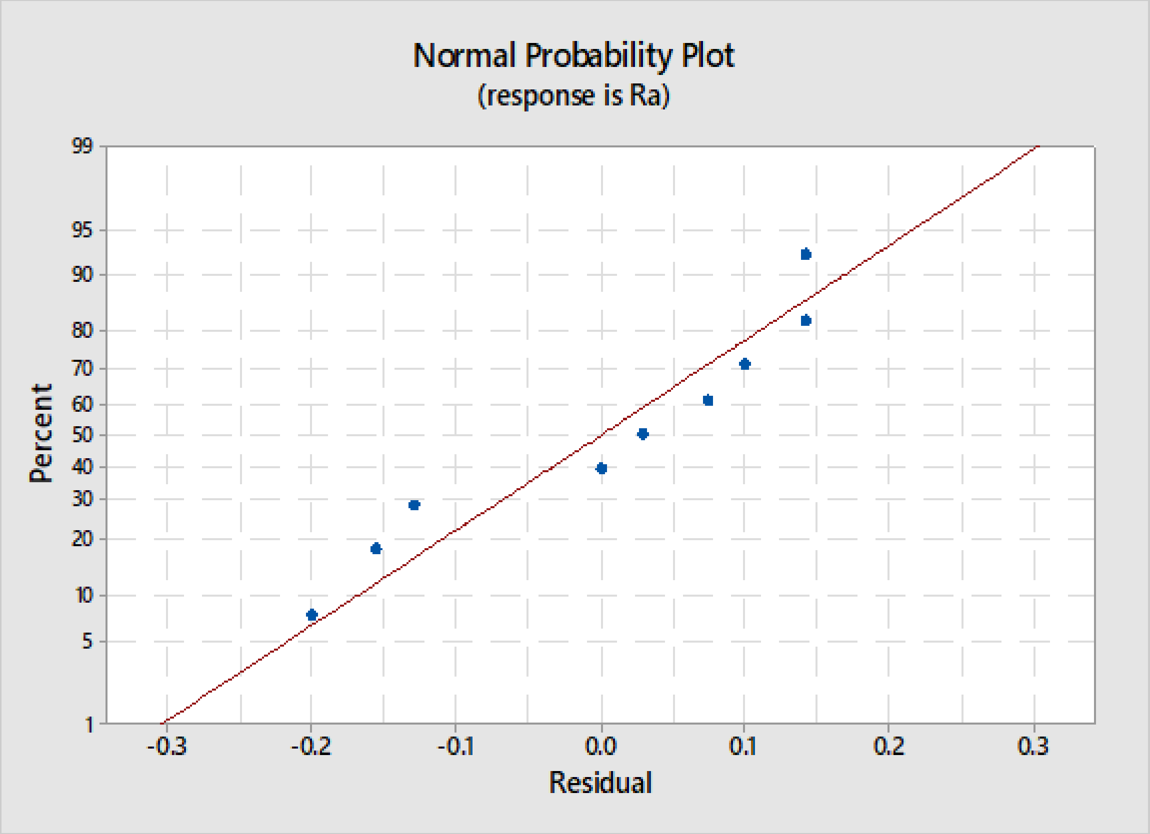


Fig 4: Normal probability plot of the residuals for surface roughness

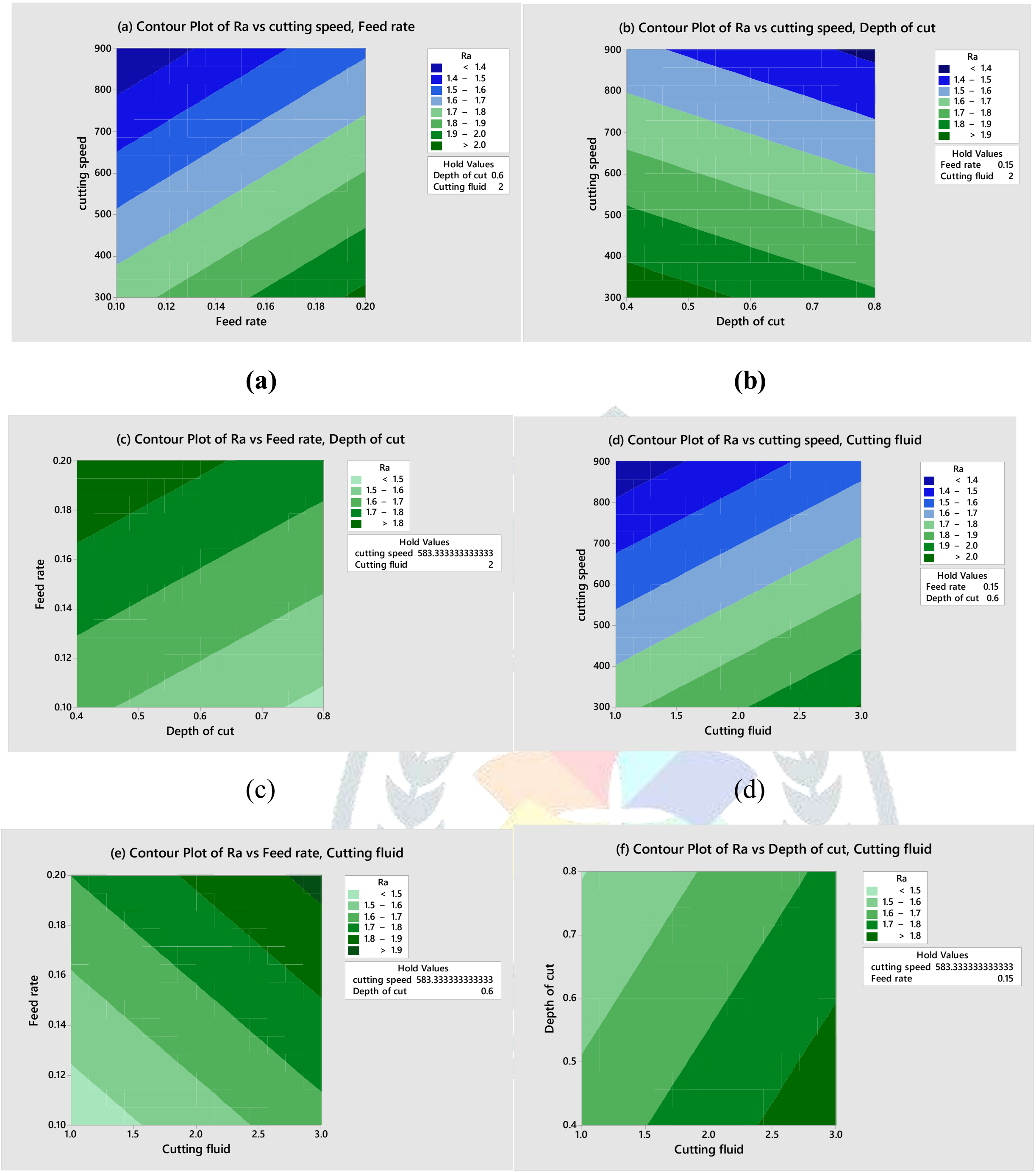
In this research, the Minitab 18.0 software tool was employed to perform linear regression analysis and develop predictive mathematical models for the dependent variable, Ra (surface roughness). The independent variables considered in the analysis were cutting speed, feed rate, depth of cut, and coolant type. No transformation was applied to the response variable. The predictive equations derived from the regression analysis are presented in Equation (1) for Ra.

$$R_a = 1.701 - 0.000736*v + 2.67*f - 0.365*d + 0.1150*CT \qquad (R^2 = 78.83\ \%) \qquad (1)$$

To evaluate the effectiveness of the developed regression models, the coefficient of determination (R^2) was employed, following the approach used by M. K. Gupta et al. [13]. R^2 ranges from 0 to 1 and indicates the degree of fit between the dependent and independent variables. A value close to 1 signifies a strong fit, indicating that new observations can be estimated with a high level of accuracy. In this study, the regression models developed for Ra demonstrated high R^2 values of 78.83%, indicating a significant level of fit between the variables. The significance of the coefficients in the predicted models was assessed using residual plots. A straight line in the residual graph indicates that the residual errors in the model follow a normal distribution, and the coefficients in the model are statistically significant. The residual plots for Ra are depicted in Figure 4. From the observations in Figure 8, it can be seen that the residuals closely align with the straight line for Ra, suggesting that the coefficient models developed are significant.

To validate the models, confirmation tests were conducted, and the results are presented in Table 9. The test results were randomly selected from the L_9 orthogonal experimental design. It was found that the predicted results from the models were in good agreement with the experimental results within the specified parameter range. This finding aligns with the results reported by M. K. Gupta et al. [14] in their study on the machining of difficult-to-cut materials, which also demonstrated agreement between process parameters and response. Overall, these results indicate that the developed regression models for Ra exhibit a strong fit with high R^2 values, and the models are validated through confirmation tests, demonstrating agreement between predicted and experimental results within the specified parameter range.

4.7 Contour Plots for *Ra*



(a) **(b)**

(c) (d)

(e) (f)

Fig. 5 Contour plot for surface roughness (a) Cutting speed Vs Feed rate (b) Cutting speed Vs Depth of cut (c) Feed rate Vs Depth of cut (d) Cutting speed Vs Coolant type (e) Feed rate Vs Coolant type (f) Depth of cut Vs Coolant type.

Contour plots were utilized to investigate the relationship between a response variable and two control variables. These plots depict discrete contours of predicted response values. In Figure 8, contour plots are used to illustrate the correlation between process parameters and surface roughness value. Figure 5 (a) discovered that a high cutting speed and low feed rate result in a lower surface roughness value. In Figure 5 (b), low surface roughness is achievable with high cutting speed and depth of cut levels. Additionally, Figure 5 (c) indicates that low surface roughness can be attained with a low feed rate and high depth of cut. Furthermore, a blend of 50% Neem and 50% Karanja yields lower Ra values compared to 33.3% Neem 66.7% Kranja blend and 33.3% Kranja 66.7% Neem blend, respectively, as demonstrated in Figure 5 (d-f).

5. Conclusion

Based on the findings of this research work, the following conclusions can be drawn:

1. The formulated non-edible oil blend of 50% Neem and 50% Karanja cutting fluid exhibited excellent physical and chemical properties, making it viable among all blends of different percentage turning operations.
2. The performance of 50% Neem and 50% Karanja oil-based cutting fluid was compared to 33.3% Neem 66.7% Kranja blend and 33.3% Kranja 66.7% Neem blend in terms of its properties, this cutting fluid demonstrated eco-friendliness, indicating its suitability for use as a sustainable cutting fluid.
3. The analysis of variance (ANOVA) results revealed that cutting speed had the most significant impact on surface roughness (Ra), accounting for 63.64 % of the variation The type of cutting fluid also had a significant impact, specifically the blend of 50% Neem and 50% Karanja oil-based cutting fluid, which contributed 12.70% to the variation in surface roughness.
4. The analysis of the experimental results involved the use of the signal-to-noise ratio and analysis of variance (ANOVA). The optimal machining parameters for achieving the minimum surface roughness were determined to be a cutting speed of 900 rpm (level 3), a feed rate of 0.10 mm/rev (level 1), a depth of cut of 0.8 mm (level 3), and a cutting fluid type 1 (level 1). Consequently, the use of a cutting fluid type 1 resulted in the optimal parameters for attaining a better surface finish on the workpiece. The optimal combination is denoted as *v3-f1-d3-CT1* for surface roughness.
5. The blend of 50% and Neem 50% Karanja oil cutting fluid demonstrated several favourable characteristics including uniform and continuous chip formation during turning.

Future Scope of Research

The recommendations for future research are given as under:

Indeed, the study conducted in this research using a conventional lathe machine with an HSS tool can serve as a foundation for further investigations in CNC (Computer Numerical Control) lathe and CNC milling operations. By extending the research to CNC turning and milling, additional insights and advancements can be made in understanding the effects of process parameters on the machining characteristics of the material. CNC machines offer several advantages over conventional machines, including higher precision, repeatability, and flexibility in controlling process parameters. Conducting the study on a CNC lathe or CNC milling machine would allow for more precise control and monitoring of cutting speed, feed rate, depth of cut, and other relevant variables. This would enable a more detailed analysis of their effects on surface roughness, chip formation, tool wear, and other performance characteristics.

The use of advanced tool materials, such as carbide or ceramic tools, commonly employed in CNC machining, could also be explored. These tools often exhibit superior wear resistance and can provide enhanced performance in terms of surface finish and tool life. Expanding the research to include CNC lathe and CNC milling operations would not only broaden the applicability of the findings but also contribute to the overall understanding of machining processes across different machine types. It would facilitate the development of optimized cutting parameters for CNC machines, leading to improved productivity, higher-quality machined surfaces, and reduced tool wear.

Therefore, future studies focusing on CNC lathe and CNC milling operations would be valuable in advancing knowledge in the field and providing practical insights for the optimization of machining processes.

References:

[1] Jeevan, T.; Jayaram, S. Performance evaluation of jatropha and pongamia oil based environmentally friendly cutting fluids for turning AA 6061. Adv. Tribol. 2018, 2018, 2425619. [CrossRef]

[2] Talib, N.; Sani, A.S.A.; Hamzah, N.A. Modified Jatropha nano-lubricant as metalworking fluid for the machining process. J. Tribol. 2019, 23, 90–96.

[3] Awode, E.I.; Abolarin, M.S.; Lawal, S.A.; Oyewole, A. Performance Evaluation of Jatropha Seed Oil and Mineral Oil-Based Cutting Fluids in Turning AISI 304 Alloy Steel. Int. J. Eng. Mater. Manuf. 2021, 5, 85–97. [CrossRef]

[4] Sarkar, J.; Ghosh, P.; Adil, A. A review on hybrid nanofluids: Recent research, development and applications. Renew. Sustain. Energy Rev. 2015, 43, 164–177. [CrossRef]

[5] Babu, J.R.; Kumar, K.K.; Rao, S.S. State-of-art review on hybrid nanofluids. Renew. Sustain. Energy Rev. 2017, 77, 551–565. [CrossRef]

[6] Gugulothu, S.; Pasam, V.K. Experimental investigation to study the performance of CNT/MoS2 hybrid nanofluid in turning of AISI 1040 stee. Aust. J. Mech. Eng. 2020. [CrossRef]

[7] L Kama, J.; Yusuf, M.; Abdulkadir, S. Effects of Different Cutting Fluids on Temperature Reduction on Mild Steel during Machining Operations. ATBU J. Sci. Technol. Educ. 2018, 6, 79–89.

[8] Gaurav, G.; Sharma, A.; Dangayach, G.; Meena, M. Assessment of jojoba as a pure and nano-fluid base oil in minimum quantity lubrication (MQL) hard-turning of Ti-6Al-4V: A step towards sustainable machining. J. Clean. Prod. 2020, 272, 122553. [CrossRef]

[9] Radhika, A.; Agari, S.; Yogesh, K.B. Evaluating machining performance of AlSI 1014 steel using gingelly oil as cutting fluid. Aust. J. Mech. Eng. 2019. [CrossRef]

[10] Jyothi, P.; Susmitha, M.; Sharan, P. Performance evaluation of NEEM oil and HONGE Oil as cutting fluid in drilling operation of mild steel. IOP Conf. Ser. Mater. Sci. Eng. 2017, 191, 012026. [CrossRef]

[11] M Susmitha1 , P Sharan1 and P N Jyothi2, Influence of non-edible vegetable based oil as cutting fluid on chip, surface roughness and cutting force during drilling operation of Mild Steel, IOP Conf. Series: Materials Science and Engineering 149 (2016) 012037 doi:10.1088/1757-899X/149/1/012037

[12] P. Sivaiah and D. Chakradhar, "Influence of cryogenic coolant on turning performance characteristics: A comparison with wet machining," Mater. Manuf. Process., 32(13), pp.1475-1485., 2017.

[13] M. K. Gupta, P. K. Sood, and V. S. Sharma, "Machining Parameters Optimization of Titanium Alloy Using Response Surface Methodology and Particle Swarm Optimization Under Minimum Quantity Lubrication Environment," Mater. Manuf. Process., 31(13), pp.1671-1682, 2016.

[14] M. K. Gupta, G. Singh, and P. K. Sood, "Modelling and Optimization of Tool Wear in Machining of EN24 Steel Using Taguchi Approach," J. Inst. Eng. Ser. C, 96(3), pp.269- 30 277, 2015.

[15] Khan M M A and Dhar N R 2006 Performance evaluation of minimum quantity lubrication by vegetable oil in terms of cutting force, cutting zone temperature, tool wear, job dimension and surface finish in turning AISI-1060 steel Journal of Zhejiang University SCIENCE A 7 1790–9

[16] Kumar B S, Padmanabhan G and Krishna P V 2016 Performance assessment of vegetable oil based cutting fluids with extreme pressure additive in machining J. Adv. Res. Mater. Sci 19 1–13

[17] Adekunle A S, Adebiyi K A and Durowoju M O 2015 Performance evaluation of groundnut oil and melon oil as cutting fluids in machining operation Acta Technica Corviniensis-Bulletin of Engineering 8 97

[18] Sohrabpoor H, Khanghah S P and Teimouri R 2015 Investigation of lubricant condition and machining parameters while turning of AISI 4340 Int. J. Adv. Manuf. Technol. 76 2099–116

[19] Machado A R, Motta M F and Da Silva M B 1997 Performance of synthetic and mineral soluble oil when turning AISI 8640 steel J. Manuf. Sci. Eng. Nov 119 580–6

[20] Mendes O C, Avila R F, Abrao A M, Reis P and Davim J P 2006 The performance of cutting fluids when machining aluminium alloys Industrial Lubrication and Tribology 58 260–8

[21] Aslan, E., Camuscu, N. and Bingoren, B. (2007) Design Optimization of Cutting Parameters When Turning Hardened AISI 4140 (63 HRC) with Al2O3 + TiCN Mixed Ceramic Tool. Materials & Design, 28, 1618-1622.

[22] Noordin, M.Y., Venkatesh, V.C., Chan, C.L. and Abdullah, A. (2001) Performance Evaluation of Cemented Carbide Tools in Turning AISI 1010 Steel. Journal of Materials Processing Technology, 116, 16-21

[23] M. Naveed 1 , A. Arslan 1 , H. M. A. Javed 2 T. Manzoor 3 , M. M. Quazi 4 , T. Imran 5 , Z. M. Zulfattah 6 , M. Khurram 7 and I. M. R. Fattah 8, Review State-of-the-Art and Future Perspectives of Environmentally Friendly Machining Using Biodegradable Cutting Fluids, Published: 7 August 2021, Energies [MDPI]

[24] Sen, B.; Gupta, M.K.; Mia, M.; Pimenov, D.Y.; Mikołajczyk, T. Performance Assessment of Minimum Quantity Castor-Palm Oil Mixtures in Hard-Milling Operation. Materials 2021, 14, 198. [CrossRef] [PubMed]

[25] Yasmin, F.; Tamrin, K.F.; Sheikh, N.A.; Barroy, P.; Yassin, A.; Khan, A.A.; Mohamaddan, S. Laser-Assisted High Speed Machining of 316 Stainless Steel: The Effect of Water-Soluble Sago Starch Based Cutting Fluid on Surface Roughness and Tool Wear. Materials 2021, 14, 1311. [CrossRef]