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PERFORMANCE EVALUATION OF JATROPHA AND NEEM SEED OIL BLEND CUTTING FLUID IN TURNING 1015 MILD STEEL

Balwan Singh [1*] and Tushar Gupta[1]

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Abstract

The machining industry commonly uses commercial mineral oil-based cutting fluids to improve machinability and productivity. However, these fluids have adverse effects on both the environment and operator health as they are non-biodegradable and hazardous. To address these issues, researchers are exploring the use of biodegradable vegetable oils as an alternative to mineral oils. In this study, a non-edible vegetable oil blend of 50% jatropha and 50% neem oil (JN-PCF) was formulated and used as a cutting fluid for turning mild steel with HSS tool bit. The effects of the blend on surface roughness *(Ra)* and tool flank wear *(Vb)* were investigated. Results obtained were compared with mineral oil (M-PCF) and neem oil (N-PCF) based cutting fluids. The experiments were carried out using Taguchi L_9 orthogonal array experimental design plan. Taguchi analysis was performed using Minitab statistical software and SN values were calculated based on the smaller-is-better principle. ANOVA analysis was also performed to determine the contribution of each factor to the response variable study. The results revealed that the blend of neem and jatropha oils-based cutting fluid (JN-PCF) obtained lower surface roughness and minimal tool flank wear than the neem oil (N-PCF) and mineral oil-based cutting fluids (M-PCF).

Keywords: Blend; Non-edible; Neem; Jatropha oil; Cutting fluid; Eco-friendly; Turning; Tool flank wear; Surface roughness.

[1]Department of Mechanical Engineering, Noida International University, Noida Yamuna Expressway, Sector 17A, Gautam Budh Nagar, Uttar Pradesh 203201, India.

Corresponding Author: bsbgaur@gmail.com, tushar.gupta@niu.edu.in

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1. Introduction

In the manufacturing industry, cutting fluids are crucially needed. This is due to the occurrence of metal shearing and chip formation during machining, where almost all the external mechanical energy is converted into heat. The heat is generated in different areas, such as the primary, secondary, and tool-chip contact zones [1-3]. The heat is distributed across the cutting tool, resulting in detrimental effects such as workpiece dimensional deformation, reduction in tool hot hardness, increased tool wear leading to premature tool failure, and compromised surface integrity [4-5]. The main functions of the cutting fluid are to control temperature rise and provide lubrication during the machining processes between the tool and workpiece [6-7]. Additionally, cutting fluids contribute to extending tool life, dampening vibrations, minimizing built-up edge (BUE) formation, and producing more manageable chips during machining [6-8]. The industry has extensively employed cutting fluids based on mineral oils. These cutting oils are derived from mineral sources and are often supplemented with additives to improve their performance. Researchers have revealed that these cutting fluids have detrimental effects on both workers and the environment. Specifically, conventional cutting fluids have been associated with the development of skin-related diseases in industrial workers [9,10]. In the recent decade, there has been growing interest in exploring vegetable oils as a substitute for mineral oils-based conventional cutting fluid for machining processes. As a result, cutting fluids derived from vegetable oils, have emerged as a potential alternative to conventional cutting fluids. Researchers have evaluated cutting fluids based on vegetable oils (edible and non-edible) demonstrates promising performance. However, due to regulatory restrictions, the use of edible vegetable oils in industrial applications is not widely recommended, as they are considered valuable food sources for humans [11-12].

Paul et al. [13] in the year 2011 investigated the performance of Neem oil and Karanja oil as cutting fluids in the machining of mild steel using High-Speed Steel (HSS) cutting tool on a lathe. The results revealed that the non-edible oils (Neem oil and Karanja oil) based cutting fluid performed lower surface roughness compared to mineral oil-based cutting fluid. The researchers also noted that the temperature variation during machining was similar for all the used cutting fluids. Sharafadeen Kunle Kolawale [14] in the year 2013 assessed the performance of palm oil and groundnut oil as cutting fluids in comparison to a mineral oil-based cutting fluid during the machining of mild steel. Based on the findings, groundnut oil and palm oil were recommended as viable alternative lubricants to mineral oil for machining mild steel. Jitendra Kumar Chandrakar [15] in the year 2014 highlighted that lubricants are crucial for smooth operation and reliability of machine functions, reducing the risk of failures. Vegetable-based bio-lubricants are non-toxic, degradable, and renewable, with good lubricating properties. Siddhu [16] in the year 2014 achieved positive outcomes in machining D2 steel using cutting fluid derived from non-edible vegetable oil. The experimental results revealed comparable surface finish and material removal rates between cottonseed oil, mineral oil, and soybean oil, with the difference among them not exceeding 10%. Bork at al. (17) in the year 2014 conducted a study to evaluate the performance of soluble cutting oil derived from Jatropha oil in milling aluminum alloy and compared it with canola oil, a synthetic ester of Jatropha, and mineral oil. The findings revealed that Jatropha oil exhibited minimal tool wear. In terms of tool life, Jatropha oil outperformed other oils, showing a 30% longer tool life across all feed rates. Additionally, Jatropha oil resulted in the lowest surface roughness values. In a study conducted by P. N. Jyothi et al. in 2017 [18], the impacts of two distinct vegetable oil blend cutting fluids, one derived from non-edible Neem oil and the other from Honge oil, were examined in the context of drilling mild steel. The researchers investigated the effects of these different ratios of cutting fluid blends on cutting temperature, hardness, and surface roughness. The findings revealed that the surface roughness of the cutting fluid blended with 50% Neem oil and 50% Honge oil was measured at 1.16 µm, which was lower compared to other types of cutting fluids utilized. Agarawal and Patil [19] in the year 2018 conducted a study to evaluate the performance of Aloe vera oil and cottonseed blend as a cutting fluid in machining M2 steel and compared it with conventional cutting fluid. They blended Aloe vera oil with cottonseed oil in a 1:1 ratio, resulting in a slightly higher viscosity (40 cst) compared to the conventional cutting fluid (38 cst). Machining was carried out using Minimum Quantity Lubrication (MQL) mode at three levels of cutting speed, feed, and depth of cut, using a Taguchi L9 orthogonal array. At all cutting conditions, the formulated blend performed better in reducing surface roughness compared to the conventional cutting fluid. Awode Emmanuel Imhanote at al. [20] in the year 2020 conducted a study using Jatropha seed oil-based cutting fluid (JBCF) and Mineral oil based cutting fluid (MBCF) in turning mild steel, and investigated the effects on tool wear, and surface roughness. The results revealed that JBCF exhibits minimal surface roughness, minimal tool wear, minimal environmental biodegradability, and overall better performance compared to MBCF which makes it more suitable for turning AISI 304 Alloy steel and is in good agreement with previous work. Awode Emmanuel Imhanote et al. [21] in the year 2022 conducted a study using Neem seed oil-based cutting fluid and Mineral oil-based cutting fluid in turning operations, and investigated the effects on tool wear, and surface roughness. The results revealed that Neem seed oil-based cutting fluid exhibits good surface roughness, minimal tool wear, and overall better performance compared to Mineral oil-based cutting fluid. Rahul Katna et al. [22] in the year 2022 studied that the Karanja oil-based cutting fluid produced 30.28 % lower surface roughness than the castor oil-based cutting fluid. Researchers have also observed that dilution also plays a role in the surface roughness and lower dilution reduced the surface roughness by 20.8 %.

1.1 Non-edible oil

Researchers have identified alternative eco-friendly and biodegradable cutting fluid feedstocks, including Neem oil (Azadirachta indica), Jatropha oil (Jatropha curcas), Karanja (Pongamia pinata), polanga (Calophylluminophyllum), Rubber (Hevea brasiliensis), and mahua (Madhuca indica), etc.

However, previous studies have mainly focused on using non-edible oils in the minimum quantity lubrication (MQL) method, and there is a lack of research on formulating water-soluble cutting fluid blends and their effects on surface finish and tool wear in turning. Additionally, there is no research on the use of a blend of Neem oil and Jatropha oil as a cutting fluid, or its effect on surface roughness and tool wear when compared to conventional cutting fluids and Neem oil-based cutting fluids.

To address these gaps in research, the novelty of the current study aims to:

1. In the present research, the blend of 50 % Jatropha and 50 % Neem non-edible vegetable oil was prepared to produce an eco-friendly oil-in-water emulsion cutting fluid by using Tween 80 as a surfactant and tested its properties in comparison to Neem oil-based cutting fluids and mineral oil-based cutting fluid.
2. This study aims to evaluate the surface roughness and tool wear when turning mild steel using a cutting fluid blend of Neem oil and Jatropha oil and compared it with conventional cutting fluids, and Neem oil-based cutting

fluids. The experiment was conducted under specific process parameters, including cutting speed, feed rate, depth of cut, and coolant type.

3. In addition to measuring surface roughness and tool flank wear, optimization of these factors was analysed. Taguchi analysis (ANOVA) and regression analysis were performed to analyse the data obtained from the experiment.

This research is novel and aims to overcome previous research gaps.

2. Materials and methods

2.1 Materials

For this research, the materials used for formulation of cutting fluids are non-edible vegetable oils, Mineral soluble oil, Tween 80 etc. and mild steel cylindrical workpieces, HSS tool bit and Center lathe Machine as under:

2.1.1 **Cutting Fluid**

In the present study, the materials used for the formulation of cutting fluids including non-edible Neem Oil, Jatropha Oil, Mineral soluble oil, and other additives, were purchased from the local market in Delhi. Other additives used include an emulsifier (Tween 80), biocide, anticorrosive agent (banana plant stem juice), and antioxidant.

2.1.2 **Machine, Workpiece, and Cutting Tool**

(i) Workpiece material: Mild steel (1015) 200 mm length and 50 mm diameter. The chemical composition of (1015) Mild steel is (% weight) 0.13 to 0.18 Carbon; 0.3 to 0.6% Manganese (Mn); 0.04 Phosphorous (P); 0.05 Sulphur (S); 99.13 to 99.57 Iron, Fe.

(ii) Lathe machine: Center lathe made in Jaipur, India, with a distance between centers of 1000 mm and a swing over bed of 400 mm.

(iii) Cutting tool: Single point cutting tool (Tool material-HSS MIRANDA S-400 STS, 5/8"x6"). Tool Signature: Back rake angle 0; Side rake angle-7; End relief angle-7, Side relief angle-7; End cutting edge angle-15; Side cutting edge angle-15; Nose radius-0.5 mm, for all types of cutting fluids.

(iv) Experiment location: Aryabhatt DSEU Ashok Vihar Campus (Delhi Skill of Entrepreneurship University, Delhi).

2.2 Methods

Methods adopted in this research for formulation, characterization of cutting fluids, experimental design and experimental setup etc. together with the measurement of tool flank wear and surface roughness are elaborated below:

2.2.1 **Formulation of cutting fluid**

The cutting fluid containing a blend (50 % jatropha oil and 50 % neem oil) and neem oil was formulated using the method adopted by Agu C. K., and Lawal et al. [23]. The formulation of mineral oil-based cutting fluid involved mixing the soluble oil (concentrate) with water at a ratio of 1: 9. For the preparation of the blend, before mixing with water, the Jatropha oil and Neem oil were mixed using a magnetic stirrer. The specific details of the mixing process are presented in Table 1. Three different cutting fluids, namely JN-PCF, N-PCF, and M-PCF, were prepared and utilized for conducting the experiments.

Table 1: Details of mixing for formulation of cutting fluid.

S. No.	Oil Name	Quantity of oil in %	Ratio	Mixing Speed of Stirrer	Mixing time (Minutes)	Other Elements of cutting fluid	Cutting fluid Code
1.	Jatropha oil & Neem oil	50% each	1:1 (blend)	700 rpm	30	Water and additives	JN-PCF
2	Neem oil	100%	-	700 rpm	30	Water and additives	N-PCF

2.2.2 **Characterization of formulated cutting fluids**

The prepared cutting fluid consisting of the blend of neem and jatropha seed oil (JN-PCF), the neem oil based cutting fluid (N-PCF) and mineral oil based cutting fluid were characterized by determining their viscosity, color, corrosion level, stability level, and pH value. The corrosion level was determined using the testing procedure outlined by Lawal, S. A., Choudhury et al. [24]. The pH values of the fluids were measured using a pH meter. The viscosities of both types of cutting fluids were determined in accordance with the ASTM D445 standard measurement procedure, and their stability was evaluated based on visual transparency within a period of 72 hours at room temperature as to separation of water and oil using test tubes.

2.2.3 **Design of Experiment**

Four different factors include cutting speed *(v)*, feed rate *(f)*, depth of cut *(d)*, cutting fluid/coolant type (CT) and their respective factor levels were selected for the study based on the literature of Agu, C. K., Lawal et al. [23]. Table 2 displays the factors levels of input variables. To conduct the experiments using specific cutting conditions, Taguchi L_9 orthogonal array Minitab 21.0 statistical software was utilized. The flood method was employed as a method of cutting fluid delivery.

Table 2: Turning process parameters and their levels.

Symbol	Process parameters	Units	Levels		
			1	2	3
v	Cutting speed	rpm	390	600	1000
f	Feed rate	mm/rev	0.10	0.15	0.20
d	Depth of cut	mm	0.3	0.6	0.9
CT	Cutting Fluid/ Coolant Type		JN-PCF	N-PCF	M-PCF

2.2.4 Physiochemical Properties

Physicochemical properties include (Flash Point, Pour Point, pH value, Viscosity, peroxity value, acid value, and specific gravity) of Neem and Jatropha Oils are presented below in Table 3.

Table 3: Physiochemical properties of Neem and Jatropha Seed Oil [20, 21]

S. No	Physiochemical Properties	Neem oil	Jatropha oil
1	pH value	7.28	6.35
2	Acid value (mg KOH/g)	5.80	4.86
3	Specific gravity	0.919	0.907
4	Viscosity @40^0 C	25.10	21.30
5	Flash point	238	260
6	Pour point	4	-1
7	Peroxity value	8.6	6.20

2.2.5 **Experimental setup and details**

In this study, turning operation was conducted on mild steel workpiece. Figure 1 illustrates the various samples of cutting fluids used in the process, while Figure 2 depicts the experimental setup used in the study. Additionally, Figure 3 shows the work piece samples prepared in the experiment. The experimental response variables for evaluating the performance of the formulated and conventional cutting fluid were chosen as surface roughness and tool wear. The machining parameters used in this experiment were cutting speed *(v)*, feed rate *(f)*, and depth of cut *(d)*, Cutting Fluid/coolant Types (CT) and three respective factor levels.

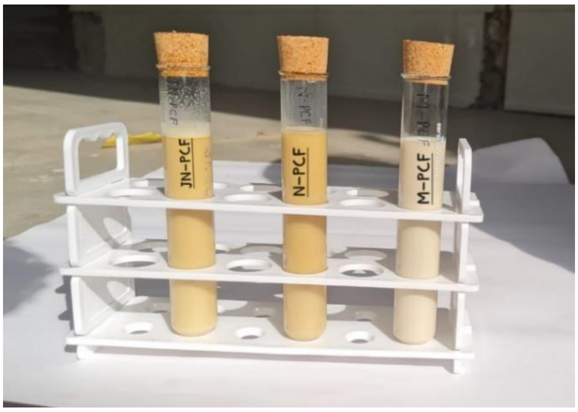

Fig.1: Different Cutting fluid samples used in turning.

Fig.2: Experimental Setup-Mild Steel being turned with HSS tool bit and flood cooling.

Sample of JN-PCF

Sample of N-PCF

Sample of M-PCF

Fig 3: Workpiece prepared with different cutting fluids.

2.2.6 Surface Roughness and Tool Flank Wear measurement

In the study, surface roughness was measured using a surface roughness tester of 'MITUTOYO' make SJ 410 model. The arithmetic mean surface roughness *(Ra)* value was obtained, with an average of five measurements on each machined surface. Tool flank wear *(Vb)* measurement was conducted by Digital Tool Marker's Microscope. The results are presented in Table 5.

3.0 RESULTS AND DISCUSSION

3.1 Experimental results

3.1.1 Characteristics of Cutting fluids

The characteristics of Oil-in-water emulsion formulated cutting fluids used in this study are presented in Table 4

Table 4: Characteristics of Oil-in-water emulsion formulated cutting fluids.

Sr. No	Properties	JN-PCF	N-PCF	M-PCF
1	pH value	7.9	8.52	8.8
2	Viscosity (mm^2/s)	0.97	0.82	0.99
3	Corrosion level	Corrosion Resistant	Corrosion Resistant	Corrosion Resistant
4	Stability	Stable	Stable	Stable
5	Color	light yellowish	Deep yellowish	Milky white

The results shown in Table 4 indicates that the JN-PCF, N-PCF and M-PCF are stable, and non-corrosive cutting fluids with viscosity of 0.97, 0.82 and 0.99 (mm^2/s) respectively, thereby making it effective and safe-to use. To determine the level of corrosion caused by the formulated cutting fluid, the method was employed using cast iron chips on filter paper, as described in literature [20,24]. This involved measuring 2g of cast iron chips on a filter paper and adding 2mL of the cutting fluid. The mixture was shaken for 2 minutes, and the fluid was then decanted, and the chips were placed on a filter paper for 2 hours. The number of corrosion spots on the filter paper was then evaluated to assess the corrosive action of the cutting fluid.

3.1.2 Experimental plan, result, and S/N Ratios

Table 5 presents the outcomes of the experimental study conducted using an experimental design layout, including their corresponding signal-to-noise (S/N) ratio values. The results indicate that alterations in the process parameters cause variations in the responses, namely surface roughness, and tool flank wear.

Table 5: Experimental plan, results, and their calculated S/N ratios.

Exp. runs	Controllable process parameters				Experimental results		S/N ratios of results	
	v	*f*	*d*	CT	Surface roughness R_a (µm) Average R_a (µm)	Flank wear V_b (µm)	R_a (dB)	V_b (dB)
1	1	1	1	1	1.651	33.231	-4.35494	-30.4309
2	1	2	2	2	1.992	52.652	-5.98579	-34.4283
3	1	3	3	3	2.610	89.864	-8.33281	-39.0717
4	2	1	2	3	1.652	49.125	-4.36020	-33.8261
5	2	2	3	1	1.595	61.658	-4.05521	-35.7998
6	2	3	1	2	1.655	86.491	-4.37596	-38.7394
7	3	1	3	2	1.514	95.235	-3.60252	-39.5759
8	3	2	1	3	1.357	104.626	-2.65160	-40.3928
9	3	3	2	1	1.569	110.298	-3.91246	-40.8514

3.2 Effect of process parameter on turning performance parameters

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

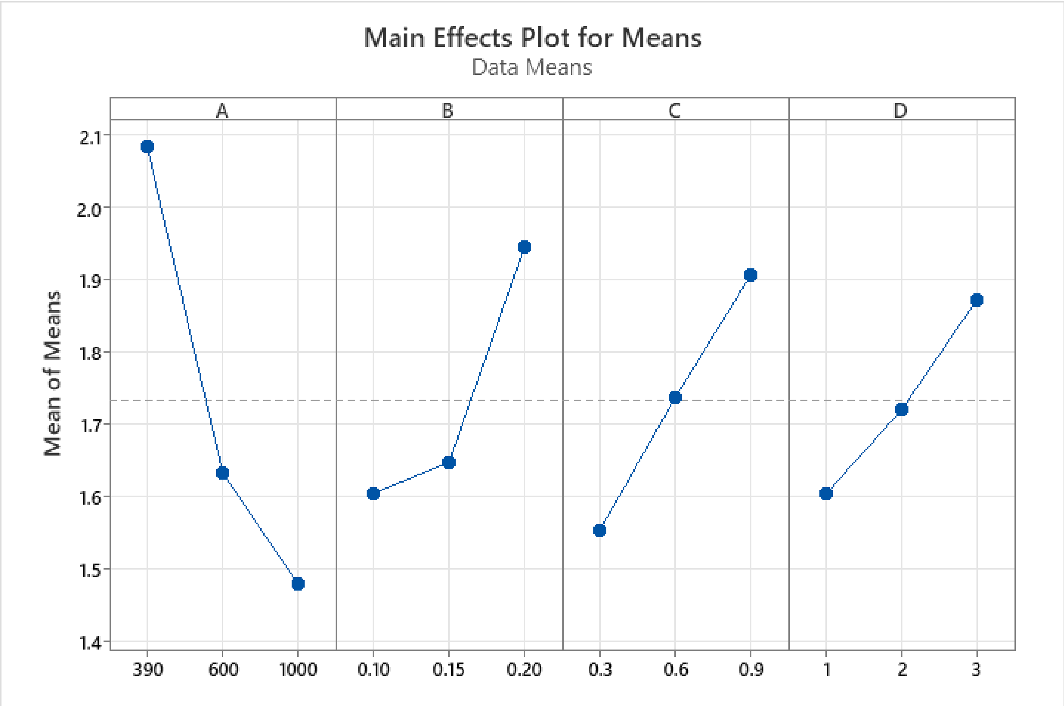

Fig. 4: Main effect plot for means for *Ra* value.

Fig. 4 illustrates how the surface roughness is affected by various process parameters. It was discovered that as the cutting speed increases, the *Ra* value decreases. This is because the increased cutting speed results in greater friction between the tool and workpiece, generating higher cutting temperatures at the machining zone, which softens the workpiece thermally and reduces smeared materials on the machined surface, ultimately leading to the lowest surface roughness [25]. In contrast, when the feed rate increases, the *Ra* value increases because of the greater tool resistance offered by the workpiece, resulting in the formation of more built-up edge (BUE) on the tool flank face and a deteriorated surface, thereby increasing the *Ra* value. Additionally, an increasing trend for *Ra* value was observed with a rise in the depth of cut. The results for surface roughness under the increasing cutting speed, feed rate, and depth of cut conditions in this study are consistent with the findings in the literature on machining difficult-to-cut materials [26]. The type of coolant/cutting fluid also plays a significant role in *Ra*, resulting JN-PCF provided lower *Ra* values than N-PCF and M-PCF, respectively, as depicted in Fig. 4. This is due to the lower cutting zone temperatures obtained when JN-PCF used at the machining zone, resulting in less debris on the machined surface and, consequently, a lower surface roughness.

3.2.2 Effect of process parameter on tool flank wear *(Vb)*

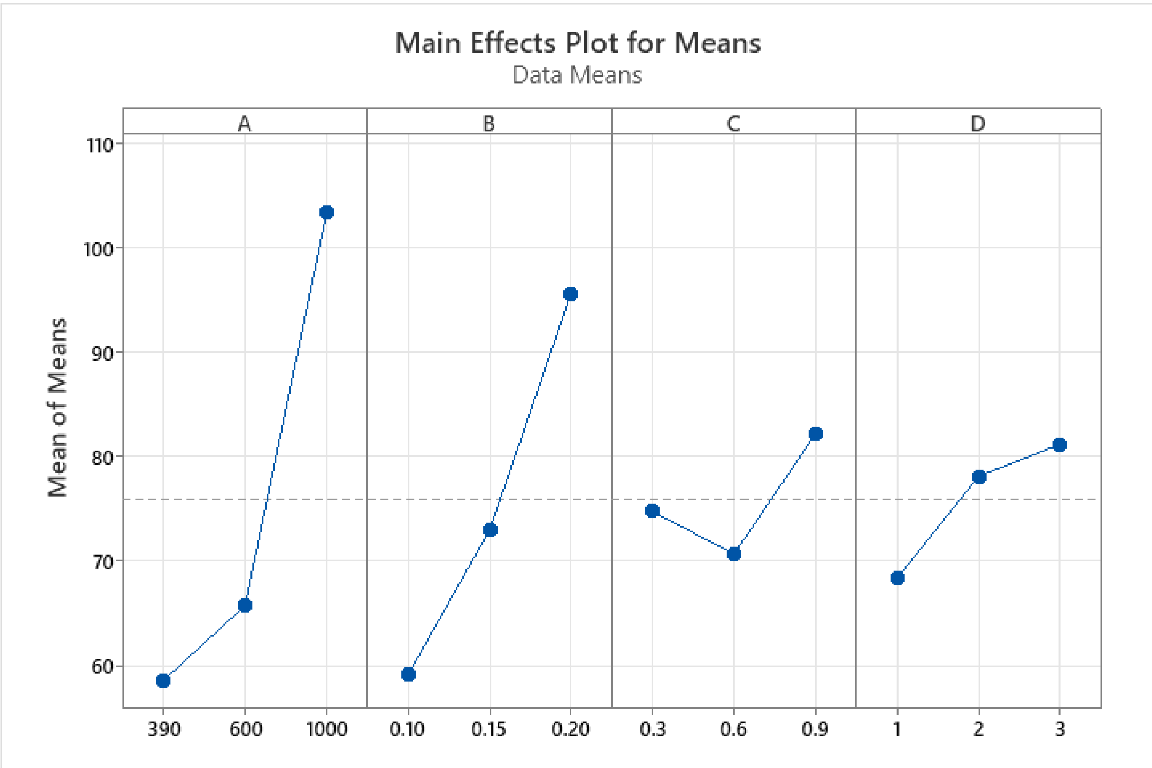

Fig. 5: Main effect plot for means for *Vb* value.

Fig. 5 demonstrates that as cutting speed, feed rate, and depth of cut increase, tool flank wear also increases. This is due to the increased machining zone temperature resulting from the higher cutting speed, feed rate, and depth of cut, which causes the concentration of more heat at the flank face of the tool, thereby reducing the tool's hardness and leading to more flank wear. These trends in tool wear are consistent with the findings in the literature [27]. Additionally, as depicted in Fig. 5, less tool flank wear was observed in JN-PCF when compared to N-PCF and M-PCF, respectively. This is because the lower temperature at the machining zone caused by JN-PCF leads to better control of adhesion wear mechanisms, resulting in lower flank wear.

3.3 Selection of optimum process parameters for *Ra* and *Vb*

Table 6: 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)	-6.225	-4.264	**-3.389**	2.836	1
f	Feed rate(mm/rev)	**-4.106**	-4.231	-5.540	1.435	3
d	Depth of cut(mm)	**-3.794**	-4.753	-5.330	1.536	2
CT	Coolant type	**-4.108**	-4.655	-5.115	1.007	4

Fig. 6: Mean S/N ratio of surface roughness

Table 6 presents the S/N ratio response data for *Ra*, while Fig. 6 shows the average S/N ratio graph generated by the Minitab software tool. The S/N ratio indicates the difference between the desired output and the measured output. A higher S/N ratio corresponds to a smaller variation between the two. The graph in Fig. 6 reveals that the process parameters yielding the highest mean S/N ratio for *Ra* are cutting speed at 1000 rpm, feed rate at 0.10 mm/rev, depth of cut at 0.3 mm, and JN-PCF as the coolant type. Thus, the Taguchi method identified these parameters as the predicted optimal values for achieving low surface roughness. These optimal values are represented as *v* = 1000 rpm, *f* = 0.10 mm/rev, *d* = 0.3 mm, and CT = JN-PCF, and they are highlighted in bold in Table 6 for easy reference. The optimal combination is denoted as *v3-f1-d1-CT1* for surface roughness.

Table 7: Mean S/N ratio response table for Flank wear *(Vb)*

Symbol	Process parameters	Mean S/N Ratio				
		Level 1	Level 2	Level 3	Max-Min	Rank
v	Cutting speed(rpm)	**-34.64**	-36.12	-40.27	5.63	1
f	Feed rate(mm/rev)	**-34.61**	-36.87	-39.55	4.94	2
d	Depth of cut(mm)	-36.52	**-36.37**	-38.15	1.78	4
CT	Coolant type	**-35.69**	-37.58	-37.76	2.07	3

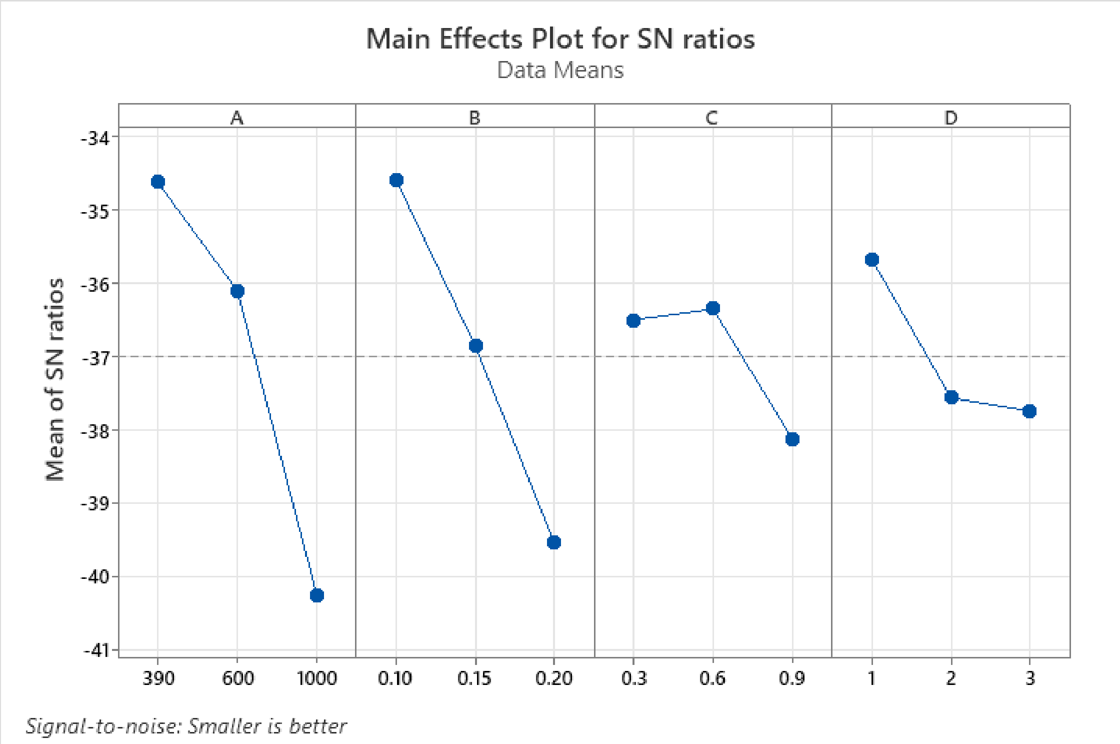

Fig. 7: Mean S/N ratio of Tool Flank Wear

The S/N ratio response data for tool flank wear is presented in Table 7, and the means of the S/N ratio are depicted in Fig. 7. The graph in Fig. 7 was used to estimate the optimal process parameters for achieving low tool flank wear, which was identified as *v* = 390 rpm, *f* = 0.10 mm/rev, *d* = 0.6 mm, and CT = JN-PCF. This combination of optimal parameters is represented as *v1-f1-d2-CT1* for tool flank wear.

3.4 Confirmation Test

Table 8: 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_1-CT_1	v_3-f_1-d_1-CT_1
Surface roughness (µm)	1.541	1.046	1.019
S/N ratio (dB)	-4.025	-1.519	-1.554
Improvement in S/N ratio (dB)	2.471		
Percentage reduction of surface roughness	51.22%		

Table 9: Confirmation test results for tool flank wear *(Vb)*

	Initial process parameter	Optimal process parameters	
		Prediction	Experiment
Level	v_2-f_2-d_2-CT_2	V_1-f_1-d_2-CT_1	V_1-f_1-d_2-CT_1
Flank wear (µm)	59.827	29.140	30.989
S/N ratio (dB)	-35.906	-30.278	-31.591
Improvement in S/N ratio (dB)	4.315		
Percentage reduction of tool flank wear	48.20%		

To validate the Taguchi predicted optimum cutting conditions, confirmation tests were conducted. The predicted S/N ratio was used to estimate and verify the response at the predicted optimum cutting conditions. The confirmation experiments were performed at the Taguchi predicted optimum cutting conditions, and the results for *Ra* and *Vb* are presented in Table 8 and Table 9, respectively. The predicted optimum cutting conditions for both *Ra* and *Vb* led to an improvement in the performance characteristic results. It was observed that the S/N ratios of the predicted and optimal cutting conditions were remarkably close for both *Ra* and *Vb*. The S/N ratio improvement found at the optimal cutting condition for *Ra* and *Vb* were 2.471 dB and 4.315 dB, respectively, when compared to the initial parameter settings, as shown in Table 7 and Table 8. The conformation experiments showed that the Taguchi predicted optimum cutting conditions provided favorable results over the initial parameter conditions. The reduction in *Ra* and *Vb* found at the Taguchi predicted optimum cutting conditions was 51.22% and 48.20%, respectively, when compared to the initial parameter conditions. Therefore, the Taguchi predicted optimum cutting conditions were taken as the optimum cutting conditions for achieving low *Ra* and low *Vb* in the machining of Mild Steel under the given conditions. Based on these results, it can be concluded that the Taguchi optimization method significantly improved the machinability characteristics of Mild Steel under the given process parameters.

3.5 Test for *Ra* and *Vb* in different experimental, predicted parameters for different cutting fluids.

Table 10: Test results for Surface Roughness *(Ra)*

S. No.	*v*	*f*	*d*	JN-PCF(µm)	N-PCF(µm)	M-PCF(µm)
1	390	0.10	0.3	1.651 *	1.766	1.919
2	390	0.15	0.6	1.876	1.992 *	2.144
3	390	0.20	0.9	2.342	2.457	2.610 *
4	600	0.10	0.6	1.384	1.499	1.652 *
5	600	0.15	0.9	1.595 *	1.710	1.863
6	600	0.20	0.3	1.539	1.655 *	1.807
7	1000	0.10	0.9	1.398	1.514 *	1.666
8	1000	0.15	0.3	1.089	1.204	1.357 *
9	1000	0.20	0.6	1.569 *	1.684	1.837
Mean Value				1.604	1.720	1.872

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

Table 11: Test results for Tool Flank Wear *(Vb)*

S. No.	*v*	*f*	*d*	JN-PCF(µm)	N-PCF(µm)	M-PCF(µm)
1	390	0.10	0.3	33.231 *	42.961	46.040
2	390	0.15	0.6	42.921	52.652 *	55.731
3	390	0.20	0.9	77.054	86.785	89.864 *
4	600	0.10	0.6	36.315	46.460	49.125 *
5	600	0.15	0.9	61.658 *	71.388	74.467
6	600	0.20	0.3	76.760	86.491 *	89.570
7	1000	0.10	0.9	85.504	95.235 *	98.314
8	1000	0.15	0.3	91.816	101.547	104.626*
9	1000	0.20	0.6	110.298 *	120.028	123.107
Mean Value				68.395	78.143	81.204

Note: * This symbol indicates Experimental Values and all remaining values are predicted using Minitab Software tool.

After conducting tests using the L_9 orthogonal array design and experimental design, it was discovered that the mean value of *Ra* in (JN-PCF) was 1.604, the mean value of *Ra* in (N-PCF) was 1.720, and the mean value of *Ra* in (M-PCF) was 1.872. Additionally, the mean value of *Vb* in (JN-PCF) was 68.395, the mean value of *Vb* in (N-PCF) was 78.143, and the mean value of *Vb* in (M-PCF) was 81.204. Therefore, it is concluded that JN-PCF yields a minimum surface roughness *(Ra)* and tool flank wear *(Vb)* as compared to N-PCF and M-PCF.

4. ANOVA analysis of Experimental Results for R_a and V_b

Table 12: ANOVA for Surface Roughness (*Ra)*

Source	DOF	Sum of squares	Mean squares	% contribution
v	2	0.59173	0.295867	54.24
f	2	0.20472	0.102362	18.77
d	2	0.18596	0.092982	17.05
CT	2	0.10843	0.054216	9.94
Total	8	1.09086		100.00

Table 13: ANOVA for Tool Flank Wear (*Vb)*

Source	DOF	Sum of squares	Mean squares	% contribution
v	2	3474.78	1737.39	58.30
f	2	2021.06	1010.53	33.96
d	2	206.18	103.09	3.75
CT	2	268.24	134.12	3.99
Total	8	5970.26		100.00

The ANOVA analysis was conducted in this study to determine the process parameters showing an impact on the performance characteristics of *Ra* and *Vb*. ANOVA results obtained for *Ra* and *Vb* were shown in Tables 12 and 13, respectively. According to Table 12, the percentage contribution of cutting speed, feed rate, depth of cut, and coolant type on Ra was 54.24%, 18.77%, 17.05%, and 9.94%, respectively. Therefore, *Ra* was significantly influenced by cutting speed, followed by feed rate, depth of cut, and coolant type. Similarly, tool flank wear *(Vb*) was also influenced by cutting speed, feed rate, coolant type, and depth of cut. The respective percentage contribution of cutting speed, feed rate, coolant type, and depth of cut on *Vb* was 58.30%, 33.96%, 3.99%, and 3.75%, respectively, as shown in Table 13. Therefore, ANOVA analysis concluded that both *Ra* and *Vb* were significantly affected by cutting speed.

4.1 Modeling

Table 14: Results for the developed models

Run	Experimental		Fits		Residuals		Error %	
	R_a (µm)	V_b (µm)	R_a (µm)	V_b (µm)	R_a (µm)	V_b (µm)	R_a	V_b
2	1.992	52.652	1.98173	55.089	0.0102653	-2.43732	0.51	4.62
6	1.655	86.491	1.78396	85.527	-0.128963	0.9640	7.79	1.11
8	1.357	104.626	1.38414	104.222	-0.027136	0.4037	1.99	0.38
9	1.569	110.298	1.46164	113.325	0.107364	-3.0268	6.84	2.74

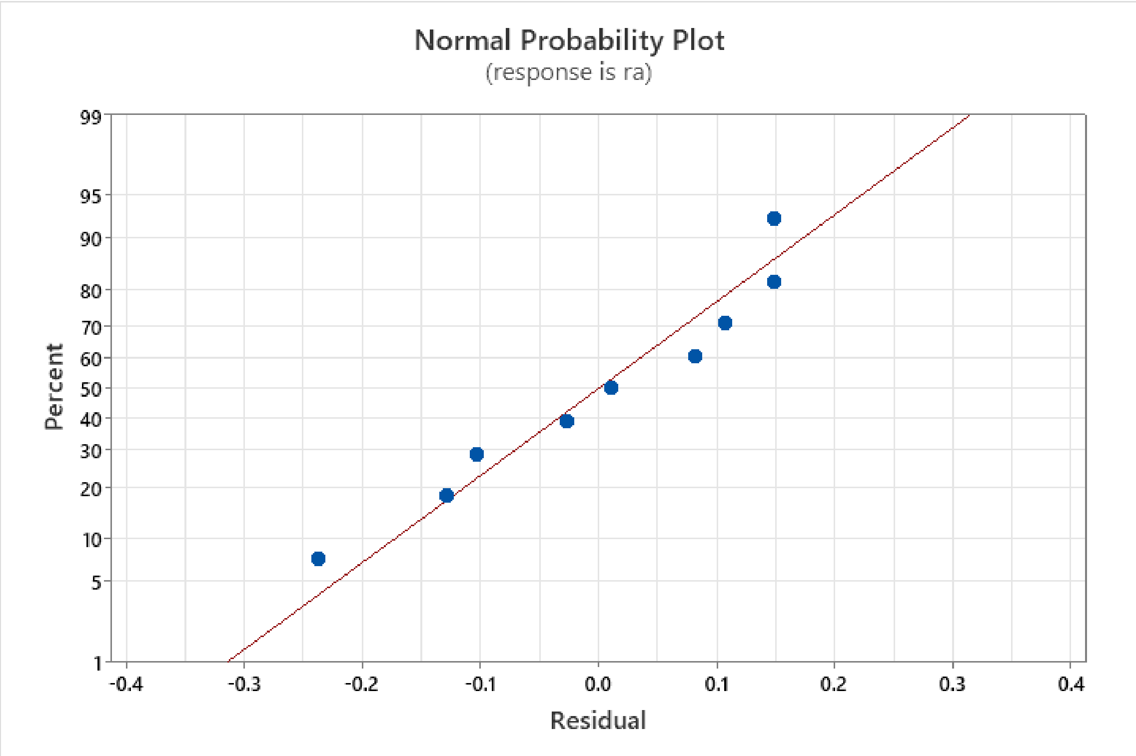

Fig 8: Normal probability plot of the residuals for surface roughness

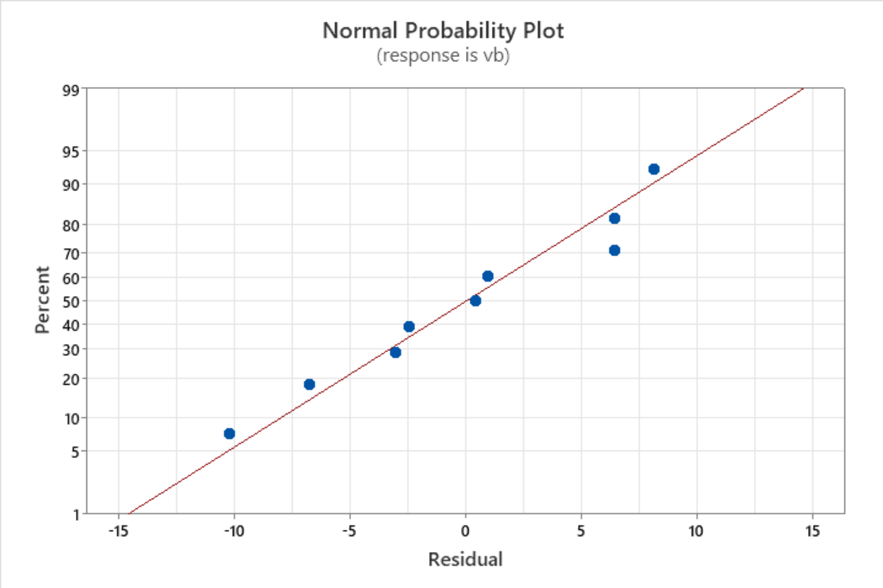

Fig 9: Normal probability plot of the residuals for Tool flank wear

In this study, the Minitab 21.0 software tool used for linear regression analysis to develop predictive mathematical models for the dependent variables of *Ra* and *Vb*. The cutting speed, feed rate, depth of cut, and coolant type were used as independent variables. No transformation was performed on each response. The predictive equations obtained from the regression analysis are presented in Eqn. (1) and Eqn. (2) for *Ra* and *Vb*, respectively.

$$R_a = 1.208 - 0.000911*v + 3.39*f + 0.587*d + 0.1340*CT \quad (R^2 = 86.54\ \%) \quad (1)$$

$$V_b = -49.4 + 0.0762*v + 363.5*f + 12.4*d + 6.40*CT \quad (R^2 = 94.72\ \%) \quad (2)$$

To assess the effectiveness of the developed models, the coefficient of determination R^2 utilized by M. K. Gupta et al. [28]. The R^2 value ranges from zero to one and indicates the degree of fit between the dependent and independent variables. An R^2 value close to one indicates a strong fit, with new observations estimated with a high degree of accuracy. In this study, the developed regression models for *Ra* and *Vb* demonstrated high R^2values of 86.54% and 94.72%, respectively. The significance of the coefficients in the predicted model was evaluated using residual plots. A straight line in the residual graph indicates that the residual errors in the model are normally distributed and the coefficients in the model are significant. The residual plots for *Ra* and *Vb* are presented in Fig. 8 and Fig. 9, respectively. Based on the observations from Fig. 8 and Fig. 9, the residuals closely align with the straight line for both *Ra* and *Vb*, indicating that the coefficient models developed are significant. To validate the models, conformation tests were performed, and the results are presented in Table 14. The test results were randomly selected from the L_9 orthogonal experimental design. It was determined that the predicted results from the models were in good agreement with the experimental results within the specified parameter range. Similar findings of agreement between process parameters and response have been reported by M. K. Gupta et al. [29] in the study for the machining of difficult-to-cut materials.

4.2 Contour Plots for surface roughness *(Ra)*

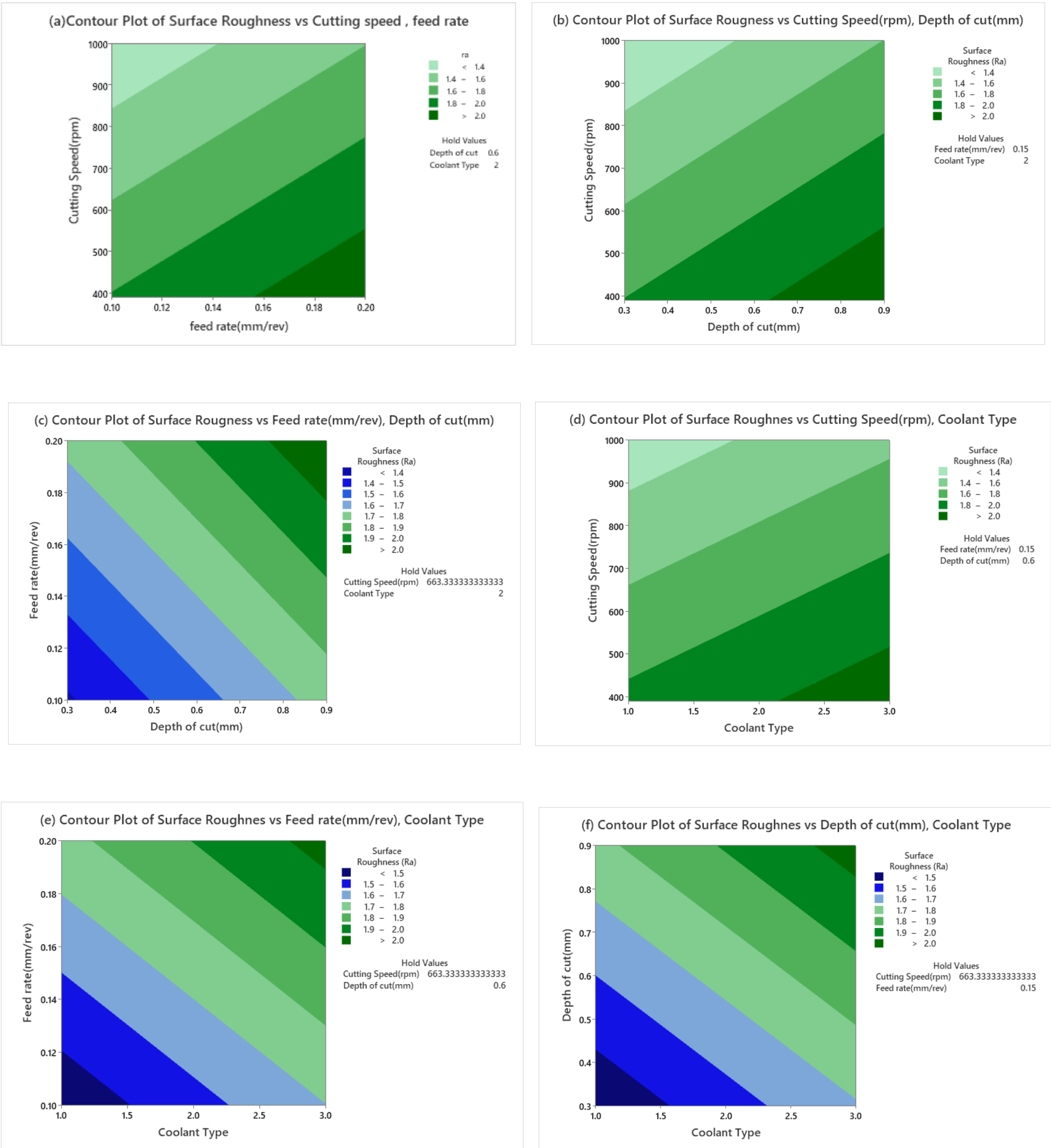

Fig. 10 Contour plot for surface roughness (a) Cutting speed Vs Feed rate (b) Cutting speed Vs Depth of cut (c) Feed rate Vs Depth of cut (d) Cutting speed Vs Coolant type (e) Feed rate Vs Coolant type (f) Depth of cut Vs Coolant type.

4.3 Contour Plots for tool flank wear (*Vb)*

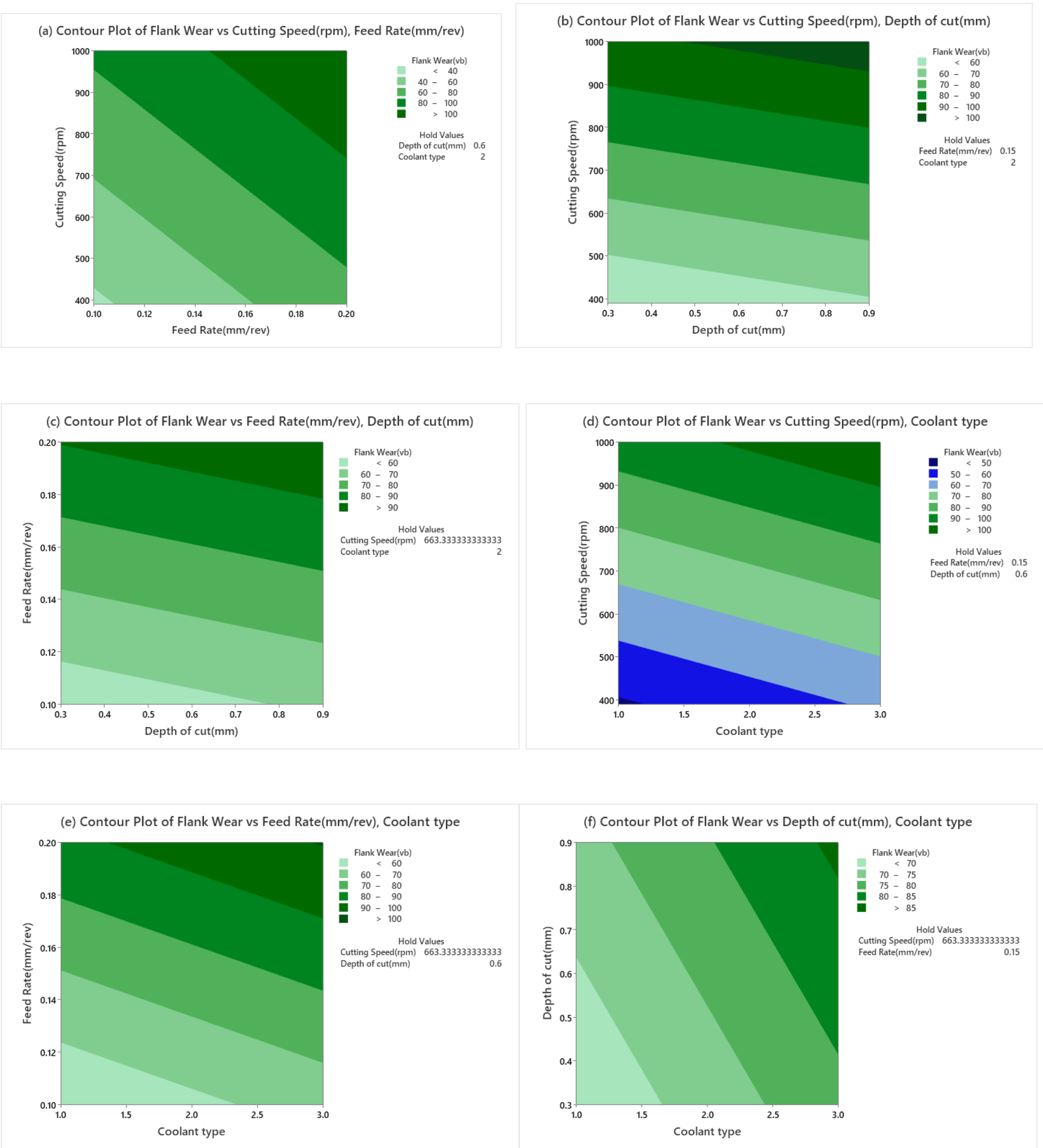

Fig. 11 Contour plot for tool flank wear (a) Cutting speed Vs Feed rate (b) Cutting speed Vs Depth of cut (c) Feed rate Vs Depth of cut (d) Cutting speed Vs Coolant type (e) Feed rate Vs Coolant type (f) Depth of cut Vs coolant type.

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 10 (a) discovered that a high cutting speed and low feed rate results in a lower surface roughness value. In Figure 10 (b), low surface roughness is achievable with high cutting speed and depth of cut levels. Additionally, Figure 10 (c) indicates that low surface roughness can be attained with a low feed rate and high depth of cut. Furthermore, JN-PCF was found to significantly decrease surface roughness in comparison to N-PCF and M-PCF, as demonstrated in Figure 10 (d-f).

Figure 11 displays contour plots that clarify the association between process parameters and tool flank wear. Figure 11(a-c), apparent that a low level of cutting speed, feed rate, and depth of cut respectively resulted in minimal tool flank wear. When comparing all the machining parameters, JN-PCF exhibited the lowest tool flank wear, as demonstrated in Figure 11 (d-f). Similar findings were discovered by M. Seeman et al. [30] in the literature regarding turning processes when dealing with difficult-to-cut materials.

5. Conclusion

In this research non-edible jatropha and neem oil blend Cutting fluid was analyzed for their physiochemical properties. The investigation on surface roughness and tool flank wear was carried out in the turning process of mild Steel and compared with neem oil and mineral oil-based cutting fluid. Taguchi L9 orthogonal array was used in the experiment. The following conclusion is drawn based on the finding of this research work:

1. The physical and chemical analysis carried out on the formulated cutting fluid has demonstrated excellent results, making it a satisfactory substitute for cutting fluids when compared to neem oil (N-PCF) and commercial mineral oil-based cutting fluid (M-PCF).
2. The performance of the developed cutting fluids (JN-PCF) was compared with Neem oil-based cutting fluid (N-PCF), and mineral oil-based cutting fluid (M-PCF) in terms of pH, stability, corrosion resistance, and viscosity. The results showed that the formulated cutting fluid found an eco-friendly cutting fluid in machining operations.
3. The ANOVA results showed that cutting speed had the most significant effect on surface roughness *(Ra)*, contributing to 54.24%, followed by feed rate at 18.77%, depth of cut at 17.05%, and Cutting Fluid (coolant) type 9.94%. Tool flank wear *(Vb)* was significantly affected by cutting speed, contributing to 58.30%, followed by feed rate at 33.96%, Cutting Fluid (coolant) type at 3.99%, and depth of cut at 3.75%.
4. Taguchi method determined optimum cutting condition for obtaining the low surface roughness as v = 1000 rpm, f = 0.10 mm/rev, d = 0.3 mm and JN-PCF (v_3-f_1-d_1-CT_1) it was observed that 51.22% reduction of surface roughness *(Ra)* was found at the Taguchi determined optimum cutting condition. In comparison to N-PCF and M-PCF, JN-PCF resulted in lower surface roughness, with mean values of 1.604 for JN-PCF, 1.720 for N-PCF, and 1.872 for M-PCF.
5. Optimum cutting condition for obtaining the low tool flank wear was observed as v = 300 rpm, f = 0.10 mm/rev, d = 0.6 mm and JN-PCF ($v1$-f_1-d_2-CT_1) using Taguchi method and it was observed that 48.20% reduction of tool flank wear *(Vb)* was found at the Taguchi determined optimum cutting condition. JN-PCF was observed to produce low tool wear than N-PCF and M-PCF, with mean values of 68.395 for JN-PCF, 78.143 for N-PCF, and 81.204 for M-PCF.

REFERENCES

[1] Shaw, M. C.; Cookson, J. O. Metal Cutting Principles; Oxford university press: New York, 2005; Vol. 2.

[2] Li, W.; Kara, S. An Empirical Model for Predicting Energy Consumption of Manufacturing Processes: A Case of Turning Process. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. 2011, 225 (9), 1636–1646. DOI: 10.1177/2041297511398541.

[3] Vernaza-Pena, K. M.; Mason, J. J.; Li, M. Experimental Study of the Temperature Field Generated during Orthogonal Machining of an Aluminum Alloy. Exp. Mech. 2002, 42(2), 221–229. DOI: 10.1007/BF02410886

[4] Bhuiyan, M. S. H.; Choudhury, I. A.; Dahari, M. Monitoring the Tool Wear, Surface Roughness and Chip Formation Occurrences Using Multiple Sensors in Turning. J. Manuf. Syst. 2014, 33(4), 476–487. DOI: 10.1016/j.jmsy.2014.04.005.

[5] Sayit, E.; Aslantas, K.; Çiçek, A. Tool Wear Mechanism in Interrupted Cutting Conditions. Mater. Manuf. Process. 2009, 24 (4), 476–483. DOI: 10.1080/10426910802714423.

[6] Sales, W. F.; Diniz, A. E.; Machado, Á. R. Application of Cutting Fluids in Machining Processes. J. Braz. Soc. Mech. Sci. 2001, 23(2), 227–240. DOI: 10.1590/S0100-73862001000200009.

[7] Sales, W. F.; Ezugwu, E. O.; Machado, Á. R.; Guimarães, G. Cooling Ability of Cutting Fluids and Measurement of the Chip tool Interface Temperatures. Ind. Lubr. Tribol. 2002, 54(2), 57–68. DOI: 10.1108/00368790210424121.

[8] Adler, D. P.; Hii, W.-S.; Michalek, D. J.; Sutherland, J. W. Examining the Role of Cutting Fluids in Machining and Efforts to Address Associated Environmental/Health Concerns. Mach. Sci. Technol. 2006, 10(1), 23–58. DOI: 10.1080/10910340500534282.

[9] J. Sánchez-Oneto, J.R. Portela, E. Nebot, E. Martínez de la Ossa, Hydrothermal oxidation: Application to the treatment of different cutting fluid wastes, J Hazard. Mater. 144 (3) (Jun. 2007) 639–644, https://doi.org/10.1016/j. jhazmat.2007.01.088.

[10] P. J. S. Grewal and G. N. E. Ludhiana, Comparative Analysis of Eco-Friendly Vegetable, Petroleum and Synthetic Oil Based Cutting Fluids, International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue 1, January – 2014

[11] Srikant, R. R.; Ramana, V. Performance Evaluation of Vegetable Emulsifier Based Green Cutting Fluid in Turning of American Iron and Steel Institute (AISI) 1040 Steel–An Initiative Towards Sustainable Manufacturing. J. Clean. Prod. 2015, 108, 104–109. DOI: 10.1016/j.jclepro.2015.07.031.

[12] P. Suvin, P. Gupta, J.-H. Horng, S.V. Kailas, Evaluation of a comprehensive nontoxic, biodegradable and sustainable cutting fluid developed from coconut oil, Proc. Inst. Mech. Eng. Part J. Eng. Tribol. (Nov. 2020) 1–9, https://doi.org/ 10.1177/1350650120975518.

[13] Paul, S.; Pal, P. K. Study of Surface Quality during High Speed Machining Using Eco-Friendly Cutting Fluid. Mach. Technol. Mater. 2011, 11, 24–28

[14] Sharafadeen K. Kolawole, Jamiu K. Odusote, "Performance Evaluation of Vegetable Oil-based Cutting Fluids in Mild Steel Machining", Chemistry and material research,Vol.3.no.9,2013.

[15] Jitendra Kumar Chandrakar and Amit Suhane, The Prospects of Vegetable Based Oil as Metal working Fluid in Manufacturing Application-A Review, International Journal of Engineering Research and Technology, Vol. 3-Issue 5 (May-2014) ISSN 2278-0181.

[16] Sidhu, Bashir, J. S. Experimental Investigation and Optimization of Process Parameters in Turning of AISI D2 Steel Using Different Lubricant, International Journal of Engineering and Advanced Technology (IJEAT), 2014, 3(5), 189–197. http:// citeseerx.ist.psu.edu/viewdoc/downloaddo i=10.1.1.678. 9084&rep=rep1&type=pdf

[17] Bork, C. A. S.; de Souza Gonçalves, J. F.; de Oliveira Gomes, J.; Gheller, J. Performance of the Jatropha Vegetable-Base Soluble Cutting Oil as a Renewable Source in the Aluminum Alloy 7050-T7451 Milling. CIRP J. Manuf. Sci. Technol. 2014, 7(3), 210–221. DOI: 10.1016/j.cirpj.2014.04.004

[18] P. N. Jyothi et al 2017 IOP "Performance evaluation of NEEM oil and HONGE Oil as cutting fluid in drilling operation of mild steel" Conf. Ser.: Mater. Sci. Eng. 191 012026 IOP Conf. Series: Materials Science and Engineering 1234567890 191 (2017) 012026.

[19] Agrawal, S. M.; Patil, N. G. Experimental Study of Non-edible Vegetable Oil as a Cutting Fluid in Machining of M2 Steel Using MQL. Procedia Manuf. 2018, 20, 207–212. DOI: 10.1016/j. promfg.2018.02.030

[20] Awode Emmanuel Imhanote, Abolarin Matthew Sunday, Lawal Sunday Albert, Adedipe Oyewole "Performance Evaluation of Jatropha Seed Oil and Mineral Oil-Based Cutting Fluids in Turning AISI 304 Alloy Steel" International Journal of Engineering Materials and Manufacture (2020) 5(3) 85-97 https://doi.org/10.26776/ijemm.05.03.2020.03 Published: 30 July 2020.

[21] E. I. Awode1, *, S. A. Lawal2 , K. A. Olaiya3 , J. Abutu4 "Characterization of Eco-Friendly Cutting Fluid Developed from Neem Seed Oil" Nigerian Journal of Technology (NIJOTECH) Vol. 41, No. 4 July, 2022, pp.700 –711 www.nijotech.com Available online 10 September 2022.

[22] Rahul Katna a,⇑ , M. Suhaib a , Narayan Agrawal b , Veerpal Bhati b , Praveen Kumar b , Mumtaz Ahmad Khan b Green manufacturing – Optimization of novel biodegradable cutting fluid for machining https://doi.org/10.1016/j.matpr.2023.03.019

[23] Agu, C. K., Lawal, S. A., Abolarin, M. S., Agboola, J. B., Abutu, J. and Awode, E. I. "Multi-Response Optimisation of Machining Parameters in Turning AISI 3041 using Different Oil-Based Cutting Fluids" Nigerian Journal of Technology, 38(2), 2019, pp. 364 – 375.

[24] Lawal, S. A., Choudhury, I. A. and Nukman. Y. "Evaluation of vegetable and mineral oil-in-water emulsion cutting fluids in turning AISI 4340 steel with coated carbide tools" Journal of Cleaner Production, 66, 2014b, pp. 610 – 618.

[25] 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.

[26] M. Mia, A. Khan, and N. R. Dhar, "High-pressure coolant on flank and rake surfaces of tool in turning of Ti-6Al-4V: investigations on surface roughness and tool wear," Int. J. Adv. Manuf. Technol., 90(5-8), pp.1825-1834. 2017

[27] G. M. Krolczyk, P. Nieslony, and S. Legutko, "Determination of tool life and research wear during duplex stainless steel turning," Arch. Civ. Mech. Eng., vol. 15, no. 2, pp. 347– 354, 2013.

[28] 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.

[29] 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.

[30] M. Seeman, G. Ganesan, R. Karthikeyan, and A. Velayudham, "Study on tool wear and surface roughness in machining of particulate aluminum metal matrix composite-response surface methodology approach," Int. J. Adv. Manuf. Technol., vol. 48, no. 5–8, pp. 613– 624, 2010.