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Development of Cutting Fluid from Mahogany Seed oil and Neem leaves for the Turning of AISI 304 Austenitic Stainless Steel

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Abstract: : In this work, mahogany seeds were locally sourced, oil extracted and characterised by determining the pH, viscosities and flash points. Two sets of cutting fluids were formulated (mahogany seed oil and mineral oil based cutting fluids) for comparison. The formulation was carried out using experimental design specified by full factorial $L_{16}2^4$ design. In addition, the effects of the formulated cutting fluids on machining performance (material removal rate, cutting temperature and surface finish) were investigated by turning AISI 304 austenitic stainless steel using coated tungsten carbide tool insert. Central composite design (CCD) technique via Response surface methodology (RSM) was adopted for design of experiment. The experimental results obtained from machining processes showed that the formulated mahogany oil based cutting fluid (MBCF) compared well mineral oil based cutting fluid (CBCF). It was also revealed that the optimal surface roughness can be achieved with formulated mahogany cutting fluid (MBCF) using spindle speed (1236.4rev/min), feed rate (0.62mm/rev) and depth of cut (0.15mm) while the optimal conditions for cutting temperature of MBCF can be obtained using spindle speed (700rev/min), feed rate (0.41mm/rev) and depth of cut (0.10mm). In addition, the optimal conditions for material removal rate (MRR) of MBCF can be obtained using spindle speed (1236.4rev/min), feed rate (0.96mm/rev) and depth of cut (0.23mm). Conclusively, based on these findings, it can be affirm that mahogany seed oil is a good candidate to serve as substitute for mineral oil in cutting fluid formulation.

1. Introduction

Cutting fluids play an important role in reducing friction, washing away the chips and cooling the work piece (Yan *et al.,* 2016). When these cutting fluids are applied, machined surface quality improves and the tool wear reduces. However, cutting fluids also render protection to machined surface against corrosion and saves energy by minimizing cutting forces (Naik and Sharma, 2022). Though, these benefits of utilising cutting fluids during machining processes are accompanied with numerous limitations or setback. Some of these limitations include; the cutting fluid costs which are sometimes double the cost of the tool, the health hazard posed to the operator as well as the disposal of the used cutting fluids (Abutu *et al.,* 2022). Lawal *et al.* (2014) have revealed that vegetable oils can be utilized as a potential candidate in industries to be used as lubricants/cutting fluids. Also, Kazeem *et al.* (2020) have revealed that vegetable oils are possible alternatives for making the production environment more sustainable and replacing the conventional mineral based oil cutting fluids. Some researchers are still ongoing while several researches have been concluded on the use of vegetable oil as based oil in the formulation of cutting fluids with the aim of utilizing the different available vegetable oils in the globe for the formulation of organic-based cutting fluids.

Kazeem *et al.* (2020) utilized Taguchi design technique and a multi-response optimization technique to investigate the performance of jatropha and mineral oil-based cutting fluids during turning of AISI 1525 steel alloy and found that the optimal conditions for the formulated jatropha oil-based cutting fluid, are cutting depth (1mm), feed rate (0.10 mm/rev) and cutting velocity (355 m/min). Also, Ojolo *et al.* (2008) utilised tungsten carbide tool to investigate the effects of different vegetable-based oils (palm kernel oil, groundnut oil, shear butter oil and coconut oil) in the turning of aluminum alloy, copper alloy and mild steel. The authors found that of all the four vegetable oils, groundnut oil performed better since it produced the minimum cutting force and that the four vegetable-based oils are material dependent. The Palm or Kernel oils were widely studied in different fiels as corrosion protection of metallic materials (Afia *et al.* (2013) and El Ouadi *et al.* (2017). In addition, Mahadi *et al.* (2017) utilised a 24 full factorial design technique as well as minimum quantity lubrication to investigate the performance of boric acid powder with palm kernel oil by comparing with mineral oil for lubrication in AISI 431 alloy steel machining. The authors revealed that the surface integrity of the workpiece is most influenced by type of lubricant and feed rate. Also, Abutu *et al.* (2022) and Lawal *et al.* (2014) utilized palm kernel oil as based oil for cutting fluid using Taguchi and Box-Behken's experimental design respectively. The authors found that palm kernel oil performed well, hence is a good substitute for asbestos for cutting fluid formulation. However, the authors recommended for research into the use of other vegetable oils such as mahogany seed oil. Therefore, in this study, mahogany-oil was extracted from its seeds and used as based oil to formulate mahogany based cutting fluid (MBCF) alongside conventional oil-based cutting fluid (CBCF) using 2-level full factorial (L1624) experimental design technique. The extracted oil and formulated cutting fluid were characterized by determining the pH as well as viscosity value. Thereafter, its effects on surface roughness, cutting temperature and material removal rate during turning of AISI 304 steel were investigated and compared with conventional mineral oil-based cutting fluid formulated using similar conditions.

2.0 Materials and Methods

2.1 Materials

2.1.1 Formulation of cutting fluid

The formulation of the cutting fluid was carried using mahogany seeds (swietenia macrophylla)- Figure 1(a), collected from a Mutum Biu, Taraba State-Nigeria and mineral (Clutch and Brake fluid). Other additives used include; neem leaves extract (anti-oxidant)- Figure 1(b), trizaine (biocide), washing soap (emulsifier) and silicones (anti-form).

2.1.2 Turning Processes

AISI 304 stainless steel was used as workpiece for the machining process. the machining operation was carried out on a Lathe machine (Figure 2) situated at the Mechanical Engineering workshop of Taraba State Polytechnic, Jalingo-Nigeria using Tungsten carbide tool inserts and AISI 304 workpiece. Other materials used for the turning operation are; Surface Roughness tester (SHAHE, Model: GS5337, Accuracy:±3um, China)-Figure 3(a), cutting temperature using an Infrared Pyrometer (Model IR-872 Omicron) – Figure 3(b) and a digital vernier caliper (CARBON FIBRE COMPOSITE, Accuracy: 0.2mm)-Figure 3(c).

Figure 1: Materials for formulation (a) mahogany seed (b) fresh neem leaves

Figure 2: Three-jaw chuck lathe machine used for machining

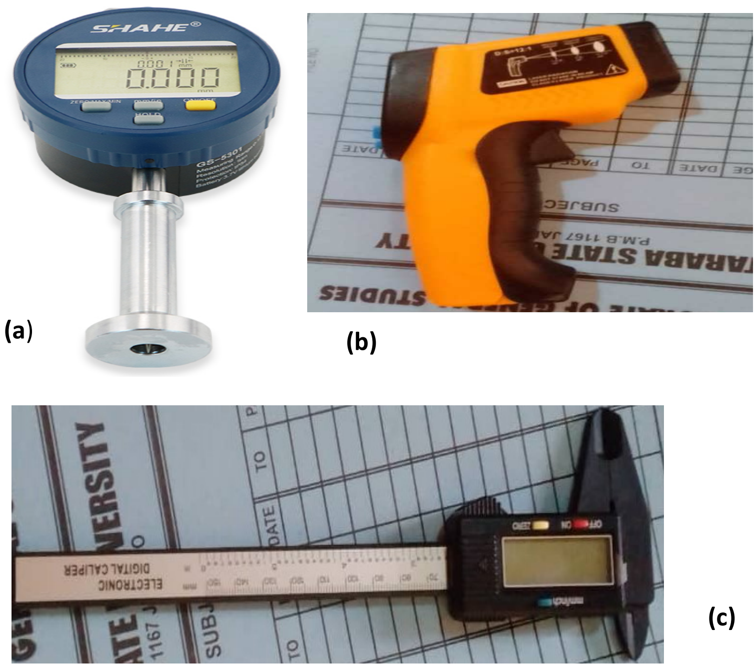

Figure 3: Machining materials (a) surface roughness tester (b) infrared pyrometer (c) digital vernier caliper

2.2 Methods

2.2.1 Extraction of neem and mahogany seed oil extract

Collected neem leaves were carefully washed under tap water and cut into tiny pieces and thereafter blended using a blender. Also, mahogany seed oil was obtained from the seeds by utilizing the extraction technique adopted by Kazeem *et al.* (2020).

2.2.2 Characterization of oil

The extracted mahogany seeds oil was characterized by investigating the pH, viscosities and flash points of the oil using analyzed using the testing procedure outlined by ASTM D4212 (viscosity value) and ASTM D7946-19 (pH value)

2.2.3 Formulation of emulsion cutting fluid

Cutting fluid formulation was carried out at the Department of Mechanical Engineering Laboratory, Taraba State University, Jalingo-Nigeria. Two different cutting fluids were formulated (mahogany oil based and mineral oil-based cutting fluids). The factor levels for variables employed in the factorial design are shown in Table 1. The formulation procedure involved the application of experimental design (DOE) technique under the conditions stipulated by $L_{16}2^4$ full-factorial design as shown in Table 2.

Table 1: Factor levels for variables.

Additives (Variables)	Level 1	Level 2
Anti-oxidant (AO) %	6.0	12
Biocide (B) %	0.8	1.6
Emulsifier (E) %	0.4	0.8
Anti-form agent (AF) %	0.5	1.0

Table 2: 2^4 full factorial experimental design matrix.

Run	B (ml)	E (ml)	AO (ml)	AF (ml)	oil (ml) 20% oil/water mixture	water (ml) 80% oil/water mixture	Total Volume of Cutting Fluid (ml)
1	0.80	4.00	3.00	0.50	18.34	73.36	100
2	1.60	4.00	5.00	0.50	17.78	71.12	100
3	1.60	8.00	3.00	1.00	17.28	69.12	100
4	0.80	8.00	6.00	0.50	16.94	67.76	100
5	0.80	4.00	3.00	1.00	18.24	72.96	100
6	1.60	8.00	3.00	0.50	17.38	69.52	100
7	0.80	8.00	3.00	0.50	17.54	70.16	100
8	0.80	4.00	6.00	0.50	17.74	70.96	100
9	1.60	4.00	6.00	1.00	17.48	69.92	100
10	1.60	8.00	6.00	1.00	16.68	66.72	100
11	1.60	4.00	3.00	1.00	18.08	72.32	100
12	0.80	8.00	6.00	1.00	16.84	67.36	100
13	1.60	4.00	3.00	0.50	18.18	72.72	100
14	0.80	8.00	3.00	1.00	17.44	69.76	100
15	1.60	8.00	6.00	0.50	16.78	67.12	100
16	0.80	4.00	6.00	1.00	17.64	70.56	100

2.2.4 *Characterization of formulated cutting fluids*

Each formulated mineral and mahogany oil-based cutting fluids were characterized by determining the power of hydrogen (pH) using A digital pH meter and Zahn viscosity cup. The data obtained for the pH and viscosity values of each formulated cutting fluid were analyzed statistically using Minitab statistical software and the optimal values combination of additive combination and percentage oil content were used to formulate the oil based cutting fluid used for the machining process. The optimized cutting fluid formulation was thereafter characterized by determining the viscosity, corrosion level, stability and pH using standard testing procedures.

2.2.5 *Turning processes*

Turning operation was carried out using the optimized mahogany oil based cutting fluid (MBCF) and mineral oil based cutting fluid (CBCF). Experimental design of the machining was carried out using Central Composite Design (CCD). Table 3 shows the factor levels of the machining parameters while the design matrix of the machining process is shown in Table 4. In addition, turning operation was carried out on a three-jaw chuck lathe machine using standard procedure specified in literatures while the material removal rate (MRR) was calculated using the change in diameter of workpiece during machining operation.

Table 3: Factor levels of turing parameters

Factors	Upper level	Lower level
Spindle speed (m/mm)	700	1100
Feed rate (mm/rev)	0.41	0.82
Depth of cut (mm)	0.1	0.2

Table 4: Experimental design matrix using CCD

S/N	Spindle speed (m/mm)	Feed rate (mm/rev)	Depth of cut (mm)
1	700	0.41	0.1
2	1100	0.41	0.1
3	700	0.82	0.1
4	1100	0.82	0.1
5	700	0.41	0.2
6	1100	0.41	0.2
7	700	0.82	0.2
8	1100	0.82	0.2
9	564	0.62	0.15
10	1236	0.62	0.15
11	900	0.27	0.15
12	900	0.96	0.15
13	900	0.62	0.07
14	900	0.62	0.23
15	900	0.62	0.15
16	900	0.62	0.15
17	900	0.62	0.15
18	900	0.62	0.15
19	900	0.62	0.15
20	900	0.62	0.15

2.2.6 Performance evaluation

The performance of the optimized MBCF and CBCF were evaluated by investigating the surface roughness, cutting temperature and material removal rate during the machining of AISI 304 workpiece using tungsten carbide tool insert. Surface roughness, cutting temperature and material removal rate were measured using the procedures specified by ASTM D7127 and ASTM E1965-19 respectively

3. Results and Discussion

3.1 Characterization of extracted oil

The results of the physiochemical and lubricity related properties of palm kernel oil are presented in Table 5. As shown in Table 5, it can be observed that the viscosity of oil is 10.3 Cst indicates that the oil possesses a good resistance to deformation under shear stress. Also, it is also clear from the result that seed oil have good flash point (171 ºC) as it compares well with conventional oils such as SAE 40 which has a flash point of 260ºC (John, 2009). In addition, the pH of the oil is alkaline (9.9) which indicate good tendency of not corroding metals during machining.

Table 5: Properties of mahogany seed oil

S/N	Properties	Values
1	pH	9.9
2	Kinematic viscosity (Cst) at 40ºC	10.3
3	Flash point (ºC)	171

3.2 Characterization of cutting fluids

The properties of the formulated mahogany oil based cutting fluid (MBCF) and the coventional oil-based cutting fluids (CBCF) are shown in Table 6. In addition, the optimum additives for 20% mahogany oil content include emulsifier (8%), anti-corrosion (6%), biocide (1.6 vol.%) and Anti-foam(1%) while The optimum additives for 20% mineral oil content include emulsifier (4%), anti-corrosion (3%), biocide (0.8 vol.%) and Anti-foam(1%).

Table 6: Characteristics of formulated cutting fluids

S/N	Property	MBCF	CBCF
2	Viscosity at 40% (Cst)	2.54	1.7
3	pH Value at 20% Oil Content	10.32	7.53
4	Stability	Stable	Stable
5	Colour	Light brown	Milky

3.3 Turning operation

The experimental results obtained during the turning operation conducted using MBCF and CBCF are shown in Table 6. Based on the experimental results shown in Table 6, it can be found that the surface roughness, cutting temperature and material removal rate (MRR) of the machining operation carried out using the newly formulated MBCF falls within 0.949-2.568 ꭒm, 32.50-50.30˚C and 1607.38-10202.70mm^3/min respectively. These results indicates that the performance of the MBCF compared favourably with that of CBCF whose surface roughness, cutting temperature and material removal rate (MRR) lies within 0.982-3.337 ꭒm, 34.60-56.70 ˚C and 1625.4-9550.9 mm^3/min respectively as presented in Table 7.

Table 7: Experimental Process Parameters, Results

Run Order	Process parameters			MBCF			CBCF		
	Cutting speed (rev/min	Feed rate (mm/rev)	Depth of cut (mm)	Surface roughness (ʋm)	Cutting Temperature (˚C)	MRR (mm^3/min)	Surface roughness (ʋm)	Cutting Temperature (˚C)	MRR (mm^3/min)
1	700	0.41	0.1	1.527	32.50	1607.38	1.841	39.90	1625.4
2	1100	0.41	0.1	1.502	35.80	2322.66	2.004	36.50	2114.9
3	700	0.82	0.1	1.518	34.80	2944.23	2.028	34.80	2971.3
4	1100	0.82	0.1	1.447	37.50	4181.56	1.834	38.40	3833.1
5	700	0.41	0.2	1.592	34.90	3047.93	2.376	34.60	3111.1
6	1100	0.41	0.2	1.456	37.20	4282.04	2.194	34.60	3981.9
7	700	0.82	0.2	1.460	35.80	5807.30	2.597	36.40	5717.1
8	1100	0.82	0.2	2.346	39.80	10202.70	3.337	46.50	9550.9
9	564	0.62	0.15	1.095	40.50	2573.42	1.696	42.60	2533.2
10	1236	0.62	0.15	0.949	41.50	6182.35	0.982	41.80	6346.0
11	900	0.27	0.15	1.540	42.50	2045.72	0.992	46.10	2068.6
12	900	0.96	0.15	1.420	40.60	7558.71	1.518	42.30	2125.9
13	900	0.62	0.07	1.474	42.70	2170.11	1.607	41.10	3839.7
14	900	0.62	0.23	2.568	50.30	7396.51	2.169	56.70	7457.0
15	900	0.62	0.15	1.420	42.90	4907.97	3.133	42.10	4986.9
16	900	0.62	0.15	1.428	42.70	4842.22	3.127	41.70	4894.8
17	900	0.62	0.15	1.433	42.60	5118.35	3.116	41.50	5131.5
18	900	0.62	0.15	1.434	43.00	5092.05	3.131	42.00	4723.9
19	900	0.62	0.15	1.445	42.80	4618.68	3.128	41.90	4723.9
20	900	0.62	0.15	1.453	42.50	4894.82	3.133	41.60	4986.9

3.3 Analysis of Experimental Results

a. Main effect plots

The results obtained from machining processes were analysed by obtaining the main effect plots which specify the optimal conditions for individual responses. These plots (Figure 4 and 5) were obtained using Minitab 19 software by selecting smaller the better quality characteristics for surface roughness and cutting temperature while larger the better quality characteristics was selected for material removal rate.

i. MBCF

As shown in Figure 4(a), the optimal conditions for surface roughness of MBCF can be obtained using spindle speed (1236.4rev/min), feed rate (0.62mm/rev) and depth of cut (0.15mm). Also, Figure 4(b) revealed that the optimal conditions for cutting temperature of MBCF can be obtained using spindle speed (700rev/min), feed rate (0.41mm/rev) and depth of cut (0.10mm) while Figure 4(c) indicates that optimal conditions for MRR of MBCF can be obtained using spindle speed (1236.4rev/min), feed rate (0.96mm/rev) and depth of cut (0.23mm). Agu et al. (2019) and Abutu et al. (2022) have revealed that any change from these optimal conditions may affect the performance of the cutting fluid during machining operations.

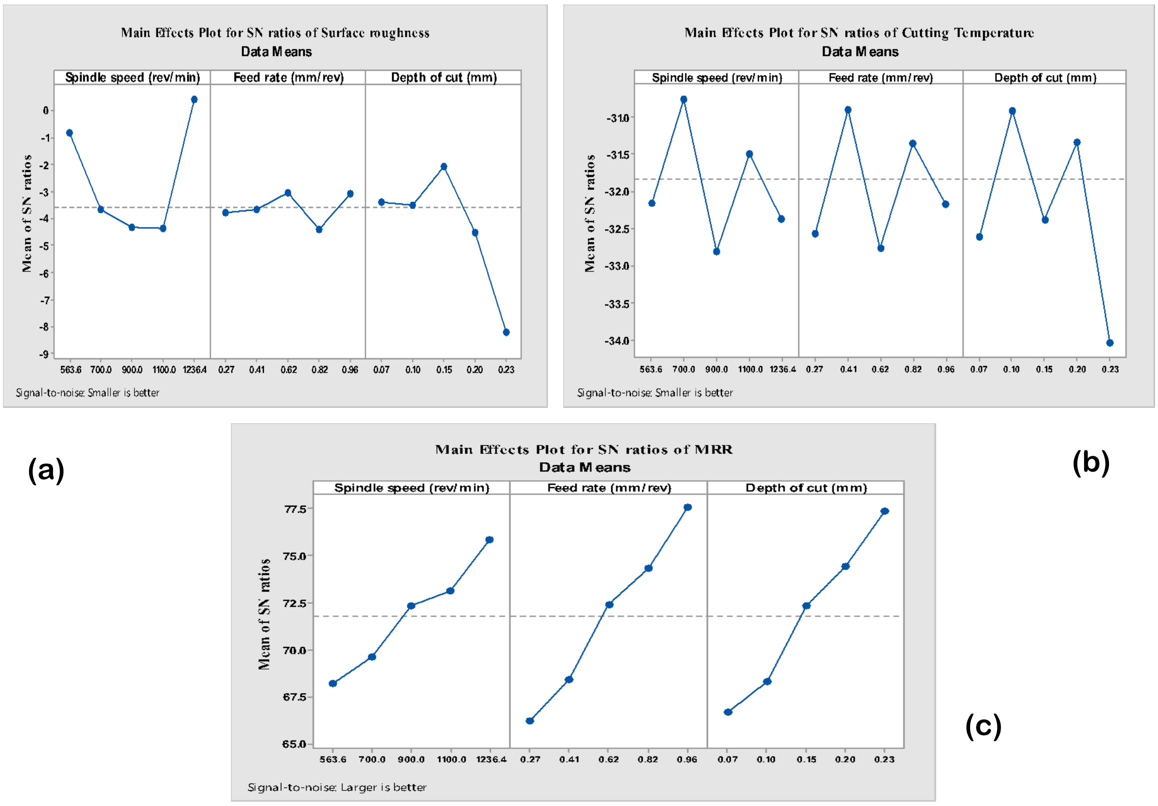

Figure 4: Main effect plots for responses of MBCF (a) Surface roughness (b) Cutting temperature (c) MRR

ii. CBCF

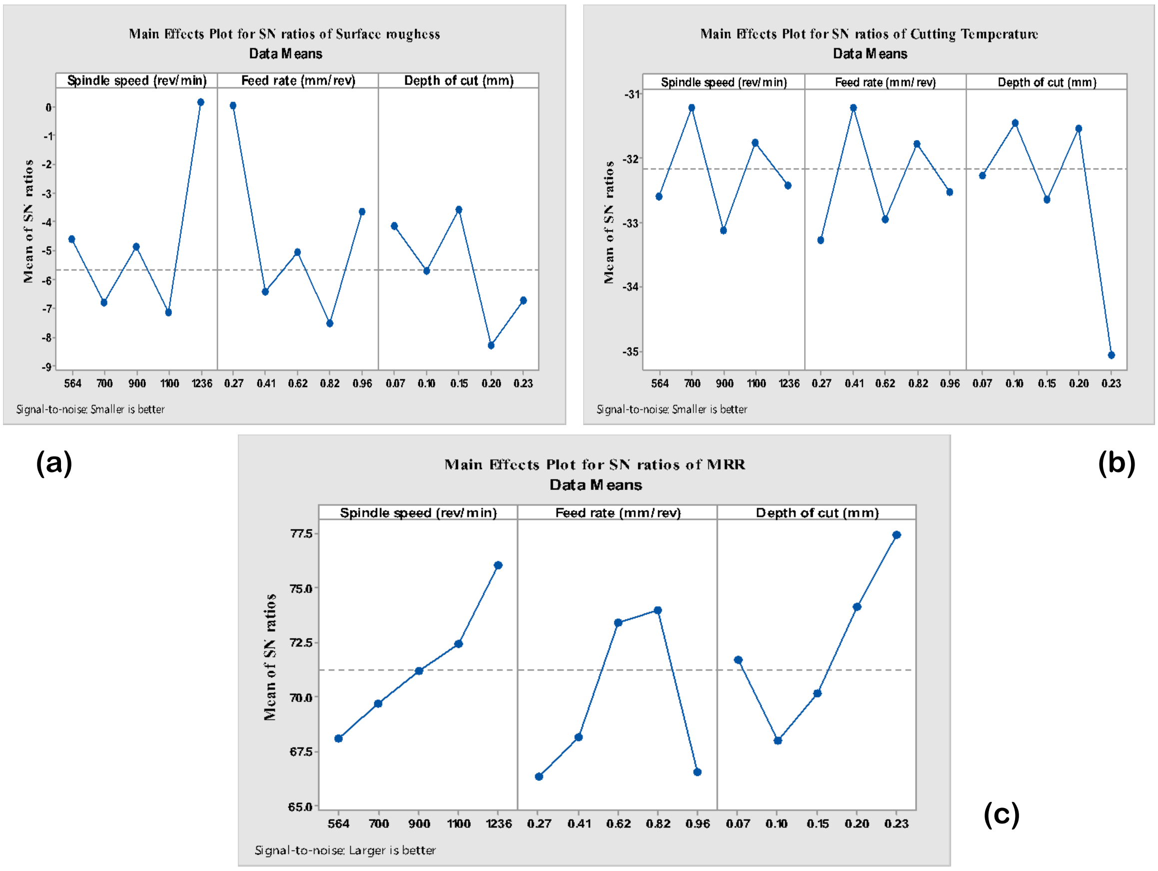

Figure 5: Main effect plots for responses of CBCF (a) surface roughness (b) cutting temperature (c) MRR

As shown in Figure 5(a), the optimal conditions for surface roughness of CBCF can be obtained using spindle speed (1236.4rev/min), feed rate (0.27mm/rev) and depth of cut (0.15mm). Also, Figure 5(b) revealed that the optimal conditions for cutting temperature of CBCF can be obtained using spindle speed (700rev/min), feed rate (0.41mm/rev) and depth of cut (0.10mm) while Figure 5(c) indicates that optimal conditions for MRR of CBCF can be obtained using spindle speed (1236.4rev/min), feed rate (0.82mm/rev) and depth of cut (0.23mm). Any change from these optimal conditions may affect the performance of the cutting fluid during machining operations (Agu et al., 2019 and Abutu et al., 2022).

b. Contour plots

Contour plots were shown in Figure 6 and 7 were used to study the effect of change in response when two most influential input variables are varied and the other variable is kept. These plots were obtained using Minitab 19 software.

i. MBCF

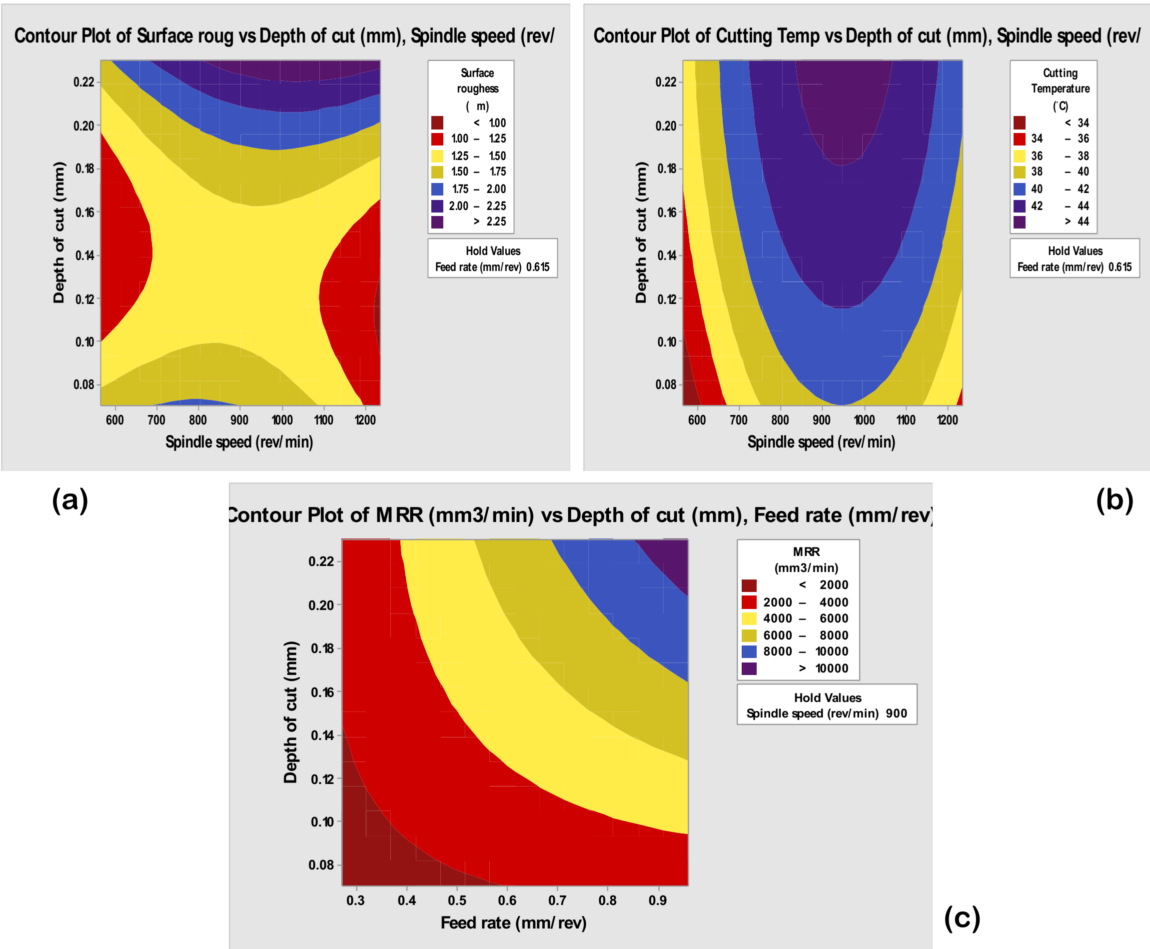

Figure 6: Contour plots for responses of MBCF (a) surface roughness (b) cutting temperature (c) MRR

Figure 6(a), shows how depth of cut and spindle speed exclusively influence the surface roughness of MBCF. It was observed that the surface roughness increases as the spindle speed increases with decreasing depth of cut. Careful observations showed that when the feed rate is kept constant at 0.615mm/rev, a surface roughness of less than 1µm can be achieved using depth of cut of 0.11m and spindle speed of 1210rev/min and vice versa. Also, Figure 6(b) shows how depth of cut and spindle speed exclusively influence the cutting temperature of MBCF. It was observed that the cutting temperature decreases as the spindle speed increases with decreasing depth of cut. Careful observations revealed that when the feed rate is kept constant at 0.615mm/rev, a cutting temperature of less than 34ºC can be achieved using depth of cut of 0.08mm and spindle speed of 590rev/min and vice versa. In addition, Figure 6(c) shows how depths of cut and feed rate exclusively influence the MRR of MBCF. It was observed that the MRR increases as the depth of cut increases with increasing feed rate. Careful observations revealed that when the spindle speed is kept constant at 900rev/min, MRR of greater than 10000mm^3/min can be achieved using depth of cut of 0.22mm and feed rate of 0.9mm/rev and vice versa.

ii. CBCF

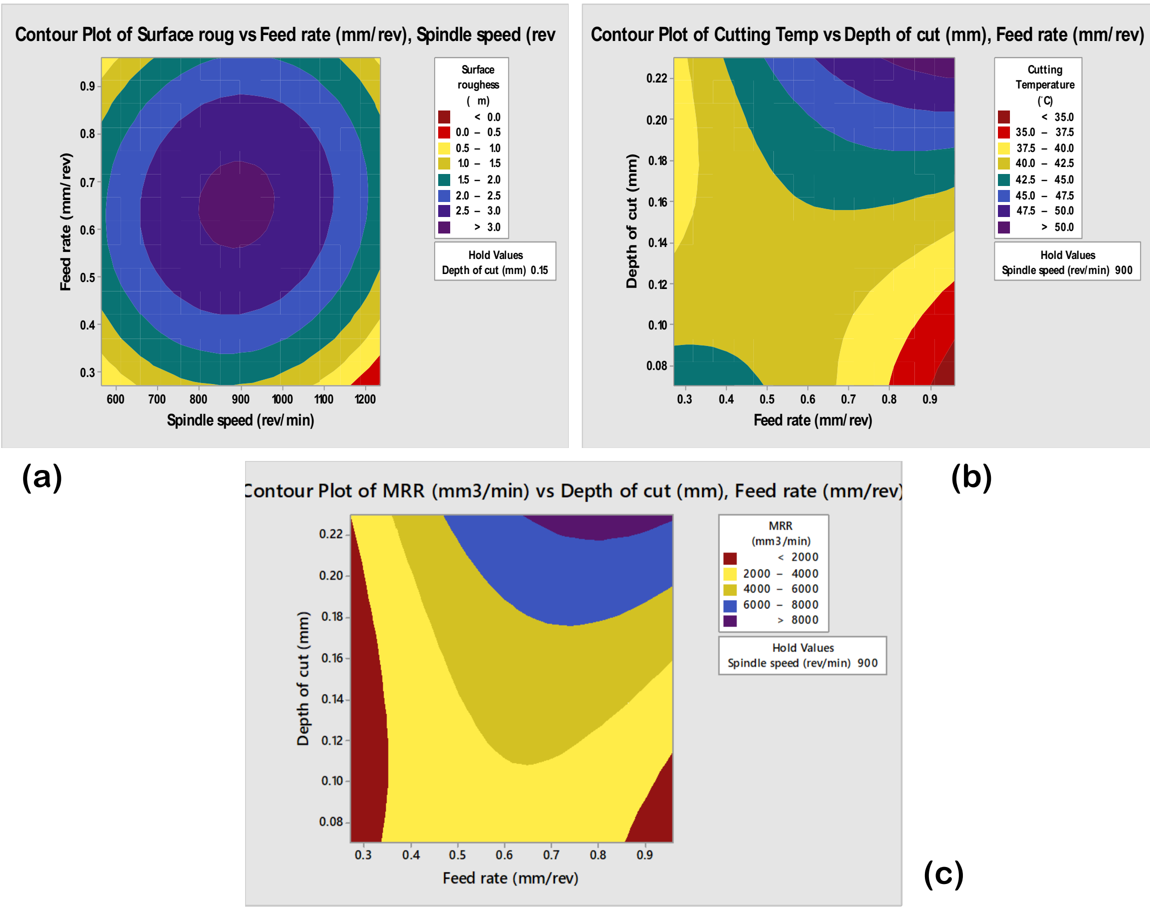

Figure 7: Contour plots for responses of CBCF (a) surface roughness (b) cutting temperature (c) MRR

Figure 7(a) shows how feed rate and spindle speed exclusively influence the surface roughness of CBCF. It was observed that the surface roughness increases as the spindle speed increases with decreasing feed rate. Careful observations showed that when the cutting depth is kept constant at 0.15mm, a surface roughness of less than 0-0.5µm can be achieved using feed rate of 0.3mm/rev and spindle speed of 1210rev/min and vice versa. Also, Figure 7(b) revealed how feed rate and cutting depth exclusively influence the cutting temperature of CBCF. It was observed that the cutting temperature increases as the depth of cut increases with decreasing feed rate. Careful observations showed that when the spindle speed is kept constant at 900rev/min, a cutting temperature of less than 35ºC can be achieved using depth of cut of 0.08mm/rev and feed rate of 0.95mm/rev and vice versa. In addition, Figure 7(c) shows how depths of cut and feed rate exclusively influence the MRR of CBCF. It was observed that the MRR increases as the depth of cut decreases with increasing feed rate. Careful observations showed that when the spindle speed is kept constant at 900rev/min, MRR of greater than 8000mm^3/min can be achieved using depth of cut of 0.14mm and feed rate of 0.3mm/rev and vice versa.

Conclusion

In this work, mahogany seed oil was sourced, extracted and characterised. Two sets of cutting fluids were formulated (mahogany seed oil and mineral oil based cutting fluids), characterized and thereafter, used for turning of AISI 304 austenitic stainless steel using coated tungsten carbide tool insert. Based on the results obtained, the following conclusion can be drawn;

i. The physicochemical related properties of mahogany seed oil proved to be satisfactory and human-friendly as a result, can be adopted as based oil for cutting fluid formulation. Hence, compared well with conventional mineral cutting fluid.
ii. The use of mahogany oil-based cutting fluid (MBCF) in the turning of AISI 304 produced; surface roughness, cutting temperature and material removal rate (MRR) of 0.949-2.568 ϋm, 32.50-50.30 ˚C and 1607.38-10202.70mm^3/min respectively while the use of mineral oil-based cutting fluid (CBCF) produced; surface roughness, cutting temperature and material removal rate (MRR) of 0.982-3.337 ϋm, 34.60-56.70 ˚C and 1625.4-9550.9 mm^3/min respectively
iii. Finally, in the future, type of cutting fluid should be set as an experimental factor along with cutting depth, feed rate and spindle speed so as to statistically evaluate its significance in machining operation.

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