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PERFORMANCE EVALUATION OF CASTOR SEED OIL AND MINERAL OIL BASED CUTTING FLUIDS IN TURNING AISI 1020 MILD STEEL

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Abstract

There is a global challenge with the roles of cutting fluids in machining operations with the setback associated with the use of mineral oil; the desire for eco – friendly, health related hazards elimination, biodegradability, minimized disposal cost and so on cannot be overemphasized. In this study, the focus is on comparing the performance of castor oil based cutting fluid (CBCF) with mineral oil based cutting fluid (MBCF) during turning of AISI 1020 Mild steel workpiece. Castor seed oil was used to formulate the oil-in-water emulsion cutting fluid with characteristics showing viscosity of 0.830 mm^2/s, pH value of 8.47, high stability, corrosion resistant and milky in colour. The FAC shows the ricinoleic acid as 86.43%. Palmitic, (0.72%) and Stearic, (0.85%) are the major saturated fatty acid. Octanoic acid, (0.34%) and Pentanoic acid, (1.38%) are the other fatty acid present. An approximately 94.48% unsaturated fatty acid with main contributors being 86.43% ricinoleic acid, 4.93% oleic acid, 2.97% linoleic acid and 0.15% linolenic acid with others. The S/N ratio for CBCF and MBCF are 800 CS, 0.4 FR and 0.8 doc; and 800 CS, 0.4 FR and 0.6 DOC respectively with R-sq and R-sq(pred) values as 95.52% and 92.83 under the CBCF and lastly 94.33% and 91.25% under the MBCF for surface roughness respectively. The R-sq and R-sq(pred) values are 88.48 % and 81.57 % under the CBCF and lastly 97.39 % and 95.82 % under the MBCF for tool wear respectively.

***Keywords**: Turning, Castor seed oil, Cutting fluid, Taguchi, Surface roughness, Tool wear*

1.0 Introduction

Metal working fluids (MWFs) or metal cutting fluids (MCFs) act as coolant as well as lubricant during machining due to the enormous heat as a result of the friction between the cutting tool and the workpiece material, and between the tool face and the chips gliding over it (Abu, 2001). Cutting fluids minimize the effect of friction and the resultant heat on tool life, reducing work piece thermal deformation, enhances surface finish, chips removal from the cutting zone during machining, machining process efficiency, enhancing surface integrity, cutting force reduction and also used as a means of conducting heat from the cutting zone, (Abu, 2001). Friction and heat are generated between the cutting tool and the workpiece and as well between the cutting tool and the chips which leads to increase in temperature at the cutting zone during cutting operation (Trent and Wright, 2000). Mineral oils are petroleum-based oil and are the most commonly used cutting fluid. They are highly toxic, non-biodegradable cutting fluids which have huge negative impact on environment and personnel health (Lawal *et al*., 2012). Apart from the irritation or allergy caused by these fluids, microbial toxins are generated by bacteria and fungi present mostly in water-soluble cutting fluids and are very harmful to the operators (Onuoha et al., 2016). The contributions of cutting fluids to machining process were investigated and the following were found out; first, it acts as lubricant by friction reduction and then reduces the heat generated. Secondly the cutting fluid must also act as an effective coolant, because frictional heating cannot be completely eliminated. Finally, it washes away the chips to counteract the tendency of the work material to weld the tool under heat and pressure by acting as an anti-weld agent (Ademoh *et al*., 2016). Due to the negative effect of the conventional cutting fluids on the environment and the human being (machinist), there is more focus on the use of environmentally friendly cutting fluids such as the bio and gaseous cutting fluids. Unlike conventional mineral based oils metal working fluids, vegetable oils lubricants are biodegradable and non-toxic (Yakubu and Bello, 2015). With the introduction of ISO1400 environmental series legislation, industries users of lubricants are encouraged to change metal cutting fluids to more environmentally friendly substances (Awode *et al*., 2020). Researchers are looking inward towards the non – edible plant oils like soya beans oil, neem seed oil, jatropha oil, rubber seed oil and so on as alternatives to the conventional metal cutting fluids. Castor seed oil has useful properties like that of the soya bean, linseed and so on. Castor seed oil has numerous industrial applications which include biodiesel and bio-lubricants, paints, soap making and so on (Osayi *et al*, 2021). These plants oil performance is as good as or even better in some cased than the mineral oil based cutting fluids. This study's main focus is the utilization of castor seed oil in formulating oil–in-water emulsion cutting fluid which is environmentally friendly and biodegradable for turning AISI 1020 Mild Steel using Taguchi experimental design. Taguchi design of experiment was chosen for this study due to its user friendly and effectiveness with minimum error variance and better precision in considering the overall main factor effects.

2.0 Materials and Method

2.1 Materials

2.1.1 Cutting Fluid Materials

In the study, the materials for the formulation of the cutting fluid include castor seed oil (CSO) obtained from the Agri Energy Nigeria, sourced from Technology Incubation Centre (TIC) farm centre, Kano state, other materials include distilled water and additives (antioxidant, emulsifier, biocide and locally prepared anti-corrosive agent using onions extract). Mineral soluble oil (MSO) sourced from the Engineering Tools market, Onitsha, Anambra state.

2.1.2 Turning Process Materials and Equipment

The workpiece material for the orthogonal turning operation for this research is AISI 1020 Mild Steel rods of 600 mm length and 50 mm diameter. The cutting tool and the tool holder used for this research are CNMG120408-QR GP1225 tungsten carbide insert and PCLNR 2020 K12 turning tool insert holder respectively. Coating of cutting tools enhances or increases its wear and oxidation resistance; reduces friction; and also increases resistance to metal fatigue and thermal shock (Harinath *et al*., 2014). The turning experiments was carried out under wet cutting conditions on a model MOOL lathe 37475 manufactured by MEUSER. Digital Surface Roughness Tester and the Dino-Capture 2.0 Version 1.5.28A Versatile Digital Microscope were used to measure the surface roughness and tool wear respectively.

2.2 Methodology

2.2.1 Determination of the Physicochemical Properties and Fatty Acid Composition (FAC)

The physicochemical properties of the Castor seed oil (CSO) which were determined at the Department of Water

Resources, Aquaculture and Fisheries Technology (WAFT) Laboratory, School of Agriculture and Agricultural Technology (SAAT), Federal University of Technology, Minna, Niger State. These parameters include the pH value, the Iodine Value, Acid Value (mgKOH/g) (ASTM D664), Specific Gravity (ASTM D4052), Kinematic Viscosity @ 40OC (ASTM D445), Flash point (ASTM D93), Saponification value (ASTM D558), Pour Point, Peroxity (ASTM DD5348), Fatty acid composition (FAC). The pH digital meter was used to determine the pH value while the Gas Chromatography was employed in determining the Fatty Acid Composition (FAC) at the American University of Nigeria, Yola, Adamawa State.

2.2.2 Gas Chromatography and Mass Spectrometer

The analysis of the Fatty Acid Composition (FAC) was determined using Gas Chromatography and Mass Spectrometer instrument GC-MS-QP2010 Shimadzu system from Japan, using a gas chromatograph interface. The machine operating conditions were as follows: Column and injection temperatures of 70 0C and 250 0C respectively. Helium gas was used as a carrier gas. Column flow was 1.80 ml/min with total flow of 40.8 ml/min at linear velocity of 49.2 cm/sec and pressure of 116.9 kpa. This process is consistent with the work of (Awode *et al*., 2020).

2.2.3 Formulation of Castor Seed Oil Based Cutting Fluid

Additives are one of the most important constituents in the development of metal working fluids. The methods used by researchers (Agu *et al*., 2019; Lawal *et al*., 2014 and Onuoha *et al*., 2016) were adopted. The additives include: (i) Anti-oxidant (ii) Anti-corrosion (iii) Emulsifier and (iv) Biocide. Oil with additives to water ratio of 1:9 was employed. Except the Anti-corrosion agent, the other additives were prepared in the Chemical Engineering Laboratory of the Federal University of Technology, Minna. Onion extract (boiled) sourced locally from Minna, with honey, acetone and diluted tetraoxosulphate (vi) acid with percentage compositions of 25%, 40%, 30% and 5% respectively was used as the anti-corrosion agent. Extract of Onions contains quercetin and is responsible for the corrosion inhibitory action and it belongs to flavonoid group which has anti-inflammatory and antioxidant properties (Sulaiman *et al*., 2012). Acetone acts as the solvent and hydrogen peroxide is often used as an anti-infective agent. The preparation approach was based on the method adopted by the following authors in Table 1

Table 1: Experimental Formulas for the Development of the Non – Edible Vegetable Oil Based Fluids (Agu *et al.*, 2019; Lawal *et al.*, 2014; Onuoha *et al.*, 2016).

Formulas	Emulsifier	Anti-Corrosion	Anti-Oxidant	Biocide
A	9.35%	10.61%	0.64%	0.97%
B	11.81%	3.67%	0.76%	0.64%
C	8.31%	2.93%	0.95%	0.99%

The mixture of oil and the additives in a measuring cylinder and the mixing was done by a mechanically powered stirrer for about 15 minutes. The materials for the formulations apart from the additives are beaker, mini and medium test tubes, distilled water, filter paper, bowls and dishes, improvised mechanical stirrer, drilling machine, electronic scale and the stop watch. The ratio of 1:9 for the oil with additives to water was used for the formulation of the castor seed oil based cutting fluid. Figure 1 shows the improvised for mixing the oil with additives and distilled water. It was observed that many of the characteristics of cutting fluid are mutually exclusive (Lawal *et al*., 2013). Three samples were developed from the non – edible vegetable oil according to the formulas adopted by Agu *et al*., 2019, Lawal *et al*., 2014 and Onuoha *et al*., 2016. The best for each of the oil-based fluid samples were chosen based on their pH values, viscosities, anti-corrosion and stability levels.

Figure 1: Mechanical Powered Stirring Oil-in Water Mixture

2.2.4 Characterization of the Formulated Castor Seed Oil Based Cutting Fluid

(i) pH Value: The pH values of the Castor oil based cutting fluid (CBCF) was measured using pH meter in the Chemical Laboratory of Federal University of Technology, Minna, Nigeria. This was carried out in accordance to ASTM standards.

(ii) Viscosity: Viscosity is a measure of a fluid's resistance to flow or change in shape. It describes the internal friction (molecular makeup) of a moving fluid. An acceptable cutting fluid should have moderate viscosity which enables pumping from the sump through hoses and pipes to the cutting zone.

(iii) Corrosion Test: The corrosion level of the formulate cutting fluid was determined based on the ASTM D4627 standard using cast iron chips on filter paper as the method adopted by (Awode *et al*., 2020). Then, the iron chips were removed and the filter paper was carefully rinsed with clean water and was found to be corrosion spot free.

(iv) Stability Test: The formulated cutting fluids were evaluated using a visual transparency within a period of 72 hours (3 days) at room temperature (250C) for stability as to separation of water and oil in a graduated 1000ml test tube. They were found to be highly stable.

2.2.5 Machining Operation Methodology

In the turning operation, AISI 1020 Mild Steel workpiece was employed. Mild steel which is a form of plain-carbon steel with low carbon content is the most commonly and widely used form of steel. The machining parameters which were taken as the experimental design factors are (i) cutting speed (A), (ii) the feed rate (B), (iii) the depth of cut (C); the cutting fluids being investigated and evaluated also had effects on the surface roughness of the finished workpiece and the rate of wear of the cutting tool.

3.0 Results and Discussion

3.1 Physicochemical Properties of Castor Oil Sample

The physicochemical properties of the Castor seed oil (CSO) are shown in Table 2.

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Table 2: Physiochemical Properties of Castor Seed Oil (CSO)

Physiochemical properties	CSO Sample	Physiochemical properties	CSO Sample
Colour	Thick Gold.	Pour Point (^{0}C)	3
pH value	5.84	Peroxide Value (meq/kg)	2.42
Acid Value (mgKOH/100g)	6.79	Iodine Value (g/100g)	84.36
Specific Gravity	0.951	Cloud Point (^{0}C)	6
Saponification (mgKOH/100g)	165.32	Free Fatty Acid (FFA) (mgKOH/100g)	13.58
Flash Point (^{0}C)	155	Viscosity @40^{0}C (mm^2)/s	22.81

3.2 Gas Chromatography Mass Spectrometer (GC-MS) Analysis.

For the fatty acid composition results of castor seed oil (CSO), the ricinoleic acid comprises about 86.43% of the total fatty acid composition. Palmitic, (0.72%) and Stearic, (0.85%) are the major saturated fatty acid. Octanoic acid, (0.34%) and Pentanoic acid, (1.38%) are the other fatty acid present in the castor seed oil. An approximately 94.48% unsaturated fatty acid with main contributors being 86.43% ricinoleic acid, 4.93% oleic acid (monounsaturated), 2.97% linoleic acid (polyunsaturated), 0.15% linolenic acid and others. According to (Kazeem *et al*.,2018), a correlation exists between linolenic acid content and the stability of the seed oil. The stability is highest for the oils containing the smallest amount of linolenic acid; hence, this explains why castor oil stability is high compared to any other formulated oil.

Table 3: GCMS Test Analysis (Fatty Acid Composition Castor Seed Oil)

Types of Acid		Symbols	Fraction (%)
Names	Formulas / Molecular Weight		CSO
Pentanoic Acid	$CH_3(CH_2)_3COOH$ (102.13g/mol)	C 5:0	1.38
Octanoic Acid	$CH_3(CH_2)_6COOH$ (144.21g/mol)	C 8:0	0.34
Palmitic Acid	$CH_3(CH_2)_{14}COOH$ (256.40g/mol)	C 16:0	0.72
Stearic Acid	$CH_3(CH_2)_{16}COOH$ (284.48g/mol)	C 18:0	0.85
Oleic Acid	$CH_3(CH_2)_7CH = CH(CH_2)_7COOH$ (282.47g/mol)	C 18:1	4.93
Linoleic Acid	$CH_3(CH_2)_4CH= CHCH_2CH= CH(CH_2)_7COOH$ (280.45g/mol)	C 18:2	2.97
Linolenic Acid	$CH_3CH_2CH= CHCH_2= CHCH_2= CH(CH_2)_7CO_2H$ (278.43)	C 18:3	0.15
Ricinoleic Acid	$C_{18}H_{34}O_3$ (298.46g/mol)	C 18:1	86.43
Others			2.23
Saturated (Sum)			3.29

Unsaturated (Sum)	94.48

From the Table 2, the castor seed oil with viscosity of 22.81 mm^2/s at 40^0C in terms of easy pumping and penetrations through the cutting zone is attainable and in terms of lubricity according to Demirbas, (2005). The pH value of castor seed oil which is 5.84 is comparable to that of rubber seed oil which is 5.42 based on Osayi *et al,* (2021) findings. Specific gravity of castor seed oil which is 0.951 is seen to be in agreement with that of rubber seed oil with a value of 0.91 according to the work of Nagaraj and Mukta (2004).

3.3 Characterization of the Formulated Vegetable Oil Based Cutting Fluid (CBCF)

The adoption of Agu *et al,* (2019) for the preparation of sample A whose values of 8.47 for pH value and viscosity of 0.830 mm2/s was chosen for this study. This viscosity value was seen to be consistent with the work of (Awode *et al*, 2020). According to (Alves and Aliveira, 2008), alkalinity of 8.3 to 11.0 is the required value that should be maintained for a cutting fluid. Table 4 shows the adopted pH Values of the three-castor oil based cutting fluid samples. According to (Byers, 2006), pH values between 8.0 and 9.3 of emulsion cutting fluids are good as metal cutting fluids. According to (Ademoh *et al*.,2016), pH values below 7.0 tends to corrode the metal while too much higher pH values affect the operator.

Table 4: Viscosity and pH Values of the Formulated Castor Oil Based Cutting Fluid

Properties	Viscosity (mm^2/s)	pH Values	Stability	Corrosion Level	Colour
Sample A	0.830	8.47	95.5	Good	Milkish
Sample B	0.823	8.16	94.0	Good	Milkish
Sample C	0.827	8.22	94.5	Good	Milkish

The sample A as shown in the above table showing the characteristics of the oil-in-water emulsion was used in the cutting process. Both the Castor Oil Based Cutting Fluid (CBCF) and the Mineral Oil Based Cutting Fluid (MBCF) were compared during the turning operation.

3.4 Machining Process Results

Taguchi experimental technique was used in the experimental design layout and was employed to obtain the experimental process parameters and results for the two cutting fluids (CBCF and MBCF). With the three input parameters of cutting speed (rev/min), feed rate (mm/rev) and depth of cut (mm) at three levels (800rpm, 1000rpm and 1250 rpm) for spindle speed, (0.4mm/rev, 0.5mm/rev and 0.6 mm/rev) for feed rate and (0.6mm, 0.8mm and 1.0mm) for depth of cut respectively.

3.5 Signal to Noise Ratio for Surface Roughness and Tool Wear

For the surface roughness and tool wear, the characteristics equations for the signal to noise ratio (S/N Ratio) for the two cutting fluids are the smaller the better for surface roughness and tool wear. The data and their corresponding S/N Ratios of the responses for each cutting fluid are shown in the Table 5.

Table 5: Experimental Values of Process Parameters.

Factors	Units	Level 1	Level 2	Level 3
Spindle Speed	Rpm	800	1000	1250

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Feed Rate	mm/rev	0.4	0.5	0.6
Depth of Cut	Mm	0.6	0.8	1.0

Table 6: Taguchi Experimental Design Matrix (CBCF & MBCF)

Trial No.	Cutting Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	800	0.4	0.6
2	800	0.5	0.8
3	800	0.6	1.0
4	1000	0.4	0.8
5	1000	0.5	1.0
6	1000	0.6	0.6
7	1250	0.4	1.0
8	1250	0.5	0.6
9	1250	0.6	0.8

3.6 Experimental Tests' Results under Castor Seed and Mineral Oil Based Cutting Fluids

Experimental tests were carried out according to the above L_9 (3^3) array experimentation design to determine the surface roughness and the tool wear under the castor seed oil-based cutting and mineral oil based cutting fluids.

Table 7: Experimental Tests' Results and Signal / Noise Ratio for Surface Roughness and Tool Wear (CBCF and MBCF)

	Castor oil Based Cutting Fluid (CBCF)				**Mineral oil Based Cutting Fluid (MBCF)**			
	Surface Roughness (µm)		**Tool Wear (mm)**		**Surface Roughness (µm)**		**Tool Wear (mm)**	
S/NO	Ra **(µm)**	**S/N Ratio**	**T.W (mm)**	**S/N Ratio**	Ra **(µm)**	**S/N Ratio**	**T. W. (mm)**	**S/N Ratio**
1	0.271	11.3406	0.214	13.3917	0.275	11.2133	0.224	12.9950
2	0.317	9.9788	0.237	12.5050	0.347	9.1934	0.239	12.4320
3	0.346	9.2185	0.252	11.9720	0.375	8.5194	0.258	11.7676
4	0.287	10.8424	0.250	12.0412	0.328	9.6825	0.252	11.9720
5	0.326	9.7356	0.274	11.2767	0.393	8.1121	0.279	11.0879
6	0.374	8.5426	0.254	11.9033	0.384	8.3134	0.250	12.0412
7	0.347	9.1934	0.284	10.9336	0.358	8.9223	0.288	10.7820
8	0.387	8.2458	0.259	11.7340	0.373	8.5658	0.267	11.4698
9	0.402	7.9155	0.263	11.6009	0.441	7.1112	0.278	11.1191

3.6.1 Main Effect Plots (Castor Seed Oil Based Cutting Fluid).

The main effect plots of signal to noise ratio (S/N Ratio) showed in Figure 2 and Figure 3 for surface roughness and tool wear respectively under Castor Seed Oil Based Cutting Fluid. For surface roughness, the optimal turning parameters are 800rpm for spindle speed (level 1), 0.4mm/rev for feed rate (level 1) and 0.8mm for the depth of cut (level 2) while for the Tool Wear, the optimum values are 800rpm for spindle speed (level 1), 0.4mm/rev for feed rate (level 1) and 0.6mm for depth of cut (level 1) as shown in Figure 3.

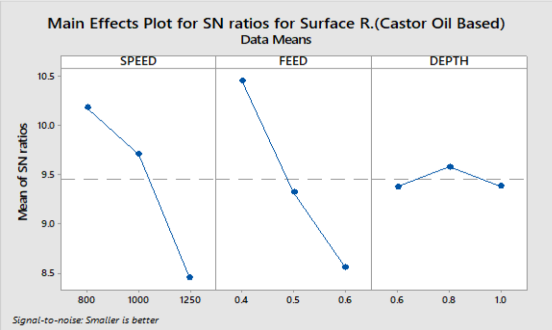

Figure 2: Main Effect Plot for S/N Ratio for S. R

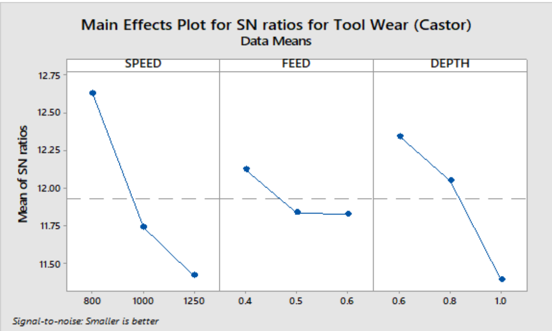

Figure 3: Main Effect Plot for S/N Ratio for T.W.

3.6.2 Main Effect Plots (Mineral Oil Based Cutting Fluid)

The main effect plots of S/N Ratio for surface roughness and tool wear under Mineral Oil Based Cutting Fluid are shown in Figure 4 and Figure 5 respectively.

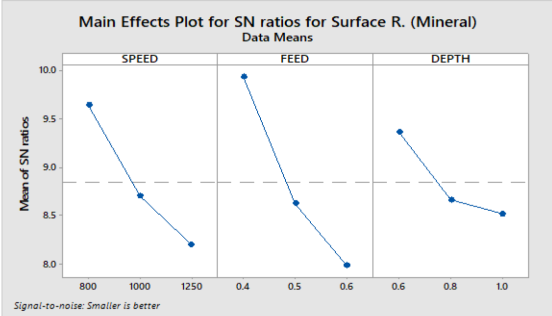

Figure 4: Main Effect Plot for S/N Ratio for S. R.

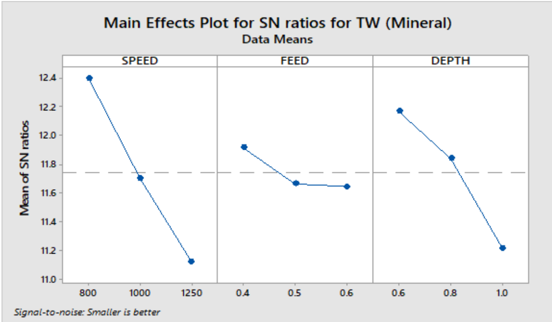

Figure 5: Main Effect Plot for S/N Ratio for T.W

The parameters are 800rpm (level 1), 0.4mm/rev (level 1) and 0.6mm (level 1) for both surface roughness and tool wear under the MBCF as shown in Figures 4 and 5.

3.5.3 ANOVA Analysis (Castor Seed Oil Based Cutting Fluid).

Table 8: Analysis of Variance (ANOVA) of Means for Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindle Speed	2	0.007313	0.007313	0.003656	28.79	46.92%
Feed Rate	2	0.007909	0.007909	0.003954	31.14	50.74%
Depth of Cut	2	0.000113	0.000113	0.000056	0.44	0.73%
Residual Error	2	0.000254	0.000254	0.000127	1.0	1.63%
Total	8	0.015588				

The significant effects of each parameter are as follows: Cutting Speed (46.92%), Feed Rate (50.74%) and Depth of Cut (0.73%). From these results, feed rate has more significant impact.

Surface R. = 0.0133 + 0.000152 Cutting Speed + 0.3617 Feed Rate - 0.0108 Depth of Cut.

Surface R. = 0.0133 + 0.000152 (800) + 0.3617 (0.4) – 0.0108 (0.8) = 0.2709 µm

R – sq = 95.52%, R – sq (adj) = 92.83%.

Table 9: Analysis of Variance (ANOVA) of Means for Tool Wear

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindle Speed	2	0.001881	0.001881	0.000940	17.97	57.42%
Feed Rate	2	0.000098	0.000098	0.000049	0.94	2.99%
Depth of Cut	2	0.001193	0.001193	0.000596	11.39	36.42%
Residual Error	2	0.000105	0.000105	0.000052	1.0	3.21%
Total	8	0.003276				

As shown in Table 9, the significant effects of each parameter are as follows: Spindle Speed (57.42%), Feed Rate (2.99%) and Depth of Cut (36.42%). From these results, the spindle speed has more significant impact on the tool wear followed by the depth of cut.

TOOL WEAR = 0.1050 + 0.000075 Cutting Speed + 0.0350 Feed Rate + 0.0683 Depth of Cut.4.8

TOOL WEAR = 0.1050 + 0.000075 (800) + 0.0350 (0.4) + 0.0683 (0.6) = 0.2200 mm

R – sq = 88.48%, R – sq (adj) = 81.57%.

3.6.4 ANOVA Analysis (Mineral Oil Based Cutting Fluid).

ANOVA statistics as shown in the Table 10 and Table 11 were used to study the significance of the input parameters on the surface roughness and tool wear.

Table 10: Analysis of Variance (ANOVA) of Means for Surface Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindle Speed	2	0.005198	0.005198	0.002599	28.21	30.61%
Feed Rate	2	0.009755	0.009755	0.004877	52.95	57.67%
Depth of Cut	2	0.001777	0.001777	0.000888	9.65	10.51%
Residual Error	2	0.000184	0.000184	0.000092	1.0	1.09%
Total	8	0.016914				

As shown in Table 10, the significant effects of each parameter are as follows: Spindle Speed (30.61%), Feed Rate (57.67%) and Depth of Cut (10.51%). From these results, feed rate has more significant impact on the surface roughness followed by the spindle speed and then the depth of cut. The regression equation is as follows:

Surface R. = - 0.0282 + 0.000128 Spindle Speed + 0.3983 Feed Rate + 0.0783 Depth of Cut.4.13

Surface R. = - 0.0282 + 0.000128 (800) + 0.3983 (0.4) + 0.0783 (0.6) = 0.2805 µm

R sq = 94.53%, R sq (adj) = 91.25%.

Table 11: Analysis of Variance (ANOVA) of Means for Tool Wear.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindle Speed	2	0.002131	0.002131	0.001065	737.62	61.27%
Feed Rate	2	0.000094	0.000094	0.000047	32.38	2.70%
Depth of Cut	2	0.001251	0.001251	0.000625	433.00	35.97%
Residual Error	2	0.000003	0.000003	0.000001	1.0	0.86%
Total	8	0.003478				100%

The effects of each parameter are as follows: Spindle Speed (61.27%), Feed Rate (2.70%) and Depth of Cut (35.97%). From these results, Spindle Speed has more significant impact.

TOOL W.= 0.1008+ 0.000083 Spindle Speed + 0.0350 Feed Rate + 0.07083 Depth of Cut.

TOOL WEAR = 0.1008 + 0.000083 (800) + 0.0350 (0.4) + 0.07083 (0.6) = 0.2237 mm.

R sq = 97.39%, R sq (adj) = 95.82%.

Table 12: Predicted Values of the Responses under the CBCF and MBCF.

Surface Roughness (µm) (CBCF)	Surface Roughness (µm) (MBCF)	Tool Wear (mm) (CBCF)	Tool Wear (mm) (MBCF)
0.2709	0.2805	0.2200	0.2237

3.6.5 Contour Plot (Castor Seed Oil Based Cutting Fluid).

Indication from Figure 6 shows that the highest surface quality is in the region of the thick blue. This occurs at both lower values of speed and feed. Lowest tool wear occurs at lower left corner of the plots (thick blue) at lowest values of cutting speed and depth of cut as shown in Figure 7.

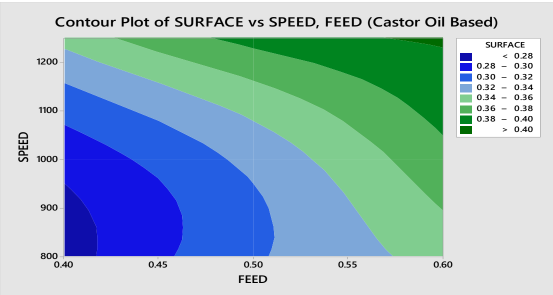

Figure 6: Contour Plots for Surface R.

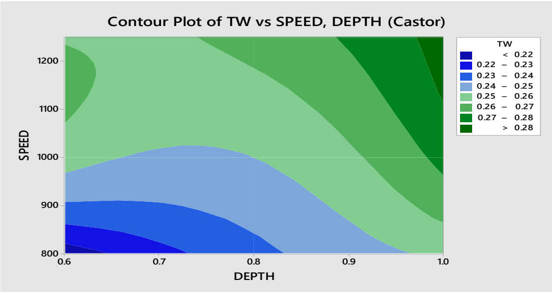

Figure 7: Contour Plots for Tool Wear

3.6.6 3D Surface Plot (Castor Seed Oil Based Cutting Fluid)

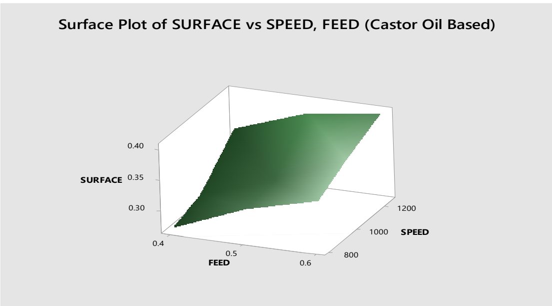

Figure 8: 3D Surface graphs for Surface R.

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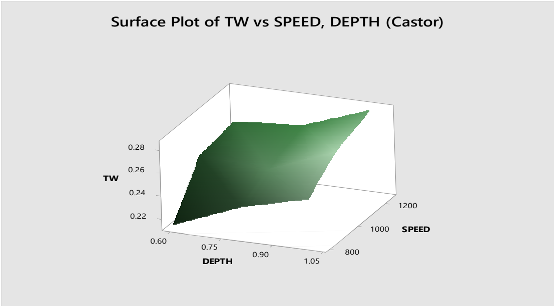

Figure 9: 3D Surface graphs for Tool Wear

From the 3D surface plots for surface roughness and tool wear in Figure 8 and Figure 9, the surface roughness and tool wear decreases with decrease in both speed and the feed rate; and both speed and the depth of cut which is in agreement with the contour plots.

3.6.7 Contour Plots (Mineral Oil Based Cutting Fluid).

The Contour Plot shows the effect of the two most influential parameters on the surface roughness and the tool wear. Figure 10 and Figure 11 indicates that the lowest surface roughness (lightest green) and tool wear (thick blue) are the down left corner and at both lowest values of speed and feed; and at lowest values of cutting speed and depth of cut.

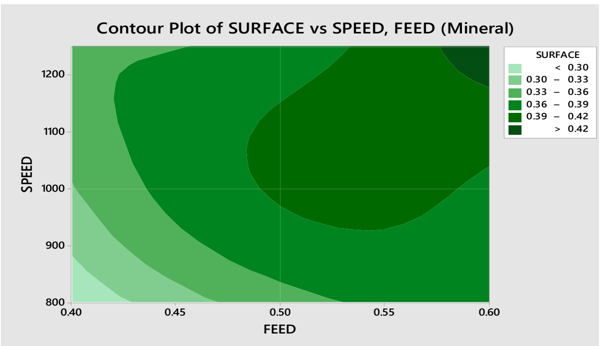

Figure 10: Contour Plots for Surface R.

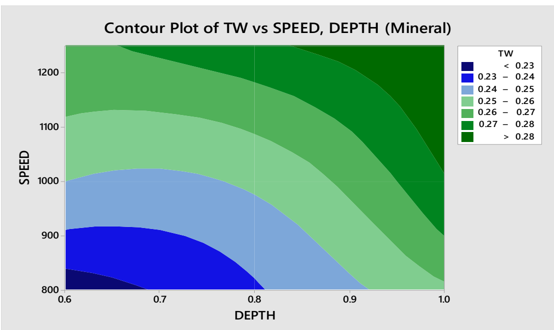

Figure 11: Contour Plots for T.W.

3.6.8 3D Surface Plot (Mineral Oil Based Cutting Fluid).

From the 3D surface plots for surface roughness and tool wear in Figure 12 and Figure 13, the surface roughness decreases with decrease in both speed and the feed rate while as the depth of cut and the spindle speed decreases, the tool wears decrease.

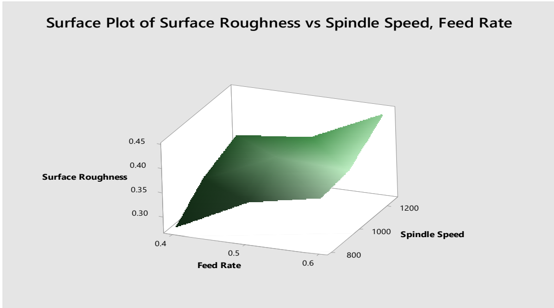

Figure 12: 3D Surface graphs for Surface R.

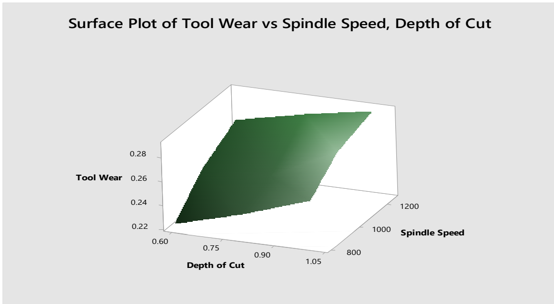

Figure 13: 3D Surface graphs for Tool Wear

4.0 Conclusions

This research presents a comparative study of oil in water cutting fluid from castor seed oil based cutting fluid which has been formulated and performance evaluation in terms of surface roughness and tool wear were conducted as compared to the mineral oil based cutting fluid. The physicochemical properties and fatty acid composition (FAC) of the sourced vegetable (castor seed) oil were determined and they were found to be completely consistent with the various existing seed oil. The formulation of the vegetable oil based cutting fluid was carried out and characterized. This castor seed oil-based fluid was found to be biodegradable, renewable and eco – friendly cutting fluid. The performance evaluation from the orthogonal optimal turning parameters for surface roughness under the CBCF and

MBCF shows predictive values as 0.2709 µm (800 rpm at level 1, 0.4 mm/rev at level 1 and 0.8 mm at level 2) and 0.2805 µm (800 rpm at level 1, 0.4 mm/rev at level 1 and 0.6 mm at level 1) respectively. From ANOVA, feed rate is the main influencing parameter followed by the spindle speed with percentage contributions of 50.24% and 46.92% under the CBCF and then 57.67% and 30.61% under the MBCF respectively. The R-sq and R-sq(pred) values are 95.52% and 92.83 under the CBCF and lastly 94.33% and 91.25% under the MBCF respectively for surface roughness. For the tool wear under the CBCF and MBCF, it shows predictive values of 0.2200 mm and 0.2237 mm respectively. Both at 800 rpm spindle speed at level 1, 0.4 mm/rev feed rate at level 1- and 0.6-mm depth of cu at level 1 under the CBCF and MBCF cutting environment. ANOVA shows that spindle speed is the main influencing parameter followed by the depth of cut with percentage contributions of 57.42% and 36.42% under the CBCF and then 61.27% and 35.97% under the MBCF respectively. The R-sq and R-sq(pred) values are 88.48 % and 81.57 % under the CBCF and lastly 97.39 % and 95.82 % under the MBCF respectively for tool wear. This shows that minimal surface roughness and tool wear is achievable under the castor seed oil-based fluid when performing orthogonal turning of AISI 1020 mild steel using coated carbide cutting tool compared to mineral oil based cutting fluid. This research attest to the fact that Onions extract has corrosion inhibitive potentials in metal cutting fluid development. The reliability of the results was confirmed by carrying out confirmation test using the regression equations. The percentage error was found to be between 0.13% and 3.08% for the two cutting fluids.

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