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Evaluation and Multi-Objective Optimisation of Cutting Parameters in Turning of AISI 1020 Mild Steel using Formulated Cutting Fluid

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Abstract: *Input parameter like the cutting fluid is one of the requirements for minimal surface roughness, cutting temperature, tool wear and optimal material removal rate coupled with improved machinability and productivity. The evaluation of the optimal factors of surface roughness, material removal rate, cutting temperature and tool wear in the turning of AISI Mild Steel with the use of eco-friendly fluids. Concerns has been raise globally about the non - biodegradability and non-recyclability of the conventional fluids in the research space. This prompted the research interest in replacing the mineral oil based fluids with eco-friendly cutting fluid such as castor seed oil based cutting fluid (CBCF). The locally sourced castor seed oil was investigated for its physiochemical properties as well as its fatty acid composition (FAC). The cutting fluid was formulated using ratio 1:9 of oil with additives to distilled water and then characterized. In turning of AISI 1020 Mild Steel, the evaluation of surface roughness, material removal rate, cutting temperature and tool wear under the CBCF compared to the mineral oil based cutting fluid (MBCF) were carried out using Taguchi experimental design and Grey Relational Analysis (GRA) for multi-response optimization. The formulated cutting fluid showed pH value of 8.47, viscosity of 0.830* mm^2/s*, good resistance to corrosion, good stability and milkfish in colour. From the GRA, the multi-response optimal factor combination under the CBCF is (1250 rev/min) spindle speed, (0.6 mm/rev) feed rate and (1.0 mm) depth of cut, all at level 3 while under the MBCF, it also shows (1250 rev/min) spindle speed, (0.6 mm/rev) feed rate and (1.0 mm) depth of cut all at level 3. The parameters from Taguchi and GRA results are in agreement with results from other vegetable oil based fluids and this study also contributes and improves the science of machining.*

Keywords: *Turning, Castor Seed Oil, Cutting Temperature, Material Removal Rate, Surface Roughness, Tool Wear, Taguchi, Multi-objective Optimization, GRA.*

1. INTRODUCTION

Metal working fluids (cutting fluids) has become a major component in the metal cutting industry today. Lubrication of the chip-tool, tool-workpiece interfaces, heat removal from the workpiece and cutting zone, flushing out of chips from the cutting zone and corrosion inhibiters are some of the traditionally responsibilities of cutting fluids. With all these functions as the justification for the use of cutting fluids, their primary functions are lubrication and cooling [1]. Cutting performance is normally improved with the application of cutting fluids or coolants in all machining operations. The contributions of cutting fluids to machining process were investigated and the following were found out; Firstly, it lubricates the cutting tool – workpiece interface and then friction and heat generated are greatly reduced. Secondly, due to the fact that the frictional heating cannot be eliminated completely, it also acts as coolant. Finally, chips are washed away by the fluid and this eliminates the tendency of the workpiece to weld the tool material as a result of heat and pressure by acting as an anti-weld agent [2]. The current classifications of the several types of conventional cutting fluids are based on their chemical formulation. Straight or neat oils are the non-water soluble fluids formulation. They can be petroleum based and animal oils. The lubricating and corrosion resistive properties of this oil are enormous. These oils must be handle with care, otherwise may results in skin problems and evaporation as vapor and micro particles that might leads to the machine operator’s health challenge [3]. Results showed that vegetable oil based fluids being biodegradable and eco-friendly and sustainable and sometimes do not compete with food consumption is the best alternative. It also enhances machining performance, extend tool life and improve surface quality [4,5]. Research was carried out on the use of rape seed oil, soya bean oil and sunflower oil as potential metal cutting fluids, the three oils were found to be promising alternatives in terms of their physicochemical properties and fatty acid composition couple with their environmental friendliness and biodegradability characteristics than the mineral (petroleum based) oil [6].

One of the most important and widely used manufacturing processes is machining in the engineering industry. The basic metal machining processes commonly used in the manufacturing industry is the turning operation. It involves metal cutting operation. By high performance in machining operations, it means good machine-ability, good surface quality, lower tool wear rate, optimum rate of material removal, and minimum cutting temperature, faster rate of production and better economy of machining [7]. Low Carbon Steel also known as mild steel (iron containing a small percentage of carbon, strong and tough but not relatively tempered), is now the most common form of steel because of its relatively low prices; while material of desirable properties acceptable for many applications are gotten from a low carbon steel. Mild Steel has a relatively low tensile strength, easy to form, malleable and ductile, they contains approximately 0.05 – 0.30% carbon.

Optimization is the selection of a best element with regard to some criterion from some set of available alternatives [8]. Another definition is the process of finding the conditions where the minimum or maximum value of a function could be given, where the function is taken as the effort required or the desired benefit [9]. Grey Relational Analysis (GRA) plays a significant role in the optimization of machining process parameters for machining of components [10]. For forecasting and decision making, Grey Relational Analysis (GRA) has proved to be a superior multi-response optimization technique and is beginning to gain recognition in several manufacturing industry [11]. This study tends to utilize Taguchi design technique and Grey Relational Analysis (GRA) for the experimental design layout and multi-response optimization in the investigation of the significance of some cutting parameters on the performance of the formulated cutting fluid in comparison with the conventional cutting fluid.

2. MATERIALS AND METHOD

2.1 Materials

The materials utilized in this research work consist of the petroleum (mineral) oil and the non–edible castor seed oil with the additives for the development of the castor seed oil based cutting fluids, workpiece, cutting tool and the machine tool components.

2.1.1 Components for the cutting fluids development

The required materials for the development of the cutting fluids in this research work include the mineral oil, the non-edible vegetable (castor) oil, distilled water and the additives (antioxidant, emulsifier, biocide and anti-corrosive agent). The locally produced corrosion inhibition mixture was prepared in Minna, Niger State. Onion extracts (boiled), honey, acetone and diluted tetraoxosulphate (VI) acid with percentage compositions of 25%, 40%, 30% and 5% respectively. Quercetin in Onions extract is responsible for the corrosion inhibitory action and it belongs to flavonoid group. Methanol helps in preserving the extract to keep the flavonoid from being damaged by the sunlight. It has anti-inflammatory and antioxidant properties [12]. Acetone acts as the solvent and hydrogen peroxide is often used as an anti-infective agent.

2.1.2 Machining process

The workpiece material for the orthogonal turning operation in this study is AISI 1020 Mild Steel rods of 600mm length and 50mm diameter as shown in Figure 1.

Figure 1: AISI 1020 mild steel workpiece

The coated carbide cutting insert with the tool holder employed in this research are CNMG120408-QR GP1225 tungsten carbide insert and PCLNR 2020 K12 turning tool insert holder respectively. The turning experiments will be carried out under wet cutting conditions on a model MOOL lathe 37475 manufactured by MEUSER.

2.1.3 Analysis of gas chromatography and mass spectrometer

The fatty acid composition analysis of the oil sample (castor seed oil) was done using a gas chromatograph interface by a Japan made Mass Spectrometer Instrument GC-MS QP2010 Shimadzu system. This analysis was done in Yola at the American University, Adamawa State. The setup of the machine used was: 70 ^{o}C of column over temperature, 250 ^{o}C injection temperature, 1.80 mL/min column flow with total flow of 40.8mL/min at 49.2 cm/sec linear velocity and 116.9 kpa pressure.

2.2 Methods

2.2.1 Determination of the physicochemical properties and fatty acid composition (FAC)

The determination of the physicochemical properties of the Castor Seed Oil (CSO) was carried out in the school laboratory of the Water Resources and Fisheries Technology Department, Federal University of Technology, Minna. Some of the determined parameters of the (CSO) include the pH Value, Acid Value (mgKOH/g) ASTM D664, the Specific Gravity (ASTM D4052), the Flash Point (ASTM D93), Saponification (ASTM D558), the Kinematic Viscosity @40 ^{o}C (ASTM D445), Pour Point, the Iodine Value, Peroxide Value (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 (FAC) at the America University, Yola.

2.2.2 Formulation of neem seed oil based cutting fluid

The method used by Agu *et al.* [13] as shown in Table 1 was adopted in the cutting fluid development. The additives includes: (i) Anti-oxidant (ii) Anti-corrosion (iii) Emulsifier and (iv) Biocide. Oil with additives – water ratio of 1:9 was used. The preparations of all the additives except the anti-corrosion agent were carried out at the school laboratory of the Chemical Engineering Department, Federal University of Technology, Minna. Onion extract (boiled) with other constituents was used as the anti-corrosion agent. It was observed that many of the characteristics of cutting fluid are mutually exclusive [14].

Table 1: Experimental method of development of the CBCF [13]

Formulas	Emulsifier	Anti-Corrosion	Anti-Oxidant	Biocide
A	9.35%	10.61%	0.64%	0.97%

Materials for the formulations includes additives are the beaker, the test tubes both mini and medium, the filter paper, the distilled water, dishes and bowls, an improvised mechanical stirrer on a drilling machine, the electronic measuring scale and the stop watch. The ratio of 1:9 for the oil with the additives -to-distilled water used for the formulation of the castor seed oil based cutting fluid [13].

2.2.3 Characterization of the formulated castor seed oil based cutting fluid

The characterization of the formulated castor seed oil based metal cutting fluid was carried out and they includes the viscosity, stability, corrosion inhibitory ability, pH value in accordance with ASTM standards. Viscosity describes the internal friction (molecular makeup) of a moving fluid and was carried out by ASTM D 445 standard. The evaluation of the formulated cutting fluid for its stability was carried out by visual transparency for a period of 72 hours (3 days) at room temperature (25 ^{o}C) for stability The determination of the corrosion inhibitory ability of the formulated cutting fluid was carried out based on the ASTM D4627 standard with cast iron chips on a filter paper used according to the method adopted by Awode *et al.* [15]. The pH value was measured in accordance to ASTM standards with pH digital meter used at the school laboratory of the Chemical Engineering Department, Federal University of Technology, Minna.

2.2.4 Experimental Design

The Design of Experiment employed for the turning process is Taguchi experimental design. A total of 9 experimental design with variation of input parameters (spindle speed. Feed rate and depth of cut) while the surface roughness, material removal rate, cutting temperature and tool wear were investigated as responses under the two cutting conditions, the (CBCF) and (MBCF). Minitab Statistical Software (Minitab 22) was used to carry out the design matrix. Table 2 and Table 3 shows the experimental values of the three process parameters at three levels and the experimental design layout respectively.

Table 2: Experimental values of process parameters

Factors	Units	Level 1	Level 2	Level 3
Spindle Speed	Rpm	800	1000	1250
Feed Rate	mm/rev	0.4	0.5	0.6
Depth of Cut	Mm	0.6	0.8	1.0

Table 3: Experimental layout using an $L_9 3^3$ orthogonal array

Trial No.	Spindle 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

2.2.5 Experimental Setup

The workpiece material for the orthogonal turning operation in this study is AISI 1020 Mild Steel rods of 600mm length and 50 mm diameter. For this research, the cutting insert and its holder (tool holder) used are CNMG120408-QR GP1225 tungsten carbide insert and PCLNR 2020 K12 turning tool insert holder respectively. For this research, Taguchi orthogonal design, L_9 (3^3), three levels of three parameters for each of the cutting fluid. A total of 9 trials were design for each cutting fluid. Table 3 shows the experimental design for this study.

2.3 Response Measuring Devices

In this study, four responses namely surface roughness; material removal rate, cutting temperature and the tool wear were considered and determined. Performance evaluation was carried out for the CBCF in comparison with the MBCF.

2.3.1 Digital surface roughness tester

Fresh cutting surface for each experimental turning operation of the workpiece was required for every measurement of surface roughness. The surface roughness tester used is a MODEL SRT-6210S ± 10% accuracy with ≤ 6% fluctuations in displayed values. This device shown in Figure 2a was developed in China by a company called GuangZhou Landtek Instruments Company Ltd. Three measurements were taken at different points for each run and the average was taken for the analysis.

2.3.2 Digital tool wear measurement

During this experimental study, a fresh insert is always used for each experimental run. This is the Dino-Lite digital tool wear microscope with a laptop employed for the tool wear measurement as shown in Figure 2b, after each experimental runs. The DinoCapture software gives the best possible digital microscopic view of the wears and this runs on a computer with Windows XP, Vista or Windows 7, 8 or 9 operating systems.

2.3.3 Cutting temperature measurement

Infra-red thermometer was use for reading the temperature at the cutting zone (cutting tool – workpiece interface) during the turning operation. The Infra-red thermometer is a simple electrical measuring device that reads and displays the temperature as the ray is beamed at the cutting zone as shown in Figure 2c.

Figure 2a: Digital Surface Roughness Tester

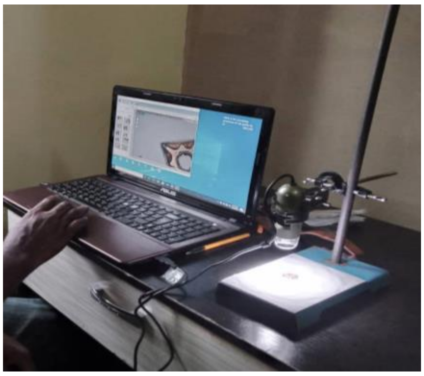

Figure 2b: Dino-Capture 2.0 Digital Microscope

Figure 2c: Digital Infra-Red Thermometer

At multiple points (cutting tool – workpiece interfaces), measurements are read and the average is taken as the cutting temperature of that experimental run. The range of this instrument is between -50 °C and 1100 °C.

2.3.4 Determination of the material removal rate (MRR)

Material removal rate in turning operation is the volume of material removed as chips, per unit time from the workpiece metal surface in mm^3/min. Material Removal Rate (MRR) is determined or calculated by the multiplication of cutting speed, feed rate and depth of cut by applying the relation:

$$MRR = \frac{\bar{\wedge}}{4}\left(D_1^2 - D_2^2\right).F.N \quad (\mathrm{mm^3/min}) \tag{1}$$

Where, D_1 and D_2 are the diameters in mm after and before turning operation. F is the feed rate in mm/rev while N is the spindle speed in rpm [16].

3. RESULTS AND DISCUSSION

3.1 Experimental Results

3.1.1 Physiochemical properties

The determination of the physicochemical properties of the castor seed oil, was carried out in the Department of Water Resources and Fisheries Technology, Federal University of Technology, Minna. Highlighted in Table 4 are the physicochemical properties of the oil.

The physical and chemical properties of the castor seed oil (CSO) were found to be agreement with existing literatures. The pH and acid values of this oil which are 5.84 and 6.79 respectively are in agreement with 5.42 and 7.29 respectively for the rubber seed oil according to Osayi *et al.* [17] findings. The specific gravity of the castor oil (0.951) is in agreement with that of rubber seed (0.91) according to Nagaraj and Mukta [18] findings. The saponification value of the castor seed oil (165.32 mg KOH/g) is comparable to that of neem (166 mg KOH/g) according to Chauhan and Chhibber [19] findings.

Table 4: The physical and chemical properties of the castor seed oil (CSO)

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

3.1.2 Analysis of gas chromatography and mass spectrometer

Shown in Table 5 are the results of the fatty acid composition of the castor seed oil (CSO)

Table 5: Fatty acid composition (FAC) of castor seed oil

Acid and others		**Symbols**	**Compositions (%)**
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

According to Kazeem *et al.* [20], a correlation exists between linolenic acid content and the stability of the seed oil. The stability is highest for the oil containing the smallest amount of linolenic acid; hence, this explains why castor oil based fluid's stability is high compared to any other formulated oil.

3.1.3 Characterization of the formulated castor seed oil based cutting fluid (CBCF)

The results of the pH values, viscosities, their corrosion inhibitory ability, stability and the colour of the formulated cutting fluids which is made up of the oil with additives making up 10% while the distilled water make up 90% by volume for Castor seeds' oil based cutting fluid and the mineral oil based cutting fluid. They all pass the corrosion test when put to tests. The summary of the characterized cutting fluids are shown in the Table 6. The castor seed oil based cutting fluid with pH value of 8.47 compares suitably with that of melon seed oil based cutting fluid of pH value of 8.20 according to Agu *et al.* [13] findings. Using the ASTM D4627 standard, the corrosion inhibitory ability was determined using cast iron chips on a filter paper according to Awode *et al.* [15] and found to be excellent.

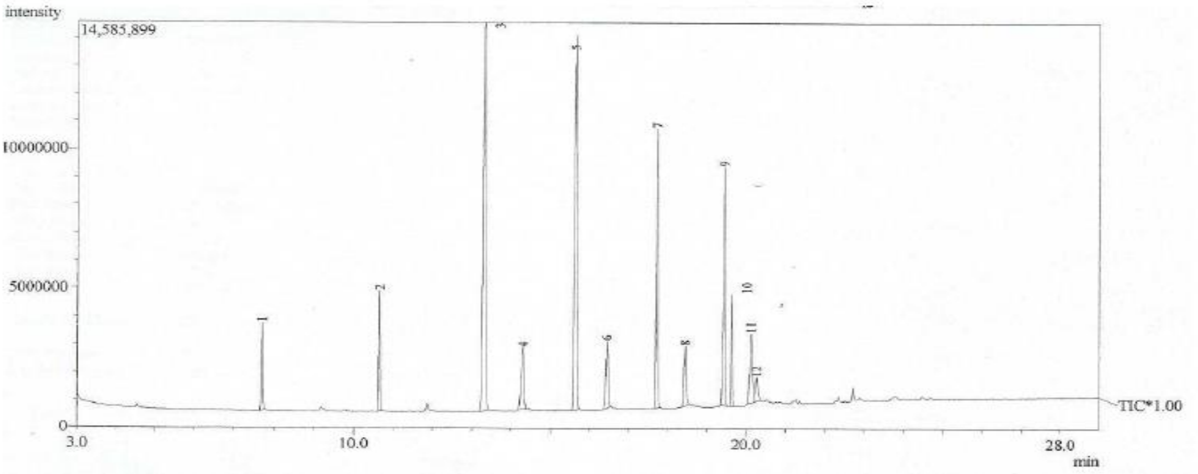

Figure 3: Gas chromatogram and mass spectrometer (GCMS) analysis for castor

Table 6: Summary of the characterized cutting fluids

S/No	Properties	CBCF	MBCF
1	pH Values	8.47	7.88
2	Viscosity	0.830 mm^2/s	0.650 mm^2/s
3	Corrosion Level	Good	Good
4	Stability	Stable	Stable
5	Colour	Milkish	Milkish

The fluids flow above room temperature will penetrate the entire machined surface – tool interface thereby enhancing the lubricating capacities and cooling [21].

3.1.4 Machining process

The experimental results of the responses under the CBCF and MBCF with their respective individual S/N ratios as shown in Table 7. The surface roughness, material removal rate, cutting temperature and the tool wear under the formulated castor oil based cutting fluid falls within 0.271 – 0.402 µm, 448.64 – 1266.23 mm^3/sec, 46.0 – 68.8 °Cand 0.214 -0.263 mm respectively then under the mineral oil based metal cutting fluid, the respective responses falls within 0.275 – 0.441 µm, 453.00 – 1229.80 mm^3/sec, 52.8 – 73.1 °Cand 0.224 – 0.278 mm respectively. The CBCF showed minimal surface roughness, cutting temperature, tool wear and maximum material removal rate compared to the MBCF. From the castor oil based cutting fluid outlook, the viscosity and its lubricity as a results of the unsaturated fatty acid composition enables good fluidity, lubricating and fast cooling capacities which are closely similar to that of the MBCF [22]. For the maximum material removal rate, chip thickness formed using a formulated vegetable oil based cutting fluid was found to be higher than that of the conventional cutting fluid under similar operating condition. The high chip thickness value is due to better lubricating properties of the formulated fluids. An advantage of quick production process is attained as a result of the easier and deeper penetration of the cutting tool into the workpiece for better metal removal rate according to [20]. A developed non-edible vegetable oil based cutting fluid from eco-friendly constituents (additives) with a balanced lipophilicity (ability of substance to dissolve in other alike substance) and hydrophilicity (ability of substance to dissolve in water) of the non-edible vegetable oil by Katna *et al.* [23]. The fluid was tested to be stable and its performance compared to the conventional mineral oil based fluid shows reduced cutting forces, surface roughness and tool wear. Ososomi and Ekhayeme [24] carried out an investigation on the effects of cutting parameters on surface roughness and cutting temperature in turning of AISI 1020 Mild Steel using Taguchi and ANOVA. The results shows the combinations for process parameters for the highest surface quality as 75 m/min cutting speed, 0.2 mm/rev feed rate and depth of cut of 0.6 mm. Feed rate and cutting speed were the most significant parameters in achieving minimum surface roughness. For cutting temperature, the lowest values were obtained at 75 m/min cutting speed, 0.2 mm/rev feed rate and depth of cut of 0.6 mm.

Poor stability and low resistance to corrosion are the main challenges faced by vegetable oil as metal cutting fluids. Different methods have explored in modifying the chemical and the physical properties of these oils. Some of them include hydrogenation, additives addition; esterification and blend with other oils and these vegetable oils were found to improve in stability, lubricity and anti-wear properties according to the work of [25]. Machining difficult to cut metals using cutting tools like coated carbide inserts, CBN and ceramics come with challenges such as excessive heat generation, friction, surface quality, tool wear, chip evacuation and vibration. From the results of the work done by Roy *et al.* [26]

Table 7: Experimental results and S/N ratios (CBCF)

S/N	**Experimental Results**				**Signal to Noise (S/N) Ratio**			
	Surface Roughness Ra (µm)	Material Removal R. (mm^3/sec)	Cutting Temperature (^{o}C)	Tool Wear (mm)	Surface Roughness	Material Removal R.	Cutting Temperature	Tool Wear
1	0.271	488.64	46.0	0.214	11.3406	53.7798	-33.2552	13.3917
2	0.317	760.78	55.1	0.237	9.9788	57.6252	-34.8230	12.5050
3	0.346	1201.5	63.6	0.252	9.2185	61.5945	-36.0691	11.9720
4	0.287	767.49	63.2	0.250	10.8424	57.7015	-36.0143	12.0412
5	0.326	1123.67	68.5	0.274	9.7356	61.0128	-36.7138	11.2767
6	0.374	916.21	60.9	0.254	8.5426	59.2399	-35.6923	11.9033
7	0.347	1173.01	65.8	0.284	9.1934	61.3860	-36.3645	10.9336
8	0.387	875.83	62.4	0.259	8.2458	58.8484	-35.9037	11.7340
9	0.402	1266.23	68.8	0.263	7.9155	62.0503	-36.7518	11.6009

Table 8: Experimental results and S/N ratios (MBCF)

S/N	**Experimental Results**				**Signal to Noise (S/N) Ratio**			
	Surface Roughness Ra (µm)	Material Removal R. (mm^3/sec)	Cutting Temperature (^{o}C)	Tool Wear (mm)	Surface Roughness	Material Removal R.	Cutting Temperature	Tool Wear
1	0.275	453.00	52.8	0.224	11.2133	53.1220	-34.4527	12.9950
2	0.347	726.59	58.2	0.239	9.1934	57.2258	-35.2985	12.4320
3	0.375	1063.82	69.1	0.258	8.5194	60.5374	-36.7896	11.7676
4	0.328	756.89	64.4	0.252	9.6825	57.8507	-36.1777	11.9720
5	0.393	1093.00	79.5	0.279	8.1121	60.7724	-38.0073	11.0879
6	0.384	927.00	65.3	0.250	8.3134	59.3416	-36.2983	12.0412
7	0.358	1051.00	72.4	0.288	8.9223	60.4321	-37.1948	10.7820
8	0.373	846.38	68.1	0.267	8.5658	58.5513	-36.6629	11.4698
9	0.441	1229.80	73.1	0.278	7.1112	61.7967	-37.2783	11.1191

the application of several cooling and lubricating technologies especially the environmental friendly strategies such as minimum quantity lubrication (MQL) and cryogenic cooling has the potentials to address those challenges and also enhances both the sustainability and machinability properties and most importantly prolong the cutting tool life.

3.2 Analysis of Experimental Results

3.2.1 Analysis of variance (ANOVA)

From the ANOVA results for the surface roughness, material removal rate, cutting temperature and the tool wear under both CBCF and MBCF. Table 9 to Table 12 indicates the most significant parameters.

Table 9: ANOVA for surface roughness

		Castor Oil BasedFluid (CBCF)				**Mineral Oil BasedFluid (MBCF)**			
Source	DF	**Seq SS**	**Adj MS**	**F**	**P(%)**	**Seq SS**	**Adj MS**	**F**	**P(%)**
Spindle Speed	2	0.007313	0.003656	28.79	46.92	0.005198	0.002599	28.21	30.61
Feed Rate	2	0.007909	0.003954	31.14	50.74	0.009755	0.004877	52.95	57.67
Depth of Cut	2	0.000113	0.000056	0.44	0.73	0.001777	0.000888	9.65	10.51
Residual Error	2	0.000254	0.000127	1.0	1.63	0.000184	0.000092	1.0	1.09
Total	8	0.015588			100	0.016914			100

Table 10: ANOVA for material removal trate

		Castor Oil BasedFluid (CBCF)				**Mineral Oil Based Fluid (MBCF)**			
Factors	**DF**	**Seq SS**	**Adj MS**	**F**	**P(%)**	**Seq SS**	**Adj MS**	**F**	**P(%)**
Spindle Speed	2	125730	62865	571.96	23.65	132039	66020	64.96	29.38
Feed Rate	2	156694	78347	712.82	29.47	154756	77378	76.13	34.44
Depth of Cut	2	249054	124527	1132.98	46.84	160541	80270	78.98	35.73
Residual Error	2	220	110	1.0	0.04	2033	1016	1.0	0.45
Total	8	531698			100	449369			100

Table 11: ANOVA for cutting temperature

		Castor Oil BasedFluid (CBCF)				**Mineral Oil Based Fluid (MBCF)**			
Factors	**DF**	**Seq SS**	**Adj MS**	**F**	**P(%)**	**Seq SS**	**Adj MS**	**F**	**P(%)**
Spindle Speed	2	204.56	102.281	20.05	49.85	220.94	110.468	14.49	42.74
Feed Rate	2	56.58	28.288	5.55	13.79	65.08	32.541	4.27	12.59
Depth of Cut	2	139.05	69.524	13.63	33.88	215.71	107.854	14.15	41.73
Residual Error	2	10.20	5.101	1.0	2.49	15.24	7.621	1.0	2.95
Total	8	410.39			100	516.97			100

Table 12: ANOVA for tool wear

		Castor Oil BasedFluid (CBCF)				**Mineral Oil Based Fluid (MBCF)**			
Factors	**DF**	**Seq SS**	**Adj MS**	**F**	**P(%)**	**Seq SS**	**Adj MS**	**F**	**P(%)**
Spindle Speed	2	0.001881	0.000940	17.97	57.42	0.002131	0.001065	737.62	61.27
Feed Rate	2	0.000098	0.000049	0.94	2.99	0.000094	0.000047	32.38	2.70
Depth of Cut	2	0.001193	0.000596	11.39	36.42	0.001251	0.000625	433.00	35.97
Residual Error	2	0.000105	0.000052	1.0	3.21	0.000003	0.000001	1.0	0.86
Total	8	0.003276			100	0.003478			100

$$(SS_{Total}) = \sum_{i=0}^{n} y_i^2 - \frac{1}{n}(y_i)^2 \quad (I = 1,2,3\ldots..9) \qquad `(2)$$

Where SS_T = Total Sum of Square, n = Number of Observation, y = Observations in the ith sample.

3.2.2 Multi – response optimization

The combination of the multi-response parameters into a single response was achieved with the use of a multi – response tool called the Grey Relational Analysis (GRA). The level of correlation between input parameters as well as the anticipated response values and also transform multiple performance characteristics into a simple and single grey relational grade (GRG) value [11]. The first step of GRA is the determination of the signal –to-noise (S/N) ratio of the responses and followed by normalizing the S/N ratios using smaller the better quality characteristics for surface roughness, cutting temperature and tool wear while the larger the better quality characteristics for the material removal rate and are shown in Table 7 and Table 8 under the two cutting conditions using Equations (3) and (4) as follows:

$$X_1 = \frac{\{M(y) - y\}}{\{M(y) - m(y)\}} \tag{3}$$

$$X_2 = \frac{\{(y) - m(y)\}}{\{M(y) - m(y)\}} \tag{4}$$

Where, X_1 and X_2 = The normalized S/N ratio for both lower and larger the better respectively. y = The S/N ratio, M = Maxi. S/N ratio for trial values, m = Mini. S/N ratio for trial values.

The second step is the determination of the Deviation = (1 – Normalised S/N Ratios)
The third step is the determination of the grey relational coefficient and it is determined as:

$$Gc = \frac{\Delta m + \gamma \Delta M}{\Delta + \gamma \Delta M} \tag{5}$$

Where, Gc = The Grey Relational Coefficient
Δm and ΔM = The Minimum and Maximum target values
γ = The Identification Coefficient (0.5)
The last step is the determination of the Grey Relational Grade which is obtained from the Grey Relational Coefficient and it is expressed as follows:

$$G = \frac{1}{N} \Sigma\, Gc \tag{6}$$

Where, G = The Grey Relational Grade, N = Number of Response Parameters

The Table 13 and Table 14 presents the grey relational generation to normalized the signal to noise, S/N Ratio under the CBCF and MBCF using the Equations (3) and (4) for both the smaller the better and the larger the better respectively. They were carried out for the 9 experimental runs. The smaller the better was applicable for surface roughness, cutting temperature and tool wear while the larger the better was applicable to the material removal rate. This normalized signal to noise S/N Ratio values was conducted. The values from these results are applicable and is in consistency with the work of [11]. The next step is the determination of the Deviation which is 1 – Normalised S/N Ratios. For the individual 9 runs, the Grey Relational Coefficient (GRC) values are determined with λ value of 0.5 multiplied by maximum changes in the individual values between 0 and 1. The determination of the individual grade values by dividing the individual GRC by the four responses under both the CBCF and MBCF. The GRA – Grade results along with their corresponding factor levels under the CBCF and MBCF are shown in Table 13 and Table 14.Table 15 shows the summary of GRA-Grade Values and Factor Levels under the CBCF and MBCF.

Table 13: Grey relational grade, coefficient and grade for CBCF

	Normalized Values				**Deviation Sequence**				**Grey Relational Coefficient**				**Grade**
	S.R	MRR	C.T	T.W	S.R	MRR	C.T	T.W	S.R	MRR	C.T	T.W	
1	0	0	0	0	1	1	1	1	0.3333	0.3333	0.3333	0.3333	0.3333
2	0.3976	0.4650	0.4484	0.3607	0.6024	0.535	0.5516	0.6393	0.4536	0.4831	0.4755	0.4389	0.4628
3	0.6196	0.9449	0.8048	0.5776	0.3804	0.0551	0.1952	0.4224	0.5679	0.9007	0.7192	0.5421	0.6825
4	0.1455	0.4742	0.7891	0.5494	0.8545	0.5258	0.2109	0.4506	0.3691	0.4874	0.7033	0.5260	0.5215
5	0.4686	0.8746	0.9891	0.8604	0.5314	0.1254	0.0109	0.1396	0.4848	0.7995	0.9787	0.7817	0.7612
6	0.8169	0.6602	0.6970	0.6055	0.1831	0.3398	0.3030	0.3945	0.7320	0.5954	0.6227	0.5590	0.6273
7	0.6269	0.9197	0.8892	1	0.3731	0.0803	0.1108	0	0.5727	0.8616	0.8186	1	0.8132
8	0.9036	0.6129	0.7575	0.6744	0.0964	0.3871	0.2425	0.3256	0.8384	0.5636	0.6734	0.6056	0.6703
9	1	1	1	0.7285	0	0	0	0.2715	1	1	1	0.6481	0.9120

S.R = Surface Roughness, MRR = Material Removal Rate, C.T = Cutting Temperature, T.W = Tool Wear

Table 14: Grey relational grade, coefficient and grade for MBCF

	Normalized Values				**Deviation Sequence**				**Grey Relational Coefficient**				**Grade**
	S.R	MRR	C.T	T.W	S.R	MRR	C.T	T.W	S.R	MRR	C.T	T.W	
1	0	0	0	0	1	1	1	1	0.3333	0.3333	0.3333	0.3333	0.3333
2	0.4924	0.4731	0.2379	0.2544	0.5076	0.5269	0.7621	0.7456	0.4962	0.4869	0.3962	0.4014	0.4452
3	0.6567	0.8548	0.6574	0.5546	0.3433	0.1452	0.3426	0.4454	0.5929	0.7750	0.5934	0.5289	0.6225
4	0.3732	0.5451	0.4853	0.4623	0.6268	0.4549	0.5147	0.5377	0.4437	0.5236	0.4928	0.4818	0.4855
5	0.7560	0.8819	1	0.8618	0.244	0.1181	0	0.1382	0.6720	0.8089	1	0.7835	0.8161
6	0.7069	0.7170	0.5192	0.4310	0.2931	0.283	0.4808	0.569	0.6304	0.6386	0.5098	0.4677	0.5616
7	0.5585	0.8427	0.7714	1	0.4415	0.1573	0.2286	0	0.5311	0.7607	0.6862	1	0.7445
8	0.6454	0.6259	0.6218	0.6892	0.3546	0.3741	0.3782	0.3108	0.5851	0.5720	0.5693	0.6167	0.5858
9	1	1	0.7949	0.8477	0	0	0.2051	0.1523	1	1	0.7091	0.7665	0.8689

S.R = Surface Roughness, MRR = Material Removal Rate, C.T = Cutting Temperature, T.W = Tool Wear

Table 15: GRA-grade values and factor levels (Summary)

Runs	**Experimental Design**			**GRA - Values**	
	Spindle Speed (rev/min)	**Feed Rate (mm/rev)**	**Depth of Cut (mm)**	**Castor Oil (CBCF)**	**Mineral Oil (MBCF)**
1	800	0.4	0.6	0.3333	0.3333
2	800	0.5	0.8	0.4628	0.4452
3	800	0.6	1.0	0.6825	0.6225
4	1000	0.4	0.8	0.5215	0.4855
5	1000	0.5	1.0	0.7612	0.8161
6	1000	0.6	0.6	0.6273	0.5616
7	1250	0.4	1.0	0.8132	0.7445
8	1250	0.5	0.6	0.6703	0.5858
9	1250	0.6	0.8	0.9120	0.8689

3.3 Main Effect Factor Levels

For the castor seed oil based cutting fluid and the mineral oil based cutting fluid, the factors effects shown in Table 16 and Table 17 respectively were obtained using the Grade values from GRA as presented in Table 15.

Table 16: Resulting factor effects of experimental factors (CBCF)

Factor Level	**Spindle Speed (rpm)**	**Feed Rate (mm/rev)**	**Depth of Cut (mm)**
Level 1	0.49	0.56	0.54
Level 2	0.64	0.63	0.63
Level 3	0.80	0.74	0.75

Table 17: Resulting factor effects of experimental factors (MBCF)

Factor Level	Spindle Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
Level 1	0.47	0.52	0.49
Level 2	0.62	0.62	0.60
Level 3	0.73	0.68	0.73

3.4 Main Effects Plots for GRA

Shown in Figure 4 and Figure 5 are the main effect plots for GRA. These specify the optimal factor levels under both the CBCF and MBCF. These plots were obtained from the factor levels of the main effects shown in Table 16 and Table 17.

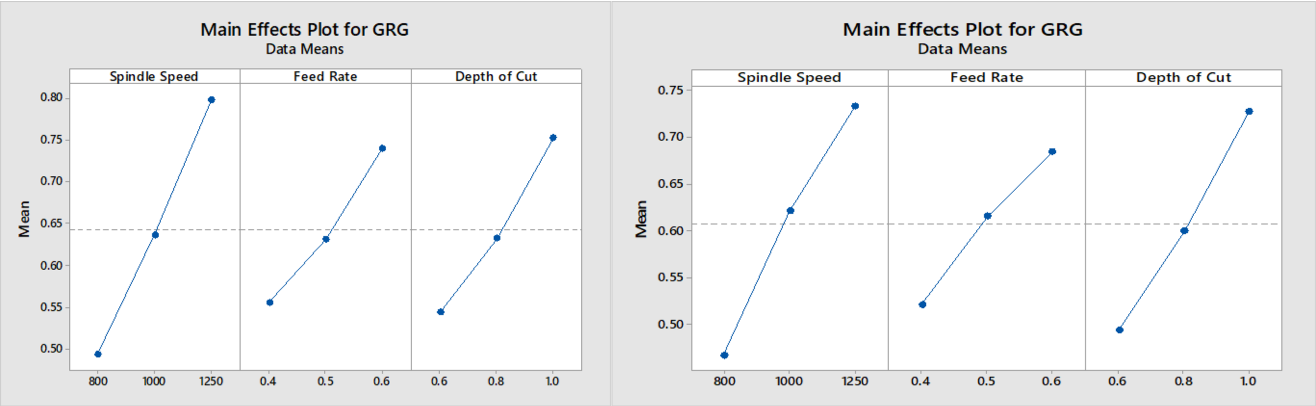

Figure 4: Main effect plot for GRA (CBCF) and (MBCF) respectively

Table 18 shows the results of the experimental test carried out using the optimal values from the main effect plots for GRA.From the results shown in the Figure 4 (CBCF) and (MBCF), the optimal multi-response performance of both CBCF and MBCF were realized when turning with spindle speed (1250 rev/min), feed rate (0.6 mm/rev) and depth of cut (1.0 mm). Thereafter, experiments were performed using the GRA optimal parameter values under the CBCF and MBCF as shown in Figure 4. Then, the performance of the two cutting fluids can be compared. The results are shown in Table 18.From the results in Table 18, the developed (CBCF) showed minimum surface quality, cutting temperature, tool wear and maximum material removal rate of (0.3840 µm), (63.50 ^{o}C), (0.2700 mm) and (1324.32 mm^{3}/sec) respectively compared to the (MBCF) which shows a surface roughness of (0.4220 µm), (71.43 ^{O}C), (0.2760 mm) and (1248.20 mm^3/sec) respectively.

Table 18: Experimental results using GRA optimal values

S/N	Experimental Responses	CBCF	MBCF
1	Surface Roughness (µm)	0.3840	0.4220
2	Material Removal Rate (mm^3/sec)	1324.32	1248.20
3	Cutting Temperature (^{O}C)	63.50	71.43
4	Tool Wear (mm)	0.270	0.2760

4. CONCLUSIONS

The novel castor seed oil based (oil-in-water emulsion) cutting fluid developed could be used to improve machining processes in the areas of better surface quality, minimum cutting temperature and tool wear and lastly maximum material removal rate during the turning of AISI 1020 Mild Steel with coated carbide tools and this contribute to the overall machining science. Based on the experimental results obtained from this study, the following conclusions were made:

i. The feasibility of utilizing the castor seed oil based cutting fluid as a better alternative to the conventional mineral oil based cutting fluid is affirmed due to the fact that the physiochemical properties and the fatty acid composition (FAC) of the castor seed oil were seen to be consistent with the various existing oils used in cutting fluid formulation according to existing literatures.

ii. In terms of pH value, viscosity, stability and corrosion resistance, the castor seed oil based cutting fluid's (CBCF) performance compares favourably with the mineral oil based cutting fluid (MBCF). As a result of these characteristics, the CBCF is biodegradable, environmental friendly, absence of health related hazards and cost effective.

iii. From the Analysis of Variance (ANOVA) results, surface roughness under the CBCF and MBCF is mostly influenced by feed rate (50.74 and 57.67%) followed by the spindle speed (46.92 and 30.61%) respectively. For material removal rate under the CBCF and MBCF, depth of cut (46.84 and 35.73%) followed by the feed rat (29.47 and 34.44%) and then the spindle speed (23.65 and 29.38%) respectively. The spindle speed (49.85 and 42.74%) followed by the depth of cut (33.88 and 41.73%) respectively under the CBCF and MBCF are the most significant parameters on the cutting temperature. Lastly, for tool wear under the CBCF and MBCF, spindle speed (57.42 and 61.27%) followed by the depth of cut (36.42 and 35.97%) respectively are the most significant parameters.

iv. The multi – objective response optimum performance of the developed castor seed oil based cutting fluid can be actualized in turning AISI 1020 Mild Steel workpiece under both the CBCF and MBCF with spindle speed (1250 rev/min, level 3), feed rate (0.6 mm/rev, level 3) and depth of cut (1.0 mm, level 3). Minimum surface roughness, cutting temperature and tool wear with maximum material removal rate and the overall better machinability will be achieved under the above machining conditions when turning AISI 1020 Mild Steel workpiece.

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