



## COMPARATIVE ANALYSIS OF MACHINING AISI 1020 MILD STEEL USING MINERAL OIL BASED AND NEEM SEED OIL BASED CUTTING FLUIDS



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### Abstract

*Retaining workpiece dimensional accuracy and quality, elongated tool life, minimal surface roughness, minimum tool wear and overall high productivity in metal cutting (machining) operations are areas the cutting fluids plays pivotal role. This study focuses on surface roughness, cutting temperature and tool wear by evaluating their optimal factor effectiveness during turning of AISI 1020 Mild Steel using an environmentally friendly cutting fluid. Serious concern has been raised about the non-biodegradable and non-recyclable of the conventional (mineral based) cutting fluid and this prompted the renewal of research interest in environmentally friendly cutting fluids such as the neem seed oil based cutting fluid. The locally sourced neem seed oil (NSO) was characterized by investigating the physiochemical properties and the fatty acid composition (FAC). Surface roughness, cutting temperature and tool wear were minimized during turning of AISI Mild Steel using coated carbide insert with the evaluation compared with the mineral oil based cutting fluid. Taguchi experimental design was employed during the optimization. The formulated fluid showed 8.35 pH value, 0.896 m<sup>2</sup>/s viscosity, good resistance to corrosion, stable and milkfish colouration. The S/N ratio for NBCF and MBCF are 800 CS, 0.4 FR and 0.6 doc; and 800 CS, 0.4 FR and 0.6 DOC respectively with R-sq and R-sq(pred) values as 98.37% and 97.38 under the NBCF and lastly 94.53% and 91.25% under the MBCF for surface roughness respectively. For cutting temperature and tool wear, S/N ratios show A<sub>1</sub>B<sub>1</sub>C<sub>1</sub> under both NBCF and MBCF. The findings shows that the neem seed oil based cutting fluid outperform the mineral oil-based fluid under the same cutting parameters and this has contributed to the science of machining.*

**Keywords:** *Neem seed oil, Cutting temperature, Taguchi, Surface roughness, Tool wear*

### 1.0 Introduction

Metal working fluids also known as cutting fluids play a pivotal role in metal removal processes. Friction reduction, heat elimination from the cutting zone, surface quality improvement and tool wear reduction are some of the responsibilities of cutting fluids. The large area of intimate contact between the cutting tool and workpiece results in substantial friction between them thereby causes rapid temperature rise which facilitates cutting tool rapid wear and then subsequent failure (Abu, 2011). Friction and heat generation between the cutting tool and the workpiece takes place at the cutting zone and this leads to increase in temperature. Tool wear and the tool life are not only affected by the high

temperature, it also leads to reduction in the surface quality of the workpiece, its dimensional accuracy and the overall quality of the product. Elongated cutting time and excessive cutting speed results in higher cutting temperature in the cutting zone (Zhang *et al*, 2009). The effect is more severe when machining difficult to cut materials (Lawal *et al*, 2014). In metal cutting (machining) processes, the work done is converted to heat and this is responsible for the high temperature in the cutting tool and the workpiece interface (Trent and Wright, 2000). Substantial friction is developed in the large area of intimate contact between the cutting tool and the workpiece, this causes high temperature rise which give rise to rapid

cutting tool failure (Abu, 2001). Unlike conventional mineral based oils metal working fluids, vegetable oils lubricants are biodegradable and non-toxic (Yakubu and Bello, 2015). Nigeria being an importing and consuming nation is heavily importing dependent as far as edible vegetable for domestic consumption is concern. Therefore, the sustainability of edible oils for industrial purposes is not feasible in the present-day realities and challenges (Woma *et al.*, 2019). This becomes imperative for researchers to pay more attention to non-edible vegetable oils such as castor seed oil, neem seed oil, jatropha and rubber seed oils as raw materials for industrial purposes like metal working and cutting fluids that are not competing with the edible oils for food consumption by human beings. These non-edible vegetable oils from plant sources seem to be more promising for raw materials because they are viable potentials that have not been completely exploited instead of being wasted (Uzu *et al.*, 1985). The global interest for eco-friendly metal cutting fluids that will have better machining performance and cost effectiveness than the conventional (mineral oil based) cutting fluids cannot be over emphasized. Over the years, researches on edible vegetable oil based cutting fluids proved to be readily biodegradable, low toxicity, renewable and eco-friendly and also proved to be effective potential alternatives to the conventional oil-based fluids. Higher viscosity index, higher lubricity, higher shear stability, low volatility and higher load carrying capacity are some of the potential properties' vegetable oil possess (De Souza *et al.*, 2019). Conventional metal cutting fluids have more recently become a source of non-value-added cost to business in machining industry though; cutting fluids have greatly improved machining performance. Heat reduction, lubrication between the tool-chip-workpiece interfaces, reduced friction and the removal of chips from the cutting zone are all due to the application of cutting fluids (Awode *et al.*, 2020). Researchers

now pay more attention on non-edible vegetable oils such as neem seed oil, castor seed oil rubber seed oil, jatropha seed oil as raw materials for industrial applications. The non-edible vegetable oil is not competing with food consumption as they are non-edible and they seem to be more promising for industrial raw materials as a result their viable potentials that are not being exploited but are being wasted (Woma *et al.*, 2019). The main focus of this research was to utilize neem seed oil-in-water emulsion cutting fluid to compare the performance in terms of surface roughness, cutting temperature and tool wear with the mineral oil based cutting fluid in turning AISI 1020 Mild Steel with coated carbide cutting inserts using Taguchi technique Anova.

## 2.0 Materials and Methods

### 2.1 Materials

#### 2.1.1 Cutting Fluid Materials

The materials for the formulation of the cutting fluid in this study include Neem seed oil (NSO) obtained from the AgriEnergy Nigeria, sourced from Technology Incubation Centre (TIC) farm centre, Kano state, other materials include distilled water and additives (antioxidant, emulsifier, biocide and anti-corrosive agent). The locally produced corrosion inhibition mixture was prepared in Minna, Niger State with boiled onion extract and honey. Onion extract (boiled), honey, acetone and diluted tetraoxosulphate (vi) acid with percentage compositions of 25%, 40%, 30% and 5% respectively. 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 in this study is AISI 1020 Mild Steel rods of 600mm length and 50mm 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 were carried out under wet cutting conditions on a model MOOL lathe 37475 manufactured by MEUSER. Digital Surface Roughness Tester was used to measure the surface roughness during the experimental tests, Infra-Red temperature reader with capacity to measure between - 50 °C to 1100 °C and then the tool wear measurement using the Dino-Capture 2.0 Version 1.5.28A Versatile Digital Microscope.

## 2.2 Methods

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

The physicochemical properties of the Neem 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 were determined: the pH value, the Iodine Value, Acid Value (mgKOH/g) (ASTM D664), Specific Gravity (ASTM D4052), Kinematic Viscosity @ 40°C (ASTM D445), Flash point (ASTM D93), Saponification (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.

### 2.2.2 Formulation of Neem 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 & Onuoha *et al.*, 2016) were adopted in the cutting fluid development. The additives include: (i) Anti-oxidant (ii) Anti-corrosion (iii) Emulsifier and (iv) Biocide. Oil with additives to water ratio of 1:9 was adopted. 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, then honey, acetone and diluted tetraoxosulphate (vi) acid with percentage compositions of 25%, 40%, 30% and 5% respectively was used as the anti-corrosion agent. Natural honey is another corrosion inhibitor. As the polarity of the extract solvent increases, its efficiency increases as well. Extract of Onions contains quercetin and is responsible for the 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 (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. 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 (neem) oil using the three formulas shown 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 materials for the formulations apart from the additives are beaker, mini and medium test tubes, distilled water, filter paper, bowls and dishes, drilling machine for an improvised mechanical stirrer, electronic 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 neem seed oil based cutting fluid. The stirring of each mixture was done by a mechanically powered stirrer at an angular speed of 1400 rev/min for about 15 minutes at room temperature to achieve a homogenous mixture.



**Figure 1:** Mechanical Powered Stirring of Oil-in Water Mixture

The best from the samples of the oil-based fluid was chosen based on their pH values, viscosities, corrosion resistance capacity and their stability levels.

### 2.2.3 Characterization of the Formulated Neem Seed Oil Based Cutting Fluid

The characterization of the formulated neem seed oil-based metal cutting fluids were carried out and they include the viscosity, stability, corrosion inhibitory ability, pH value in accordance with ASTM standards. 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 and this was carried out by ASTM D 445 standard. An acceptable cutting fluid should have moderate viscosity which enables pumping from the sump through hoses and pipes into the cutting zone to permeate the tool-chip interface for cooling by removing the heat generated and for lubrication to reduce

friction and heat. The stability of the formulated cutting fluids were evaluated using a visual transparency within a period of 72 hours (3 days) at room temperature (25<sup>0</sup>C) for stability as to separation of water and oil in a graduated 1000ml test tubes. They were found to be highly stable. 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). From the formulated vegetable cutting fluids corrosive actions, the number of corrosion spots if any on the test filter paper were evaluated. The pH values of the Neem seed oil based cutting fluid (NBCF) was measured using pH digital meter in accordance to ASTM standards.

### 2.2.4 Design of Experiment (DOE) for the Turning Process

The Design of Experiment employed for the turning process is Taguchi experimental design. A total of 9 experimental design with variation of input parameters under the two cutting conditions, the NBCF and MBCF. Minitab Statistical Software (Minitab 18) was used to carry out the design matrix. Table 2 and Table 3 show the turning process parameters, their levels and the design matrix.

### 2.2.5 Turning Process

The workpiece material for the orthogonal turning operation in this study is AISI 1020 Mild Steel rods of 600mm length and 50mm 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. The turning experiments will be carried out under wet cutting conditions on a model MOOL lathe 37475 manufactured by MEUSER.

**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<sub>9</sub>3<sup>3</sup> Orthogonal array**

| Trial No. | Spindle (rpm) | Speed | 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               |

### 2.2.6 Determination of Surface Roughness

At different points along the turned workpiece surface, three readings were taken and the average value adopted for the analysis. The device is a digital surface roughness tester MODEL SRT-6210S with  $\pm 10\%$  accuracy with not more than 6% fluctuation display value. Each turning operation of the workpiece uses a fresh or new cutting edge of the cutting tool insert.

### 2.2.7 Determination of Cutting Temperature

Infra-red thermometer was used for reading the temperature at the cutting zone (cutting tool – workpiece interface) during the turning operation. 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  $-50^{\circ}\text{C}$  and  $1100^{\circ}\text{C}$ .

### 2.2.8 Determination of the Tool Wear

During this experimental study, a fresh insert is always used for each experimental run. Dino-Lite Version 2017Q2 IDCP BV, designed and manufactured in Taiwan. This is the Dino-Lite digital tool wear microscope with a laptop employed for the tool wear measurement as shown in Figure 3, after each experimental run.



**Figure 2:** Dino-Capture 2.0 Digital Microscope

## 3.0 Results and Discussion

### 3.1 Characterization of the Neem Seed Oil

From the Table 4, the NSO with viscosity of  $28.74 \text{ mm}^2/\text{s}$  at  $40^{\circ}\text{C}$  in terms of easy

pumping and penetrations through the cutting zone is attainable and in terms of lubricity according to (Demirbas, 2005). The pH and acid values are 6.20 and 7.57 for NSO respectively. Neem seed oil with acid value of (7.57 mg KOH/g) is comparable to that of melon seed oil of acid value (9.39 mg KOH/g) based on Agu *et al.*, (2019) findings. The pH value of neem seed oil which is 6.20 is comparable to that of rubber seed oil which is 5.42 based on (Osayi *et al.*, 2021) findings.

The neem seed oil (NSO) which is also an anti-bacteria, has acid values of approximately 29.11% saturated fat with the main contributors being 12.98% palmitic acid, 16.13% stearic acid and others. About 59.64% of the neem seed oil is unsaturated with 41.34% oleic acid (monounsaturated), 18.23% linoleic acid (polyunsaturated), 0.07% Linolenic and others.

**Table 4: Physiochemical Properties of Neem Seed Oil (NSO)**

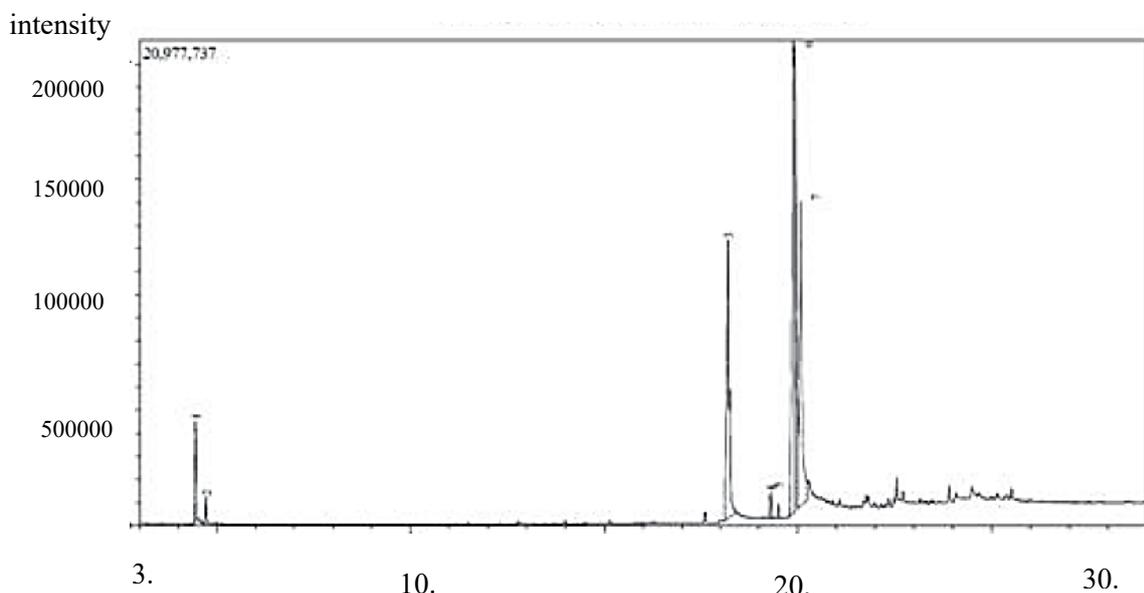
| Physicochemical properties                        | NSO Sample    |
|---|---------------|
| Colour  | Golden Colour |
| pH value  | 6.20          |
| Acid Value mgKOH/100g                             | 7.57          |
| Specific Gravity                                  | 0.897         |
| Viscosity @40 <sup>0</sup> C (mm <sup>2</sup> )/s | 28.74         |
| Flash Point ( <sup>0</sup> C)                     | 225           |
| Saponification mgKOH/100g                         | 192.95        |
| Pour Point ( <sup>0</sup> C)                      | 5             |
| Peroxide Value (meq/kg)                           | 3.85          |
| Iodine Value g/100g                               | 88.75         |
| Cloud Point ( <sup>0</sup> C)                     | 14            |
| Free Fatty Acid (mgKOH/100g)                      | 15.14         |

**Table 5: Fatty Acid Composition (FAC) of Castor and Neem Oils**

| Acid and others   |  | Symbols | Fraction (%) |
|-------------------|--|---------|--------------|
| Names             | Formulas / Molecular Weight  |         | NSO          |
| Pentanoic Acid    | CH <sub>3</sub> (CH <sub>2</sub> ) <sub>3</sub> COOH (102.13g/mol)   | C 5:0   | -            |
| Octanoic Acid     | CH <sub>3</sub> (CH <sub>2</sub> ) <sub>6</sub> COOH (144.21g/mol)   | C 8:0   | -            |
| Palmitic Acid     | CH <sub>3</sub> (CH <sub>2</sub> ) <sub>14</sub> COOH (256.40g/mol)  | C 16:0  | 12.98        |
| Stearic Acid      | CH <sub>3</sub> (CH <sub>2</sub> ) <sub>16</sub> COOH (284.48g/mol)  | C 18:0  | 16.13        |
| Oleic Acid        | CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CH = CH(CH <sub>2</sub> ) <sub>7</sub> COOH (282.47g/mol)                                | C 18:1  | 41.34        |
| Linoleic Acid     | CH <sub>3</sub> (CH <sub>2</sub> ) <sub>4</sub> CH= CHCH <sub>2</sub> CH= CH(CH <sub>2</sub> ) <sub>7</sub> COOH (280.45g/mol)           | C 18:2  | 18.23        |
| Linolenic Acid    | CH <sub>3</sub> CH <sub>2</sub> CH= CHCH <sub>2</sub> = CHCH <sub>2</sub> = CH(CH <sub>2</sub> ) <sub>7</sub> CO <sub>2</sub> H (278.43) | C 18:3  | 0.07         |
| Ricinoleic Acid   | C <sub>18</sub> H <sub>34</sub> O <sub>3</sub> (298.46g/mol)   | C 18:1  | -            |
| Others            |  |         | 11.25        |
| Saturated (Sum)   |  |         | 29.11        |
| Unsaturated (Sum) |  |         | 59.64        |

The oleic acid content suggests the degree of oiliness of seed oil samples. This is the ability of the oil adhere to the metal surfaces

which is an important property in boundary lubricating conditions (Kazeem *et al.*, 2018).



**Figure 3:** Gas Chromatogram and Mass Spectrometer (GCMS) Analysis for Neem Oil.

### 3.2 Characterization of the Formulated Cutting Fluid

Table 6 shows the characterization of the formulated neem seed oil based cutting fluid. Observations show that the viscosity of the formulated neem seed oil based cutting fluid is 0.896 mm<sup>2</sup>/s. The pH value of the neem seed oil based cutting fluid is 8.35 and it compares favourably with the

pH value of rubber seed oil based cutting fluid according to (Osayi *et al.*, 2021). There was no phase separation of the oil and water from the stability test carried out and this indicates that the cutting fluid is indeed stable. Anti-corrosion test carried out shows that the cutting fluid has perfect corrosion inhibitory capacity.

**Table 6: Summary of the Characterized Cutting Fluids**

| S/N0 | Properties      | NBCF                     | MBCF                     |
|------|-----------------|--------------------------|--------------------------|
| 1    | pH Values       | 8.35                     | 7.88                     |
| 2    | Viscosity       | 0.896 mm <sup>2</sup> /s | 0.650 mm <sup>2</sup> /s |
| 3    | Corrosion Level | Good                     | Good                     |
| 4    | Stability       | Stable                   | Stable                   |
| 5    | Colour          | White – Milkish          | Milkish                  |

### 3.3 Experimental Results and Signal / Noise Ratio

The responses evaluated include the surface roughness, cutting temperature and the

cutting tool wear during the turning processes under the neem seed oil based cutting fluid and mineral oil based cutting fluid. The data with their corresponding

S/N ratios for each cutting fluid shown in Table 7 and Table 8.

**Table 7: Experimental Results and S/N Ratios under the NBCF**

| Exp. Run | Experimental Results |                     |           | S/N Ratio (dB)    |                     |           |
|----------|----------------------|---------------------|-----------|-------------------|---------------------|-----------|
|          | Surface Roughness    | Cutting Temperature | Tool Wear | Surface Roughness | Cutting Temperature | Tool Wear |
| 1        | 0.223                | 48.7                | 0.216     | 13.0339           | -33.7506            | 13.3109   |
| 2        | 0.269                | 54.3                | 0.229     | 11.4050           | -34.6960            | 12.8033   |
| 3        | 0.311                | 59.1                | 0.236     | 10.1448           | -35.4317            | 12.5050   |
| 4        | 0.273                | 57.7                | 0.241     | 11.2767           | -35.2235            | 12.3597   |
| 5        | 0.309                | 63.3                | 0.258     | 10.2008           | -36.0281            | 11.7676   |
| 6        | 0.321                | 56.2                | 0.240     | 9.8699            | -34.9947            | 12.3958   |
| 7        | 0.297                | 71.3                | 0.264     | 10.5449           | -37.0618            | 11.5679   |
| 8        | 0.325                | 65.4                | 0.240     | 9.7623            | -36.3116            | 12.3958   |
| 9        | 0.364                | 63.7                | 0.255     | 8.7780            | -36.0828            | 11.8692   |

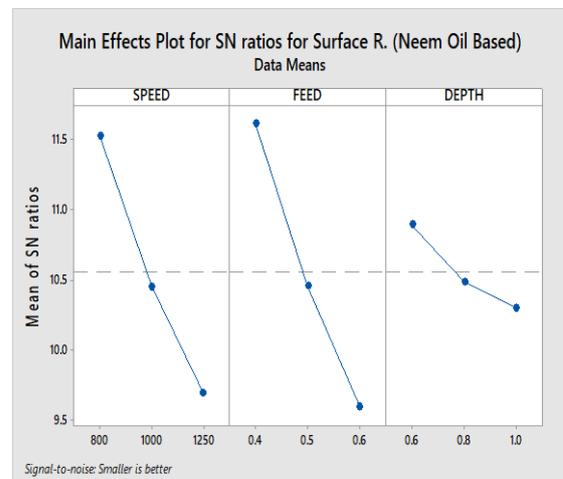
**Table 8: Experimental Results and S/N Ratios under the MBCF**

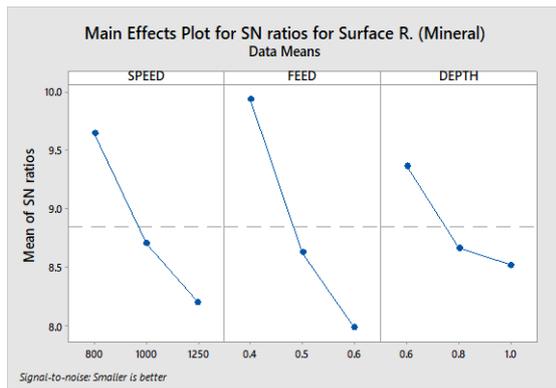
| Exp. Run | Experimental Results |                     |           | S/N Ratio (dB)    |                     |           |
|----------|----------------------|---------------------|-----------|-------------------|---------------------|-----------|
|          | Surface Roughness    | Cutting Temperature | Tool Wear | Surface Roughness | Cutting Temperature | Tool Wear |
| 1        | 0.275                | 52.8                | 0.224     | 11.2133           | -34.4527            | 12.9950   |
| 2        | 0.347                | 58.2                | 0.239     | 9.1934            | -35.2985            | 12.4320   |
| 3        | 0.375                | 69.1                | 0.258     | 8.5194            | -36.7896            | 11.7676   |
| 4        | 0.328                | 64.4                | 0.252     | 9.6825            | -36.1777            | 11.9720   |
| 5        | 0.393                | 79.5                | 0.279     | 8.1121            | -38.0073            | 11.0879   |
| 6        | 0.384                | 65.3                | 0.250     | 8.3134            | -36.2983            | 12.0412   |
| 7        | 0.358                | 72.4                | 0.288     | 8.9223            | -37.1948            | 10.7820   |
| 8        | 0.373                | 68.1                | 0.267     | 8.5658            | -36.6629            | 11.4698   |
| 9        | 0.441                | 73.1                | 0.278     | 7.1112            | -37.2783            | 11.1191   |

### 3.4 Main Effect Plots

#### 3.4.1 Main Effect Plot for Surface Roughness

The main effect plots of signal to noise ratio (S/N Ratio) shown for surface roughness reveals the optimal turning parameters for the surface roughness as 800 rpm for spindle speed (level 1), 0.4 mm/rev for feed rate (level 1) and 0.6 mm for the depth of cut (level 1) under both the neem seed oil based and mineral oil based cutting fluids as shown in Figure 5. The lower the better characteristics were chosen for surface roughness.





**Figure 4:** Main Effect Plot for Surface Roughness under NBCF and MBCF

Regression Equation (NBCF):

$$\text{Surface Roughness Ra } (\mu\text{m}) = -0.0388 + 0.000135 Vc + 0.3383 Fr + 0.0400 DOC$$

$$= -0.0388 + 0.000135 (800) + 0.3383 (0.4) + 0.0400 (0.6) = 0.2285 \mu\text{m}$$

$$R\text{-sq} = 98.37\%, R\text{-sq (adj)} = 97.38\%$$

Regression Equation (MBCF):

$$\text{Surface Roughness Ra } (\mu\text{m}) = -0.0282 + 0.000128 Vc + 0.3983 Fr + 0.0783 DOC$$

$$= -0.0282 + 0.000128 (800) + 0.3983 (0.4) + 0.0783 (0.6) = 0.2805 \mu\text{m}$$

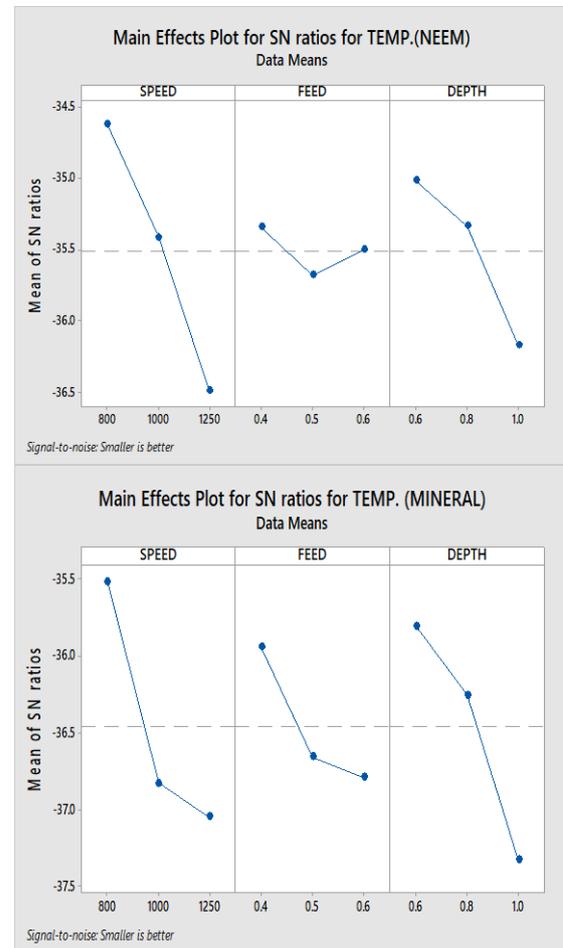
$$R\text{-sq} = 94.53\%, R\text{-sq (adj)} = 91.25\%$$

The surface roughness values under the NBCF are 0.2285  $\mu\text{m}$ , and under MBCF is 0.2805  $\mu\text{m}$ . This are attributed to the viscosities and fatty acid compositions of these vegetable oil based cutting fluids. Conclusions were made that the (NBCF) shows lower surface roughness values compared to the MBCF during turning operation.

### 3.4.2 Main Effect Plot for Cutting Temperature

The main effect plots of signal to noise ratio (S/N Ratio) shown for cutting temperature reveals the optimal turning parameters for the cutting temperature as 800 rpm for spindle speed (level 1), 0.4 mm/rev for feed rate (level 1) and 0.6 mm for the depth of cut (level 1) as shown in Figure 6. The

lower the better characteristics was chosen for cutting temperature under both the NBCF and MBCF, this is consistent with the results of (Kumar *et al.*, 2016).



**Figure 5:** Main Effect Plot of S/N Ratio for Cutting Temperature under NBCF and MBCF

Regression Equation (NBCF):

$$\text{Cutting Temperature } (^{\circ}\text{C}) = 14.33 + 0.02848 Vc + 2.17 Fr + 19.50 DOC$$

$$= 14.33 + 0.02848 (800) + 2.17 (0.4) + 19.50 (0.6) = 49.68 ^{\circ}\text{C}$$

$$R\text{ sq} = 93.57\%, R\text{ sq (adj)} = 89.71\%$$

Regression Equation (MBCF):

$$\text{Cutting Temperature } (^{\circ}\text{C}) = 4.4 + 0.02404 Vc + 29.8 Fr + 29.00 DOC$$

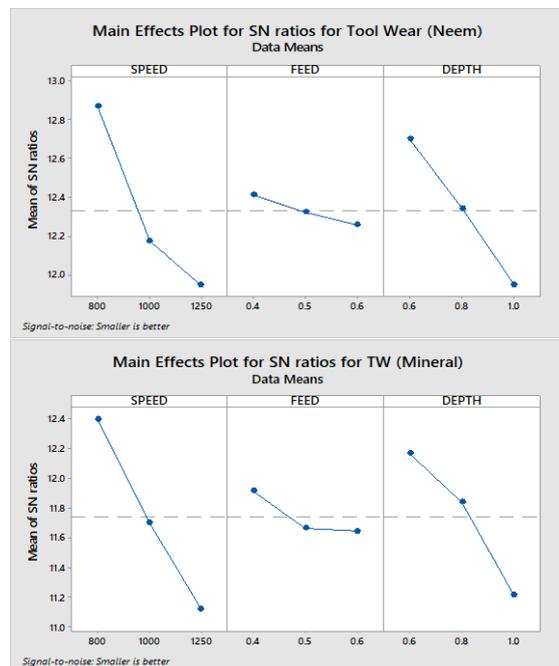
$$= 4.4 + 0.02404 (800) + 29.8 (0.4) + 29.00 (0.6) = 52.95 ^{\circ}\text{C}$$

$$R\text{-sq} = 83.46\%, R\text{-sq (adj)} = 73.54\%$$

It can be seen that under the NBCF and MBCF based metal cutting fluids, the values of cutting temperature were found to be 49.68 °C and 52.95 °C respectively. This indicates that the vegetable oil based cutting fluids performs better and more effective in minimizing cutting temperature during turning operation. The lowest values of cutting temperature were obtained with low spindle speed, low feed rate and low depth of cut which conforms with (Osayi *et al.*, 2021) findings.

### 3.4.3 Main Effect Plot for Tool Wear

The main effect plots of signal to noise ratio (S/N Ratio) shown for tool wear reveals the optimal turning parameters for the tool wear as 800 rpm for spindle speed (level 1), 0.4 mm/rev for feed rate (level 1) and 0.6 mm for the depth of cut (level 1) under both the neem seed oil based and mineral oil based cutting fluids as shown in Figure 7. The lower the better characteristics were chosen for tool wear.



**Figure 6:** Main Effect Plot of S/N Ratio for Tool Wear under NBCF and MBCF

Regression Equation (NBCF):

$$\begin{aligned} \text{Tool Wear, (mm)} &= 0.1343 + 0.000056 V_c \\ &+ 0.0183 Fr + 0.0525 \text{ DOC} \\ &= 0.1343 + 0.000056 (800) + 0.0183 (0.4) \\ &+ 0.0525 (0.6) = 0.2179 \text{ mm} \end{aligned}$$

R-sq = 91.25%, R-sq (adj) = 85.99%

Regression Equation (MBCF):

$$\begin{aligned} \text{Tool Wear (mm)} &= 0.1008 + 0.000083 V_c \\ &+ 0.0350 Fr + 0.07083 \text{ DOC} \\ &= 0.1008 + 0.000083 (800) + 0.0350 (0.4) + \\ &0.07083 (0.6) = 0.2237 \text{ mm} \end{aligned}$$

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

There is always a high strength lubricant thin film formed between the tool-workpiece interfaces during machining with vegetable oil-based fluids. This is due the high proportion of unsaturated fatty acids in the vegetable oil and enhances the release of oil as high strength lubricant film which tends to protect the tip of the cutting tool from rapid wear. As a result, vegetable oils show lower tool wear compared to the conventional mineral oil based cutting fluid and it agrees with the work of Yan and Jian (2013).

### 3.4.4 ANOVA Analysis for Surface Roughness under both NBCF and MBCF

As shown in Table 4.18 and Table 4.19, the significant effects of cutting speed, feed rate and depth of cut on the surface roughness under the NBCF are as follows: Spindle Speed (43.11%), Feed Rate (53.02%) and Depth of Cut (3.25%) and and this conforms to the results of (Jeevan and Jayaram, 2018).

**Table 9: Analysis of Variance (ANOVA) of Means for Surface Roughness**

| Source        | DF | Seq SS   | Adj SS   | Adj MS   | F     | P(%)  |
|---------------|----|----------|----------|----------|-------|-------|
| Spindle Speed | 2  | 0.005598 | 0.005598 | 0.002799 | 68.63 | 43.10 |
| Feed Rate     | 2  | 0.006884 | 0.006884 | 0.003442 | 84.41 | 53.02 |
| Depth of Cut  | 2  | 0.000422 | 0.000422 | 0.000211 | 5.17  | 3.25  |

|                |   |          |          |          |     |      |
|----------------|---|----------|----------|----------|-----|------|
| Residual Error | 2 | 0.000082 | 0.000082 | 0.000041 | 1.0 | 0.63 |
| Total          | 8 | 0.012985 |          |          |     | 100  |

For under the MBCF are also 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 under both cutting conditions and this conforms to the results of (Jeevan and Jayaram, 2018).

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

| Factors        | 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 |          |          |       | 100   |

**3.4.5 ANOVA Analysis for Cutting Temperature under both NBCF and MBCF**

From results in Table 4.18 and Table 4.19, the significant effects of cutting speed, feed

rate and depth of cut on the cutting temperature under the NBCF are as follows: Spindle Speed (68.52%), Feed Rate (1.40%) and Depth of Cut (27.64%).

**Table 11: Analysis of Variance (ANOVA) of Means for Cutting Temperature**

| Factors        | DF | Seq SS  | Adj SS  | Adj MS  | F     | P(%)  |
|----------------|----|---------|---------|---------|-------|-------|
| Spindle Speed  | 2  | 248.127 | 248.127 | 124.063 | 28.05 | 68.52 |
| Feed Rate      | 2  | 5.087   | 5.087   | 2.543   | 0.57  | 1.40  |
| Depth of Cut   | 2  | 100.080 | 100.080 | 50.040  | 11.31 | 27.64 |
| Residual Error | 2  | 8.847   | 8.847   | 4.423   |       | 2.44  |
| Total          | 8  | 362.140 |         |         |       | 100   |

While under the MBCF are also as follows: Spindle Speed (42.74%), Feed Rate (12.59%) and Depth of Cut (41.73%). From these results, spindle speed has more

significant impact on the cutting temperature followed by the depth of cut and then the feed rate under both cutting conditions.

**Table 12: Analysis of Variance (ANOVA) of Means for Cutting Temperature**

| Factors        | DF | Seq SS | Adj SS | Adj MS  | F     | P(%)  |
|----------------|----|--------|--------|---------|-------|-------|
| Spindle Speed  | 2  | 220.94 | 220.94 | 110.468 | 14.49 | 42.74 |
| Feed Rate      | 2  | 65.08  | 65.08  | 32.541  | 4.27  | 12.59 |
| Depth of Cut   | 2  | 215.71 | 215.71 | 107.854 | 14.15 | 41.73 |
| Residual Error | 2  | 15.24  | 15.24  | 7.621   | 1.0   | 2.95  |
| Total          | 8  | 516.97 |        |         |       | 100   |

**3.4.6 ANOVA Analysis for Tool Wear under both NBCF and MBCF**

From the ANOVA in Table 4.18 and Table 4.19, the significant effects of cutting

speed, feed rate and depth of cut on the tool wear under the NBCF are as follows: Spindle Speed (59.51%), Feed Rate (1.12%) and Depth of Cut (37.08%).

**Table 13: Analysis of Variance (ANOVA) of Means for Tool Wear**

| Factor         | DF | Seq SS   | Adj SS   | Adj MS   | F     | P(%)  |
|----------------|----|----------|----------|----------|-------|-------|
| Spindle Speed  | 2  | 0.001064 | 0.001064 | 0.000532 | 26.46 | 59.51 |
| Feed Rate      | 2  | 0.000020 | 0.000020 | 0.000010 | 0.50  | 1.12  |
| Depth of Cut   | 2  | 0.000663 | 0.000663 | 0.000331 | 16.48 | 37.08 |
| Residual Error | 2  | 0.000040 | 0.000040 | 0.000020 | 1.0   | 2.24  |
| Total          | 8  | 0.001788 |          |          |       | 100   |

Under the MBCF are also as follows: Spindle Speed (61.27%), Feed Rate (2.70%) and Depth of Cut (35.97%). From these results, spindle speed has more significant

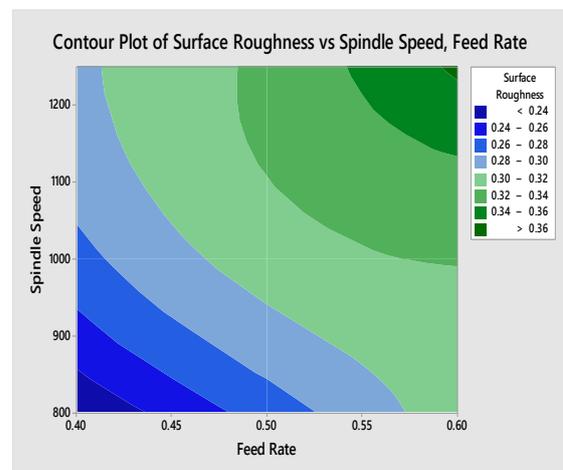
impact on the tool wear followed by the depth of cut and then the feed rate under both cutting conditions.

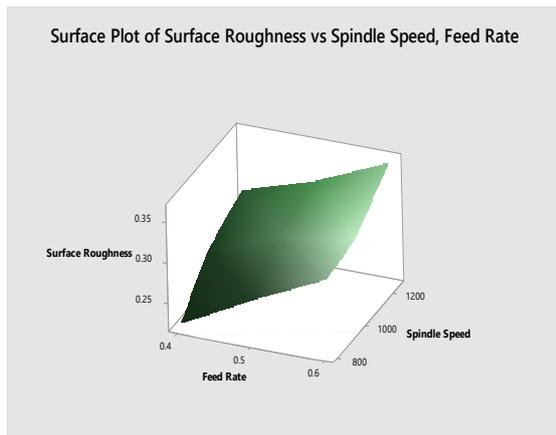
**Table 14: Analysis of Variance (ANOVA) of Means for Tool Wear**

| Factors        | 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   |

**3.4.7 Contour Plots and 3D Surface Plots**

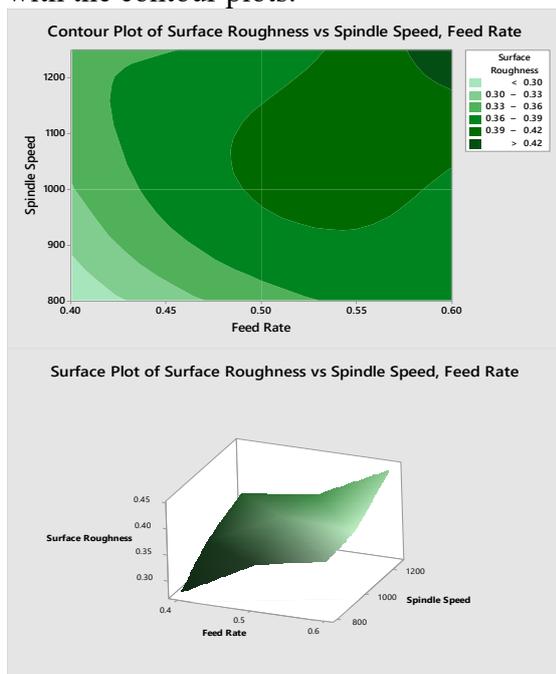
The Contour Plot shows the effect of the two most influential parameters. From these plots, it can be deduced that surface roughness, cutting temperature and tool wear increases with increase in the spindle speed and feed rate under the two-cutting condition (NBCF and MBCF) and this agrees with the 3D surface plots.



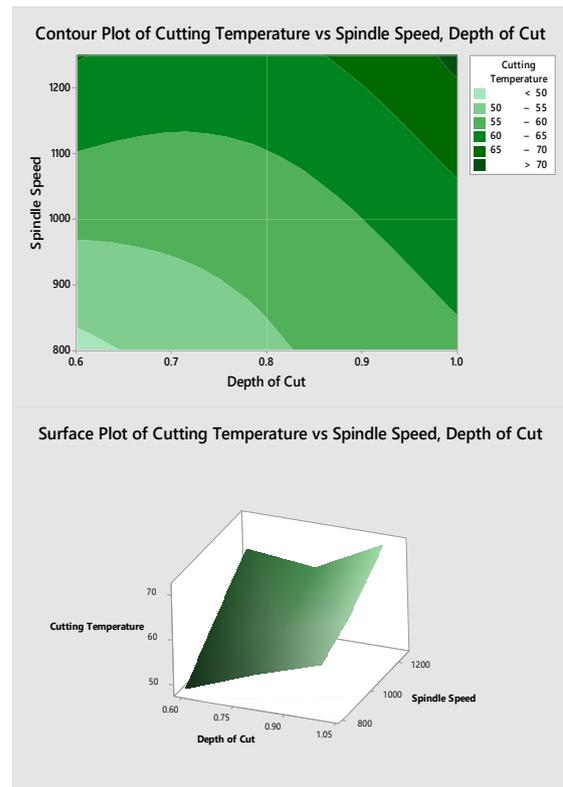


**Figure 7:** Contour Plot and 3D Surface Plot for Surface Roughness (NBCF)

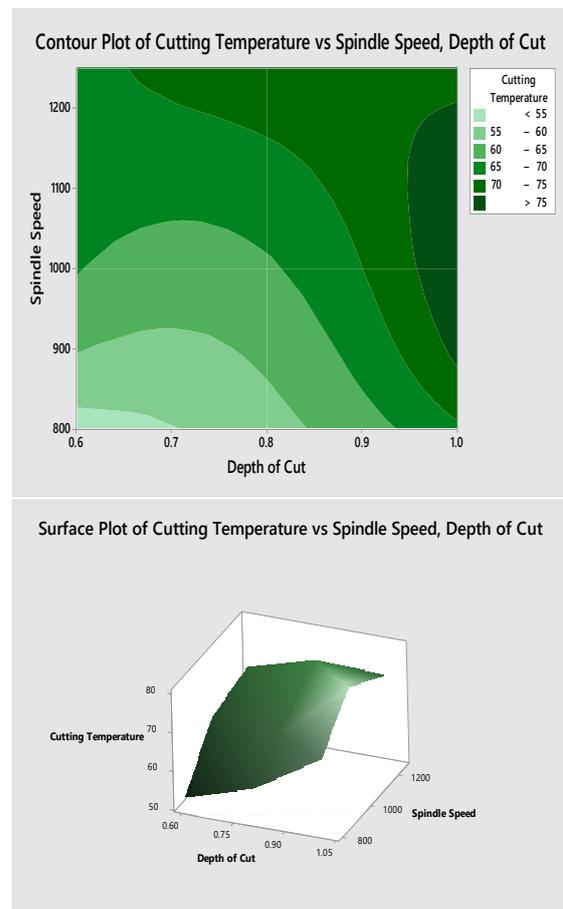
Figure 8 to Figure 13, it indicates that the highest surface quality, minimum cutting temperature and tool wear are in the lower left region of the plots. This occurs at both lowest values of spindle speed, feed rate and depth of cut as the case may be. The contour plot is in accordance with (Lawal *et al.*,2014) finding. The 3D Surface Plot shows the effect of the two most influential parameters on the surface roughness, cutting temperature and tool wear. From the 3D surface plot, the surface roughness, cutting temperature and tool wear decreases with decrease in both spindle speed, feed rate and depth of cut which are in agreement with the contour plots.



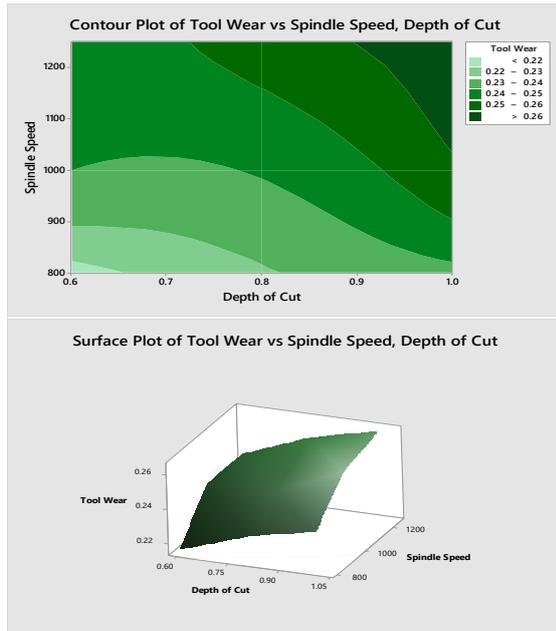
**Figure 8:** Contour Plot and 3D Surface Plot for Surface Roughness (MBCF)



**Figure 9:** Contour Plot and 3D Surface Plot for Cutting Temperature (NBCF)



**Figure 10:** Contour Plot and 3D Surface Plot for Cutting Temperature (MBCF)



**Figure 11:** Contour Plots and 3D Surface Plot for Tool Wear (NBCF)

### 3.5 Confirmation Test

From the regression analysis, the regression equations were used for the calculation of the predictive (calculated) values for the surface roughness, cutting temperature and the tool wear using the optimal values from the main effect plots. The experimental values are the values gotten from the workshop and laboratory after experimental tests using the optimal values from the main effect plots as the input parameters.

**Table 15: Predicted Responses' Values at all Conditions**

| Responses                               | Neem Oil Based Fluid | Mineral Oil Based Fluid |
|---|----------------------|-------------------------|
| Surface Roughness, Ra ( $\mu\text{m}$ ) | 0.2285               | 0.2805                  |
| Temperature ( $^{\circ}\text{C}$ )      | 49.68                | 52.95                   |
| Tool Wear (mm)                          | 0.2179               | 0.2237                  |

**Table 16: Experimental Responses' Values at all Conditions**

| Responses                               | Neem Oil Based Fluid | Mineral Oil Based Fluid |
|---|----------------------|-------------------------|
| Surface Roughness, Ra ( $\mu\text{m}$ ) | 0.231                | 0.284                   |
| Temperature ( $^{\circ}\text{C}$ )      | 48.5                 | 53.7                    |
| Tool Wear (mm)                          | 0.223                | 0.224                   |

$$\text{Percentage Error} = \frac{\text{Experimental Values} - \text{Predicted Values}}{\text{Experimental Values}} * 100 \quad (3.1)$$

The percentage error from the predicted and the experimental values is determined by the equation (3.1).

**Table 17: Percentage Errors at all Conditions**

| Responses                               | Neem Oil Based Fluid | Mineral Oil Based Fluid |
|---|----------------------|-------------------------|
| Surface Roughness, Ra ( $\mu\text{m}$ ) | 1.08%                | 1.23%                   |
| Temperature ( $^{\circ}\text{C}$ )      | 2.40%                | 1.40%                   |
| Tool Wear (mm)                          | 2.29%                | 0.13%                   |

The confirmation test as concluded is reliable having the percentage error between 0.13% and 2.40% for the three responses and it conforms to literature (Awode *et al.*, 2020). The  $R^2$  for any linear regression analysis is expected to be within 0.8 and 1.0 as revealed by Montgomery *et al* (1998) and this shows that the regression results from this study compared favourably.

### 3.6 Conclusion

A novel oil-in-water metal cutting fluid from neem seed oil based cutting fluid using onions extract as corrosion inhibiting agent was developed and the corrosion test carried out shows the high effectiveness of the anti-corrosion agent used. Performance evaluation was conducted in terms of surface roughness, cutting temperature and tool wear as compared to the mineral oil-based metal cutting fluid. The findings shows that the neem seed oil based cutting fluid performed better than the mineral oil-based fluid under the same cutting parameters. The performance evaluation from the orthogonal optimal turning parameters for surface roughness, cutting temperature and tool wear under the NBCF and MBCF shows optimal values of 800 rpm spindle speed at level 1, 0.4 mm/rev feed rate at level 1- and 0.6-mm depth of cut at level 1 under the CBCF and MBCF with predictive values of (0.2285  $\mu\text{m}$  and 0.2805  $\mu\text{m}$ ), (49.68  $^{\circ}\text{C}$  and 52.95  $^{\circ}\text{C}$ ) and (0.2179 mm and 0.2237 mm) respectively. ANOVA shows that the significant effects of the parameters on the surface roughness under the NBCF and MBCF are as follows: Spindle Speed (43.11% and 30.61%), Feed Rate (53.02% and 57.67%) and Depth of Cut (3.25% and 10.51%) respectively. For cutting temperature, the significant effects of the parameters under the NBCF and MBCF are as follows Spindle Speed (68.52% and 42.74%), Feed Rate (1.40% and 12.59%) and Depth of Cut (27.64% and 41.73%) respectively. Lastly, the significant effects of the parameters on the tool wear under the NBCF and MBCF are as follows:

Spindle Speed (59.51% and 61.27%), Feed Rate (1.12% and 2.70%) and Depth of Cut (37.08% and 35.97%) respectively. The  $R$ -sq and  $R$ -sq(pred) values are 98.37 % and 97.38 % under the CBCF and lastly 94.53 % and 91.25 % under the MBCF respectively for surface roughness. The  $R$ -sq and  $R$ -sq(pred) values are 93.57 % and 89.71 % under the CBCF and lastly 83.46 % and 73.54 % under the MBCF respectively for cutting temperature while 91.25 % and 85.99 % under the CBCF and lastly 97.39 % and 95.82 % under the MBCF respectively for tool wear.

The confirmation test as conducted is reliable having the percentage error between 0.13% and 2.40% for the three responses at the two cutting conditions.

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