Nigerian Journal of Technology (NIJOTECH)
Vol. 41, No. 4 July, 2022, pp.700 –711
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v41i4.8

Characterization of Eco-Friendly Cutting Fluid Developed from Neem Seed Oil

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Article history: Received 23 May 2022; Revised form 21 June 2022; Accepted 30 June 2022; Available online 10 September 2022

Abstract
Cutting fluid is a key component in retaining workpiece quality, tool life and overall high productivity in machine operations. It is needed as input for minimal surface roughness, minimal tool wear and better machining finished product. This study addressed tool wear and surface roughness by evaluating optimal factor effectiveness of the surface roughness and tool wear during turning of AISI 304 alloy steel using an environmentally friendly fluid. The non-biodegradable and non-recyclable nature of conventional cutting fluids as mineral oils have raised serious concerns with the research community and prompted the renewal of research in this area with focus on replacing the mineral based cutting fluids with environmentally friendly cutting fluids such as neem seed prepared cutting fluid (N-PCF). The neem seed oil (NSO) was sourced locally and characterized by investigating the physiochemical properties as well as it's fatty acid composition (FAC). The cutting fluid formulation was 1:9 of oil to water in the ratio. The cutting fluids which aided surface roughness and tool wear reduction during turning of the austenitic stainless steel AISI 304 and improved the carbide insert tool was evaluated and compared with mineral oil-based cutting fluid. Also, the response surface method (RSM) of experimental design and Grey relational analysis (GRA) multi-response optimization were employed respectively. The experimental results revealed that the formulated oil showed 8.67 pH value, 0.50 mm^2/s viscosity, resistant to corrosion, stable and deep yellowish colouration. The multi-response optimal factor combination obtained from GRA showed multi-response effect of the formulated Neem seed prepared cutting fluid at feed rate of 0.82 mm/rev, depth of cut of 0.65 mm and cutting velocity of 800 rev/min while that of Mineral prepared cutting fluid (M-PCF) was achieved with feed rate (0.82 mm/rev), depth of cut (0.65 mm) and cutting velocity (500 rev/min). GRA and RSM results showed acceptable parameters that contribute to the science of machining and this is in good agreement when compared with those obtained from other cutting fluids used for turning operation.

Keywords: Turning, Neem seed oil, Cutting fluid, GRA, tool wear, RSM, surface roughness.

1.0 INTRODUCTION

Over the years, efforts have been geared towards addressing the need for improving machining efficiency and minimised materials cost with growing development in mechanical characterization, microstructure, processing and wear [1]. Also, the need for high performing and low-cost materials with different particles have been studied using promising structural materials as a result of their high corrosion and wear resistance, specific modulus, and weight for automobile and aerospace applications [2]. [3] adopted Taguchi design technique by utilising palm kernel oil, cottonseed oil and mineral oil in the formulation of cutting fluids and found that the vegetable oil-prepared cutting fluids stand to be the excellent option to mineral oil prepared cutting fluids due to its chemical properties contents and their ability to biodegrade, however, the use of a multi-response technique which combines all the responses together as single response was not adopted.

[4] also conducted a his review on the use of vegetable-based oil for cutting fluid formulation as substitute for mineral oil-based cutting fluid and established that during machining processes, vegetable oil-based metal-working-fluids (MWFs) performed better than mineral oil-prepared cutting fluids, however, [5], conducted similar review work on metal cutting tools and cutting lubricants and revealed that the treatment of cutting fluid in order to obtain eco-friendly and cheaper product, coupled with reduced machining tool wear rate and enhanced surface

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morphology and shelve lives are key requirements in achieving a sustainable machining process. Contrarily, in another review work conducted by [6], which focused on the sustainability of machining processes. The authors claimed that an increase in complexity for machining engineering is determined by the sustainable paradigms to achieve a unified global index for sustainable machining design. In addition, [7] investigated the effect of cutting fluids on tool wear and surface roughness during turning of AISI 304 austentic stainless steel and revealed that the focus of modern machining industries is to achieve a high quality process, in terms of minimised wear on the cutting tools, better surface finish, improved production rate, acceptable work piece dimensional accuracy, and improved the performance of the product with less environmental impact, however, [8] in their study which focused on the machining of similar alloy by accessing the surface integrity and material removal rate, in a contrary opinion, claimed that advanced machining processes and methods coupled with the use of machine tools are key enablers in achieving productivity goals and overall quality that meet the requirements of future markets. [9] have revealed that the use of mineral cutting fluids overtime has led to the biodegradation of the environment and also posed great negative effects on humans and other animals. This means vegetable oils with high oleic content are a potential factor to replace traditional mineral oil-based lubricating oils and synthetic esters [10].

In India, neem seed oil (Meliaceae) is one of the richest sources of secondary metabolites in nature and it is grown as a tree in the temperate woodlands of southern West Africa [11]. [12] work suggested that since neem seed oil can be readily poured, it is a suitable coolant for use in tropical region like Nigeria where temperature rarely drops to 8°C. Previous study conducted by [13] have shown the presence of both fatty acids and oily substance in the extract of the neem seed. In view of this, [14] recommended that, it is therefore important to investigate the suitability of the oil as in cutting fluid formulation for use in machining operation. [15] work suggested that the formulation of this cutting fluid must involve the inclusion of additives like anti-oxidant agent, anti-corrosion agent, emulsifier and biocide at a considerable ratio. [14] work shows that carbide tool was employed in the study of the effect of formulated cutting fluids on the tool wear and surface roughness during the turning of AISI 304 austenitic stainless steel. The outlook from the experiments showed that the use of coconut oil based formulated cutting fluid gave a better surface finish and tool wear, followed by straight cutting oil and finally, soluble oil which had the lowest effect at a constant depth of cut. The experimental design and multi-response optimisation technique which are capable of aiding optimisation and decision process were not adopted. In the work of [16], the effects of hybridization of two different nano-fluids (alumina and molybdenum disulphide) were investigated using Response Surface Methodology (RSM) in turning of AISI 304 stainless steel. The authors found that compared to Al_2O_3 mixed nano-fluid, the use of Al-MoS_2 showed a significant reduction of 7.35%, 18.08%, 5.73%, and 2.38% in cutting force (F_k), feed force (F_i), thrust force (F_j) and surface roughness (R_a) respectively. However, the use of a multi-response optimisation technique may have aid the comparison and optimisation process since three responses (cutting force, feed force, thrust force and surface roughness) were investigated in the study. Also, [17] studied the tool wear rate of three surface-treated drills effect and a AlCrN (Alcrona) coated drill at separate cutting velocity during the machining of AISI 304 and found that reduced tool wear was recorded as a result of lower volume fraction of primary carbides present in the microstructure of the M2-ST drills used. However, cutting fluids which have the tendency of reducing wear and prolonging tool life was not used during the machining process. In addition, [18] utilised minimum quantity lubrication (MQL) to study the performances modified jatropha oils (MJO_1, MJO_3 and MJO_5) during turning of AISI 1045, both with and without hexagonal boron nitride (hBN) particles. The authors found that the MJO_5 sample showed the lowest values of cutting force, cutting temperature and surface roughness, with a prolonged tool life and less tool wear, thereby, qualifying it as a potential alternative to the synthetic ester, with regard to the environmental concern. The authors also revealed that the seeds from the jatropha fruit contained vegetable oil varying in the range of 25–45%. [1] work suggested that cost and environmental impact must be considered and the quality enhancement of machined parts during machining operation is a risky challenge. Therefore, the use of experimental design technique for optimisation process is recommended.

In addition, [19] have suggested that multi-response optimisation technique such as Grey Relational Analysis (GRA) and Principal Component Analysis (PCA) play a great role in the optimization of process parameters for the machining of components. The use of optimisation technique have not been fully utilised by several authors who have carried out researches in machining. Though, Grey Relational Analysis (GRA) which has proved to be a superior multi-response optimization technique for forecasting and decision-making is beginning to gain popularity in several manufacturing sector [20]. Summarily, this study seeks to employ central composite RSM design and GRA for experimental design and multi-response optimisation respectively in the investigation of impact of the selected cutting parameters (cutting velocity, feed rate and depth of cut) on the performance formulated and conventional cutting fluid was also studied. Neem seed oil-prepared cutting fluid was formulated and characterised and thereafter used in the turning of AISI 304 alloy steel using coated tungsten carbide tool.

2.0 MATERIALS AND METHODS

2.1 Materials

Some of the materials used include Graduated 1000ml test tube, PH meter, 1400 magnetic stirrer and measuring tube.

2.1.1 Cutting Fluid Formulation

The cutting oil used includes; Neem seed oil (NSO) and Mineral soluble oil (MSO). These oils were sourced from local market situated in Katsina-Nigeria and Agarawu market in Lagos-Nigeria respectively. In addition, the additives utilised during the formulation of the N-PCF include; emulsifier, biocide, anti-corrosive agent and anti-oxidant.

2.1.2 Machining process

The materials used for the machining processes include Tungsten carbide insert (RP8025 CNMG120404-PM 3688-288L 10PCS), cutting tool insert holder (MTJNR 2020 K16), a 3-jaw-chuck lathe (Model: M00L Lathe 37475) and an AISI 304 alloy stainless steel workpiece sourced in Lagos-Nigeria (Figure 1). The experiment was conducted in the Air Force Institute of Technology, Kaduna-Nigeria.

Figure 1: AISI 304 stainless steel workpiece

2.1.3 Gas Chromatography and Mass Spectrometer

A mass spectrometer (GC-MS) instrument GC-MS-QP2010 Shimadzu system, from Japan was used to analyse the Fatty Acid Composition (FAC), which was conducted using a gas chromatograph interface. The following machine conditions were used: Column flow was 1.80mL/min with total flow of 40.8mL/min at linear velocity of 49.2cm/sec, pressure of 116.9kpa and column over temperature of 70.0°C and injection temperature of 250.0°C.

2.1.4 Dinolite Digital Tool Marker's Microscope

Dino-Lite version 2017Q2 IDCP BV used was designed and produced in Taiwan is a Dino-Lite digital tool wear microscope. The DinoCapture software is designed to give the best possible digital microscopy experience by the inventors of the handheld digital microscope. The DinoCapture software runs on computers with a Windows XP, Windows Vista or Windows 7/8/10 operating system.

2.2 Methods

2.2.1 Physiochemical Properties and fatty acid composition

Several physio-chemical tests were conducted on the sourced neem seed oil sample. The properties investigated include; pH value, acid value, specific gravity, viscosity at 40^0C, flash point, pour point and peroxide value. The pH value was obtained using pH meter while acid and peroxide value of the neem seed oil was studied using the procedure outlined by Association of Official Analytical Chemists. In addition, the specific gravity and viscosity at 40^0C, flash point and pour point were investigated using the procedure outlined by ASTM D287, ASTM D445, ASTM D93 and ASTM D97 respectively. Also, the oil fatty acid composition was obtained using gas chromatography mass spectrometer (GC-MS) instrument (GC-MS-QP2010 Shimadzu system) utilising column over temperature (70.0°C), injection temperature (250.0°C), column flow of 1.80mL/min with total flow of 40.8mL/min at linear velocity of 49.2cm/sec and pressure of 116.9kpa.

2.2.2 Formulation of cutting fluid

The neem oil-prepared cutting fluid formulation was based on the method adopted by [21] and [15] who utilized percentage ratio of oil to water and other additives as 1:9. The procedure adopted by these authors involved controlled addition of additives to the neem seed oil using a measuring tube of maximum level (100ml) and a magnetic stirrer operating at an angular speed of 1400 rev/min which help for the homogeneity of the mixture at a minimal time. For each mixture, a time of 12 minutes was observed at ambient temperature.

2.2.3 Cutting fluids characterization

The formulated neem seed oil prepared cutting fluid (N-PCF) and Mineral oil based cutting fluids (M-PCF) were characterized by determining the value of pH, value of viscosity, level of corrosion, stability level and colour. The corrosion level was determined using the testing procedure utilised by [22] while pH values were measured with pH meter.

Also, the viscosities of N-PCF and M-PCF were determined in accordance with ASTM D445 standard measurement procedure while their stabilities were evaluated based on visual transparency within a period of 24 hours at room temperature using 1000ml graduated test tubes.

2.2.4 Experimental Design

Central Composite Design (CCD) using a Response surface methodology (RSM) was employed for the design of experiment. This design method was preferred to other design methods because it is user friendly and effective. It also provides precise factor effects estimation and the interaction between different responses [20]. The machining parameters selected in this study include; cutting speed (CS), feed rate (FR) and depth of cut (DOC) while tool wear as well as surface roughness were investigated as responses. Table 1 shows the experimental factor levels while the design matrix is shown in Table 2.

Table 1: Machining parameters factor levels

Factors	Unit	Level 1 (-1)	Level 2(+1)
Cutting speed (CS)	rev/min	630	1000
Feed rate (FR)	mm/rev	0.65	1.00
Depth of cut (DOC)	mm	0.3	1.00

Table 2: RSM-CCD Experimental design

Run Order	*Orthogonal array*			*Experimental matrix*		
	CS(rev/min)	*FR (mm/rev)*	*DOC (mm)*	*CS(rev/min)*	*FR (mm/rev)*	*DOC (mm)*
1	-1.00	-1.00	-1.00	630	0.65	0.30
2	1.00	-1.00	-1.00	1000	0.65	0.30
3	-1.00	1.00	-1.00	630	1.00	0.30
4	1.00	1.00	-1.00	1000	1.00	0.30
5	-1.00	-1.00	1.00	630	0.65	1.00
6	1.00	-1.00	1.00	1000	0.65	1.00
7	-1.00	1.00	1.00	630	1.00	1.00
8	1.00	1.00	1.00	1000	1.00	1.00
9	-1.68	0.00	0.00	500	0.82	0.65
10	1.68	0.00	0.00	1250	0.82	0.65
11	0.00	-1.68	0.00	800	0.52	0.65
12	0.00	1.68	0.00	800	1.15	0.65
13	0.00	0.00	-1.68	800	0.82	0.10
14	0.00	0.00	1.68	800	0.82	1.24
15	0.00	0.00	0.00	800	0.82	0.65
16	0.00	0.00	0.00	800	0.82	0.65
17	0.00	0.00	0.00	800	0.82	0.65
18	0.00	0.00	0.00	800	0.82	0.65
19	0.00	0.00	0.00	800	0.82	0.65
20	0.00	0.00	0.00	800	0.82	0.65

2.2.5 Experimental setup

Turning operation was conducted using the experimental design presented in Table 2. The number of run used is 20 run order and three repeated runs per run order. Surface roughness and tool wear were selected as experimental responses in studying the performance of the formulated and conventional cutting fluid while experiments were conducted on the stainless steel (AISI 304) round bars of 25mm diameter by 500mm length to achieve a diameter to length ratio of 1:20 which will help in eliminating flexing and ensures rigidity during the turning operation [23]. As suggested by [24], twenty workpieces were selected for the experimental design using L_{20} orthogonal array, and for every experiment, a new workpiece was introduced each time. Afterward, selected test samples were placed on the 3-jaw-chuck lathe within the live centre and chuck in order to increase the force of clamping when carrying out the turning process [21]. This procedure was followed by machining off a thin surface part of the workpiece samples before the process so as to ensure infirmity of the work piece samples. Thereafter, turning was carried out on the workpiece at varying cutting velocity, feed rate and depths, after considering the lathe calibration, as specified in Table 2. This was followed bv surface roughness and tool wear measurement. In addition, tool wear was measured using a Dinolite digital tool makers microscope with specifications; view field diameter (13 mm), eyepiece (15x), total magnification (30x), objective (2x) and working distance (65 mm). This is represented in Figure 2. While surface roughness was measured using a surface roughness tester (Model: STR- 6210S, GuangZhouLandtek) at three locations around the workpiece circumference as adopted by [21], [15] and [3]. After which, the average values for each experiments were recorded.

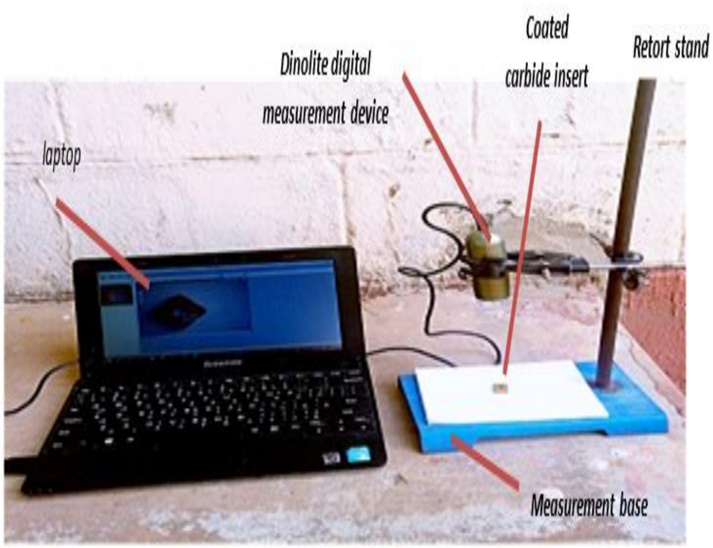

Figure 2: Measurement of tool wear

3.0 RESULTS AND DISCUSSION

3.1 Experimental results

3.1.1 Physiochemical Properties

The data for the physical and chemical characteristics of Neem seed oils are shown in Table 3. Based on the results presented in Table 3, it can be found that the physiochemical properties of NSO were consistent with existing aforementioned literatures. The pH value of the oil extract is in alkaline state (7.28) which indicates that it will not corrode metal during machining processes [25] while the viscosity value of 25.10 signified the measure of fluid friction, as a result represent a good internal resistance of the oil to flow [26]. It was observed that increase in temperature reduces the oil viscosity. In addition, the pH values, specific gravity and acid value agrees with the findings of [27] who utilised jatropha seed oil and reported values of 9.3, 0.89 and 5.22 respectively. Based on these results, the oil extracts can be adopted in the preparation of the vegetable oil cutting fluids.

3.1.2 Gas Chromatography Mass Spectrometer (GC-MS) Analysis

The results of gas chromatography-mass spectrometer (GC-MS) analysis of the neem seed oils (NSO) are presented in Figure 3. The fatty acid profile showed saturated fat of approximately 37.0% with 18.1% palmitic acid and 18.1% stearic acid being the major contributor, while unsaturated fat is about 63.0% with 44.5% mono-unsaturated oleic acid and 18.3% polyunsaturated linoleic acid which are main contents.

Table 3: Physiochemical properties of Neem Seed Oil (NSO)

Physiochemical Properties	***NSO Sample***
pH value	7.28
Acid value (mg KOH/g)	5.80
Specific gravity	0.919
Viscosity @40^0C	25.10
Flash point	238
Pour point	4
Peroxity value	8.6

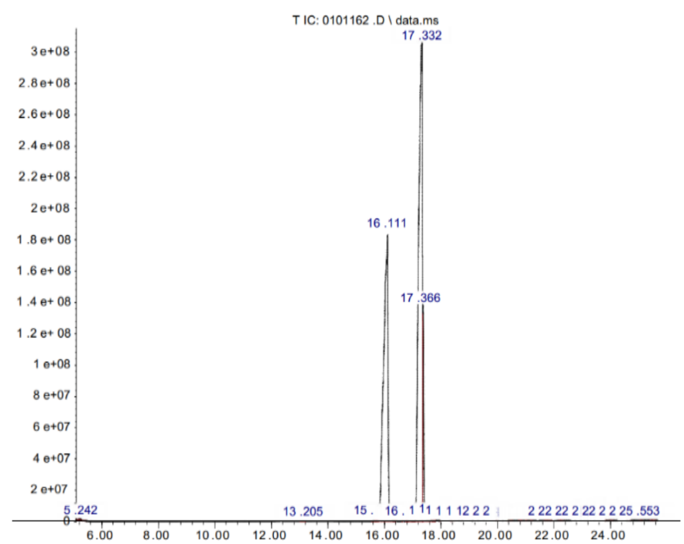

Figure 3: GC-MS Chromatogram of NSO

3.1.3 Characterisation of cutting fluids

The formulated oil-in-water emulsion (N-PCF) and commercial mineral oil cutting fluid (M-PCF) characteristics are shown in Table 4. The concentrated mineral oil was utilised in preparing the emulsion metal cutting fluid without adding any additive while the optimum values of additives obtained using $L_{16}2^4$ full factorial design for the Neem seed oil emulsion cutting fluid formulation include, emulsifier (9.35%); anticorrosion (10.61%); antioxidant (0.64%), bio-cide (0.97%). The formulated cutting fluid corrosion level was determined using the ASTM D4627 cast iron chips on filter paper [28]. However, this test was carried out to evaluate the number of corrosion spots on a test filter paper, from the formulated vegetable cutting fluids corrosive action(s). The experiment was carried out by measuring 2g of cast iron chips on a filter paper and placed on the G&G electronic scale. The particular 2ml vegetable oil cutting fluid collected was stirred and gradually poured on the iron chips in a baker, and then shaken for 2 minutes to mix the chips and fluid. The fluid was decanted and chips placed on a filter paper for 2 hours. Thereafter, the iron chips were removed and the filter paper carefully rinsed out with tap water. Table 4 shows that some of the properties of the formulated cutting fluids are in close comparison with the conventional mineral oil based cutting fluid. The pH of 8.67 recorded for N-PCF is in good agreement with the conventional cutting fluid (8.8), and also in close agreement with the reported of other authors [21], [27]. Also, at room temperature, there is similarity between the viscosity values of neem emulsion and mineral oil emulsion. This implies that at temperatures above room conditions, the fluids flow will cover the entire machined surface thereby enhancing the lubricating capabilities and cooling [29].

Table 4: Oil-in-water emulsion cutting fluids characteristics

S/N	*Property*	*N-PCF*	*M-PCF*
1	pH value	8.67	8.8
2	Viscosity (mm^2/s)	0.80	0.99
3	Corrosion level	Corrosion Resistant	Corrosion Resistant
4	Stability	Stable	Stable
5	Colour	Deep yellowish	Milky

Table 5: Experimental responses and signal-to-noise ratios.

Run	*N-PCF*				*M-PCF*			
	Response values		*Signal-to-Noise Ratios*		*Response values*		*Signal-to-Noise Ratios*	
	Surface roughness(Ra) µm	*Tool Wear (Tw) mm*	*Surface roughness(dB)*	*Tool Wear (dB)*	*Surface roughness(Ra) µm*	*Tool Wear (Tw) mm*	*Surface roughness(dB)*	*Tool Wear (dB)*
1	0.61	0.09	4.36	21.31	2.63	0.13	-9.82	18.70
2	0.42	0.15	7.55	16.34	2.86	0.10	-7.69	22.82
3	0.67	0.02	3.43	32.57	2.90	0.11	-9.92	10.76
4	0.44	0.51	7.19	5.77	2.62	0.12	-9.24	19.06
5	0.53	0.18	5.55	14.98	3.40	0.62	-6.72	22.61
6	0.45	0.20	6.87	13.93	3.14	0.29	-11.39	10.08
7	0.45	0.12	6.86	18.71	3.71	0.31	-10.62	4.13
8	0.46	0.16	6.67	15.66	4.77	1.02	-13.02	18.51
9	0.47	0.26	6.51	11.72	2.42	0.07	-13.00	17.15
10	0.48	0.13	6.45	17.46	1.40	0.13	-12.97	18.22
11	0.45	0.18	6.90	14.95	1.42	0.13	-3.03	17.78
12	0.64	0.20	3.94	13.78	2.17	0.07	-9.14	19.63
13	0.41	0.10	7.67	20.43	2.30	0.07	-2.94	17.58
14	0.50	0.39	6.10	8.23	3.10	0.12	-8.40	17.46
15	0.79	0.13	2.08	17.54	4.48	0.12	-13.01	17.79
16	0.80	0.14	1.92	17.46	4.47	0.14	-13.00	17.34
17	0.79	0.15	2.07	14.95	4.45	0.12	-13.57	-0.14
18	0.79	0.15	2.02	13.78	4.47	0.13	-13.02	17.88
19	0.81	0.14	1.86	20.43	4.47	0.14	-7.22	23.10
20	0.80	0.15	1.90	8.23	4.48	0.13	-8.37	18.43

3.1.4 Machining processes

The performances of the N-PCF and M-PCF with their individual S/N ratios are shown in Table 5. The surface roughness and tool wear of the formulated N-PCF falls within the range of 0.41–0.81µm and 0.09–0.39 mm respectively while that of the commercial M-PCF falls in the range of 2.17-4.77µm and 0.07-0.62mm respectively. The N-PCF showed minimal surface roughness compared to that of mineral oil based emulsion fluid, though both cutting fluids exhibited relatively close performances in terms of tool wear. This formulated cutting fluid outlook may be associated to the oil viscosities which have earlier been revealed to possess good fluidity and fast cooling capacity which are closely similar to that of mineral oil [30].

3.2 Analysis of experimental results

3.2.1 Analysis of variance

Analysis of variance (ANOVA) which comprises the Degree of freedom (DOF), sum of square (SS), mean square (MS), f-value (F) and percentage contribution (P) was conducted on the experimental results in order to study the percentage contributions of machining parameters on the performance of cutting fluids (N-PCF and M-PCF). The level of confidence adopted for this analysis was 95% and level of significance was5%. Also, the sum of square total (SS_T) for all ANOVAs was calculated using Equation. 1.The ANOVA results presented in Table 6 and 7 indicate that the performance (surface roughness and tool wear) of the N-PCF is most affected by cutting velocity (37.26 and 40.41%). This was followed by depth of cut (36.74 and 38.72%) and finally the least significant, feed rate (24.78 and 16.46%). This implies that feed rate has less effect on the performance of the formulated N-PCF. On the other hand, the ANOVA results for M-PCF presented in Table 6 revealed that the surface roughness of the commercial cutting fluid is most influenced by feed rate (38.289%), followed by cutting velocity (33.689) and finally, depth of cut (24.529%) while Table 7 indicates that using M-PCF, tool wear is most affected by depth of cut (58.367%), followed by feed rate (20.818%) and finally, cutting velocity (20.251%). Consequently, these results implied that the effect of cutting velocity on performance of M-PCF is less significant.

$$(SS_{Total})=\sum_{i=1}^{n} y_i^{\ 2} - \frac{1}{n}(y_i)^2 \ (i=1,2,3\ldots, 20) \quad (1)$$

Where SS = sum of square, n = number of observation and y = observations in *i*th sample

Table 6: ANOVA for Surface roughness

	N-PCF					M-PCF				
Factor	***DOF***	***SS***	***MS***	***F***	***P (%)***	***DOF***	***SS***	***MS***	***F***	***P (%)***
Cutting velocity	4	0.172	0.043	53.554	37.26	4	7.426	1.857	16.877	33.689
Feed rate	4	0.114	0.029	35.609	24.78	4	8.440	2.110	19.182	38.289
Depth of cut	4	0.170	0.042	52.806	36.74	4	5.407	1.352	12.289	24.529
Error	7	0.006	0.001		1.22	7	0.770	0.110		3.493
Total	19	0.461	0.024		100.00	19	22.043	1.160		100.000

Table 7: ANOVA for Tool wear

	N-PCF					M-PCF				
Factor	***DOF***	***SS***	***MS***	***F***	***P (%)***	***DOF***	***SS***	***MS***	***F***	***P (%)***
Cutting velocity	4	0.0884	0.0221	16.051	40.41	4	0.200	0.050	62.803	20.251
Feed rate	4	0.0360	0.009002	6.5384	16.46	4	0.206	0.051	64.559	20.818
Depth of cut	4	0.0847	0.021178	15.381	38.72	4	0.577	0.144	181.005	58.367
Error	7	0.0096	0.001377		4.406	7	0.006	0.001		0.564
Total	19	0.2188	0.011514		100	19	0.989	0.052		100.0

3.2.2 Multi-response optimization

Grey Relational Analysis (GRA) was used as a multi-response tool with the aim of combining the multi-response parameters into a single response. This type of optimization technique was adopted to ascertain the level of correlation between comparability sequence (input values) as well as the reference sequence (anticipated value), and change complex performance characteristics into a simple and single grey relational grade (GRG) value as the optimization criterion [20]. As stated by [20], the first step of GRA is the calculation of signal-to-noise (S/N) ratio of responses using smaller-the better quality characteristics (Equation 2). This is preceded by the calculation of Grey Relational Generation (GRG) using smaller-the-better attributes (Eqn. 3). The essence of the GRG is to normalize the S/N ratio values in the range between 0 and 1 [20]. The GRG was thereafter, followed by the calculation of grey relational coefficient (GRC) using Equation 4. The last step in GRA is the Grey relational grade (G-grade) calculation using Equation 5. Distinguishing coefficient (ƛ) was employed to expand or compress the range of the GRC and the accepted value is 0.5 [28].

The GRG result, GRC and G-grade for N-PCF and M-PCF are shown in Tables 8 and 9 respectively while the factor effects for N-PCF and M-PCF obtained from G-grade values are also shown in Table 10 and 11 respectively. The values in bold signifies the optimal values of experimental input factors. In addition, the main effect plots for N-PCF and M-PCF are represented in Figures 4 and 5 respectively.

Smaller-the-better, S/N = 10log $[\frac{1}{n}\sum_{i=1}^{n} k_i^2]$ (2)

Where k = response value

Smaller-the-better attributes = $\frac{A_{ij} - \underline{A}_j}{\overline{A_j} - \underline{A}_j}$ (3)

Where, A_{ij} is the individual response value and $\overline{A_j}$ = max $\{A_{ij}$, i= 1, 2, . . . , m$\}$ and $\underline{A_j}$ = min$\{x_{ij}$, i= 1, 2, . . . , m$\}$.

GRC= $\frac{\Delta_{\min} + \tau\Delta_{\max}}{\Delta_{ij} + \lambda\Delta_{\max}}$ (i= 1, 2, ...m and j = 1, 2, . . . , n) (4)

Where $\Delta_{ij} = A_{0j} - A_{ij}$ while Δ_{min} = min (0) and Δ_{max} = max (1) τ is the distinguishing coefficient, $\beta \in [0, 1]$.

Grade $= \frac{Indivisual\ GRC}{Number\ of\ responses}$ (5)

Table 8: Results of GRG, GRC and Grade (N-PCF)

	GRG		***GRC***		***Grade***
Sn	***Surface roughness***	***Tool Wear***	***Surface roughness***	***Tool Wear***	
X_o	1.00	1.00	0.00	0.00	0.00
1	0.57	0.42	0.54	0.46	0.50
2	0.02	0.61	0.34	0.56	0.45
3	0.73	0.00	0.65	0.33	0.49
4	0.08	1.00	0.35	1.00	0.68
5	0.37	0.66	0.44	0.59	0.52
6	0.14	0.70	0.37	0.62	0.49
7	0.14	0.52	0.37	0.51	0.44
8	0.17	0.63	0.38	0.58	0.48
9	0.20	0.78	0.38	0.69	0.54
10	0.21	0.56	0.39	0.53	0.46
11	0.13	0.66	0.37	0.59	0.48
12	0.64	0.70	0.58	0.63	0.60
13	0.00	0.45	0.33	0.48	0.41
14	0.27	0.91	0.41	0.85	0.63
15	0.96	0.56	0.93	0.53	0.73
16	0.99	0.56	0.98	0.53	0.76
17	0.96	0.66	0.93	0.59	0.76
18	0.97	0.70	0.95	0.63	0.79
19	1.00	0.45	1.00	0.48	0.74
20	0.99	0.91	0.99	0.85	0.92

Table 9: Results of GRG, GRC and Grade (M-PCF)

	GRG		***GRC***		*Grade*
Sn	***Surface roughness***	***Tool Wear***	***Surface roughness***	***Tool Wear***	
X_o	1.000	1.000	0.00	0.00	0.00
1	0.65	0.19	0.59	0.38	0.48
2	0.45	0.01	0.48	0.34	0.41
3	0.66	0.53	0.59	0.52	0.55
4	0.59	0.17	0.55	0.38	0.46
5	0.36	0.02	0.44	0.34	0.39
6	0.80	0.56	0.71	0.53	0.62
7	0.72	0.82	0.64	0.73	0.69
8	0.95	0.20	0.91	0.38	0.65

Sn	GRG Surface roughness	GRG Tool Wear	GRC Surface roughness	GRC Tool Wear	Grade
9	0.95	0.26	0.90	0.40	0.65
10	0.94	0.21	0.90	0.39	0.64
11	0.01	0.23	0.34	0.39	0.36
12	0.58	0.15	0.55	0.37	0.46
13	0.00	0.24	0.33	0.40	0.36
14	0.51	0.24	0.51	0.40	0.45
15	0.95	0.23	0.91	0.39	0.65
16	0.95	0.25	0.90	0.40	0.65
17	1.00	1.00	1.00	1.00	1.00
18	0.95	0.23	0.91	0.39	0.65
19	0.40	0.00	0.46	0.33	0.39
20	0.51	0.20	0.51	0.39	0.45

Table 10: Resulting Factor Effects of Experimental Factors (N-PCF)

Factor Level	*Cutting velocity(rev/min)*	*Feed rate (mm/rev)*	*Depth of cut (mm)*
Level 1	0.5384	0.4793	0.4055
Level 2	0.4865	0.4899	0.5291
Level 3	0.6807	0.6722	0.6774
Level 4	0.5237	0.5203	0.4812
Level 5	0.4608	0.6042	0.6258

Table 11: Resulting Factor Effects of Experimental Factors (M-PCF)

Factor Level	*Cutting velocity(rev/min)*	*Feed rate (mm/rev)*	*Depth of cut (mm)*
Level 1	**0.6528**	0.3643	0.3647
Level 2	0.5283	0.4744	0.4770
Level 3	0.5429	**0.5903**	**0.5908**
Level 4	0.5337	0.5877	0.5850
Level 5	0.6433	0.4577	0.4523

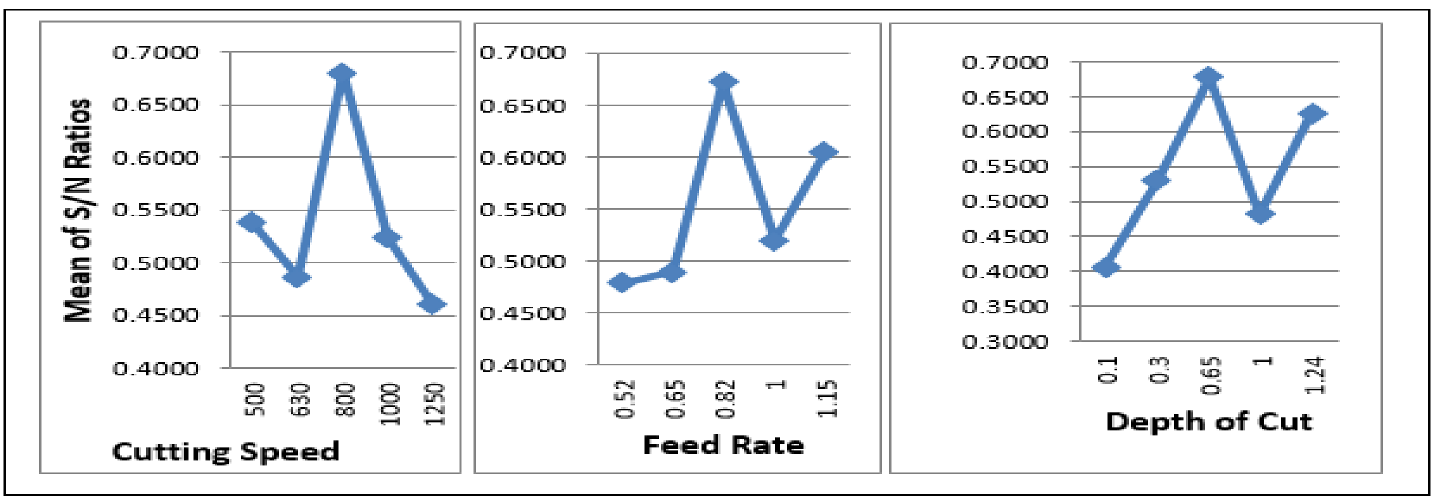

Figure 4: Main effect plot for N-PCF

Based on the result represented in Figure 4, it was found that optimal multi-response performance of the formulated N-PCF was realised when turning with cutting velocity (800 rev/min), feed rate (0.82 mm/rev) and depth of cut (0.65mm). In addition, Figure 5 shows that optimal multi-response performance of the commercial M-PCF can be realised when turning with cutting velocity (500 rev/min), feed rate (0.82 mm/rev) and depth of cut

(0.65mm). Experiments were thereafter performed using these GRA optimal values for N-PCF (Figure 4) and M-PCF (Figure 5) so as to compare the performance of the two cutting fluids. These results are presented in Table 12.

Table 12: Optimal values of experimental responses

Responses	***N-PCF***	***M-PCF***
Surface roughness (μm)	0.786	2.34
Tool Wear (mm)	0.126	0.074

The results presented in Table 12 revealed that the formulated N-PCF showed better surface roughness (0.786 μm) compared to the commercial M-PCF which produced a surface roughness of 2.34 μm while the commercial-based cutting fluid produced a lesser tool wear of 0.074mm compared to that of the formulated cutting fluid which gave a tool of 0.126mm. The differences between the values of tool wear for the two cutting fluids are negligible and can be overlooked.

As a result, based on these findings, it can be concluded that the formulated N-PCF compared favourably with commercial M-PCF and it is suitable and recommendable for application as cutting fluid in machining operations.

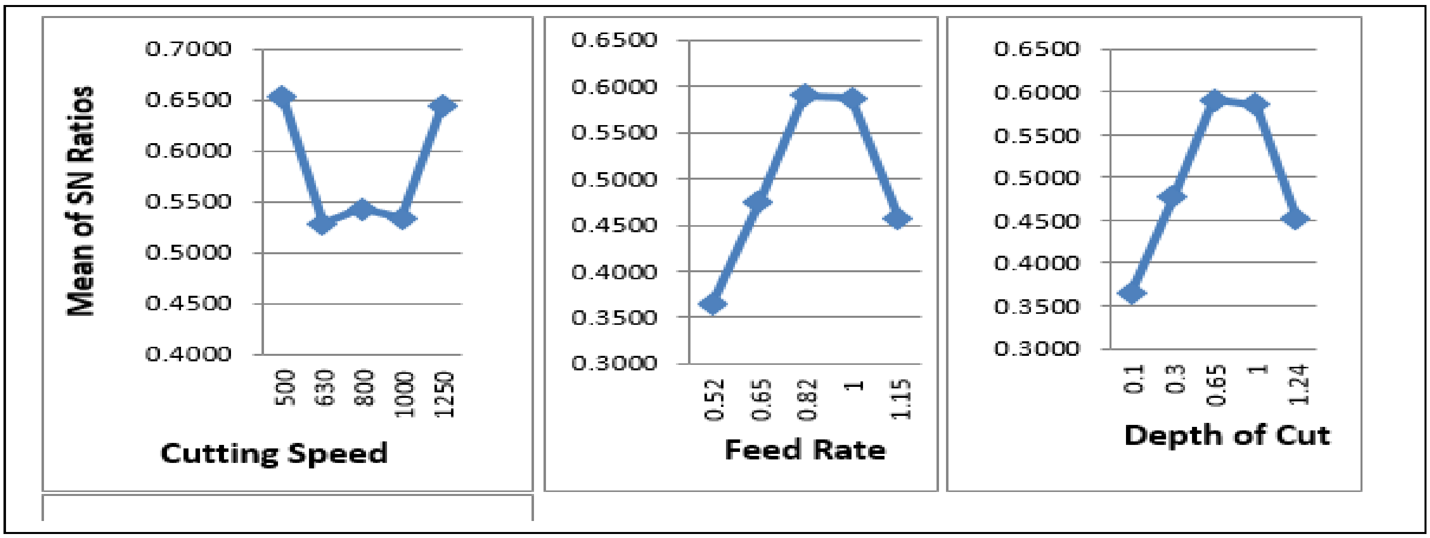

Figure 5: Main effect plot for M-PCF

4.0 CONCLUSIONS

The major contribution of this work is that novel vegetable oil-in-water emulsion cutting fluids formulations have been developed, which could be used to improve the surface roughness and tool wear during turning of AISI 304L alloy steel with coated carbide tools and contribute to the overall machined science.

The following conclusions can be drawn, based on the experimental results obtained:

(a) The fatty acid composition and physiochemical properties results of the sourced Neem seed oil were consistent with the various existing oils used in cutting fluid formulation as reported in literatures. As result, the feasibility of using neem seed oil as a substitute for mineral-based oils in cutting fluid formulation is affirmed.

(b) The performance of the formulated cutting fluid in terms of stability, corrosion resistant, pH and viscosity compared favourably with M-PCF. As a result, it is environmentally friendly as it is safe to be used as cutting fluid in machining operations.

(c) Also, the Analysis of variance (ANOVA) results revealed that the performance of the N-PCF is most affected by cutting velocity and least affected by feed rate.

(d) In the turning of AISI 304 alloy steel, the multi-response optimum performance of the formulated neem oil prepared cutting fluid can be realised when turning with cutting velocity (800 rev/min), feed rate (0.82 mm/rev) and depth of cut (0.65mm) while multi-response performance of the of the commercial M-PCF can be realised when turning with cutting velocity (500 rev/min), feed rate (0.82 mm/rev) and depth of cut (0.65mm). Employing these machining conditions, will enable minimal wear, good surface finish and overall machine product quality when turning AISI 304 alloy steel.

Conflict of Interest: The authors declare that they have no conflict of interest.

REFERENCES

[1] Das, P, Sharma, N. and Puzari A. "Synthesis and characterization of neem (*Azadirachtaindica*) seed oil-based alkyd resins for efficient anticorrosive coating application" *Polymer Bulletin.* 2020

[2] Brousseau, E. B., Dimov, S. S. and Pham, D. T. "Some recent advances in multi-material micro- and nano-manufacturing" *The International Journal of Advanced Manufacturing Technology*, 47, 2010, pp. 161–180.

[3] Lawal, S.A., Choudhury, I.A., and Nukman, Y. "Experimental Evaluation and Optimization of Flank Wear During Turning of AISI 4340 Steel with Coated Carbide Inserts Using Different Cutting Fluids" *Journal of the Institution of Engineers India: Series C. Mechanical, Production, Aerospace and Marine Engineering,* 2014.

[4] Lawal SA, Choudhury I A & Nukman Y "Application of vegetable oil-based metal working fluids in machining ferrous metals-A review" *International journal of machine tools and manufacture.* 52, 2012, pp. 1-12.

[5] Abdelrazek A. H., Choudhury, I. A, Nukman, Y. and Kazi. S. N. "Metal cutting lubricants and cutting tools: a review on the performance improvement and sustainability assessment" *The International Journal of Advanced Manufacturing Technology*, 106, 2020, pp. 4221–4245.

[6] Álvarez, M. E. P., andGonzález, F. A. "On the sustainability of machining processes. Proposal for a unified framework through the triple bottom-line from an understanding review" journal of Cleaner Production, 142(4), 2017, pp. 3890-3904.

[7] Xavior MA and Adithan M "Determining the effect of cutting fluids on tool wear and surface roughness during turning of AISI 304 austentic stainless steel" J. Mater. Process. Technol. 209, 2009, pp. 900-909.

[8] Gegor, K., Christoph, H., Mark, H., Martin, W. and Marc, B. "Modern Machining of Advanced Aerospace Alloys - Enabler for Quality and Performance" 5th CIRP Conference on High Performance Cutting 2012, Procedia CIRP 1, pp. 28 – 43.

[9] Maier, M., Zwicker, R., Akbari, M., Rupenyan, A. and Wegener, K. "Bayesian optimization for autonomous process set-up in turning" CIRP Journal of Manufacturing Science and Technology, Volume 26, Pages 81-87.

[10] Sevim, Z. E., Brajendra, K. S.,Zengshe, L. and Atanu, A. "Lubricant Base Stock Potential of Chemically Modified Vegetable Oil, Journal of Agricultural and Food Chemistry" 56(19), 2008, pp. 8919–8925.

[11] Ademoh, N. A., Didam, J. H. And Garba. D. K. "Investigation of Neem Seed Oil as an Altanative Metal Cutting Fluid" *American Journal of Mechanical Engineering*, 4(5), 2016, pp. 191-199.

[12] Robbers, J. E., Speedie, M.K. and Tyler, V.E. "Pharmacognosy and Pharmacobiotechnology", Williams & Wilkins, Batimore, 1996, pp. 64–71.

[13] Wodarz, D. and Nowak, D.A. Proc. Natl. Acad. Sci. USA 1999, 96 (25), pp. 14464–14469.

[14] Gossé, B., Amissa, A.A., Anoh, A.F., Bobélé, N.F.,

Ollivier, D. And Yoichiro, I. "Analysis of Components of Neem (Azadirachtaindica) Oil by Diverse Chromatographic Techniques" Journal of Liquid Chromatography & Related Technologies, 28(14), 2007, pp. 2225-2233.

[15] Onuoha, O.J., "Determining the Effect of Cutting Fluids on Surface Roughness in Turning AISI 1330 Alloy Steel Using Taguchi Method" Modern Mechanical Engineering, 6, 2016, pp. 51-59.

[16] Anuj, K. S., Rabesh, K. S., Amit, R. D. and Arun, K. T. "Novel uses of alumina-MoS2 hybrid nanoparticle enriched cutting fluid in hard turning of AISI 304 steel" *Journal of Manufacturing Processes* 30, 2017, pp. 467-482.

[17] Sarmad A. K., Sumbul, S., Saqib, A., Amjad, H., Shafiq, A. and Mustafa, S. "Wear performance of surface treated drills in high speed drilling of AISI 304 stainless steel" *Journal of Manufacturing Processes*, 58, 2020, pp. 223-235.

[18] Talib, N., Sasahara, H. and Rahim, E. A. "Evaluation of modified jatropha-based oil with hexagonal boron nitride particle as a biolubricant in orthogonal cutting process" *The International Journal of Advanced Manufacturing Technology,* 92, 2017, pp. 371–391.

[19] Jagadish, D. and Amitava, R. "Optimization of process parameters of green electrical discharge machining using principal component analysis (PCA)" *The International Journal of Advanced Manufacturing Technology* 87, 2016, pp. 5-8:1-13.

[20] Abutu, J., Lawal, S.A., Ndaliman, M.B., Lafia-Araga, R.A., Adedipe, O. and Choudhury, I. A. “Production and Characterization of Brake pad developed from Coconut shell reinforcement material using Central Composite Design” *SN Applied Sciences*, 2019, pp. 1:18.

[21] Agu, C. K., Lawal, S. A., Abolarin, M. S., Agboola, J. B., Abutu, J. and Awode, E. I. “Multi-Response Optimisation of Machining Parameters in Turning AISI 304l using Different Oil-Based Cutting Fluids” *Nigerian Journal of Technology*, 38(2), 2019, pp. 364 – 375.

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

[23] Olaiya, K. A., Lawal, S. A., Babawuya, A. and Adedipe, O. “Parameters Optimisation of Energy Consumption in Turning of AISI 304 Alloy Steel” *Nigerian Journal of Technology, 39(2),* 2020, pp. 452 – 463.

[24] Senthil K. K., and Senthilkumaar, J.S. “Analysis and Optimization of Output Parameters using Taguchi Design Analysis. Recent Patents on Mechanical Engineering” **7(2),** 2014.

[25] Eze, S.O.O. “Physico-chemical properties of oil from some selected underutilized oil seeds available for biodiesel preparation” Afr Journal Biotechnol, 11(42), 2012, pp.10003–10007.

[26] Nzikou, J.M., Mvoula-Tsiér, M., Ndangui, C.B., Pambou-Tobi, N.P.G., Kimbonguila, A., Loumouamou, B. “Characterization of seeds and oil of sesame (Sesamumindicum L.) and the kinetics of degradation of the oil during heating” Res J Appl Sci Eng Technol, 2(3),2010, pp. 227–232.

[27] Kazeem, R.A., Fadare, D.A., Abutu, J.,Lawal, S.A. and Adesina, O.S. “Performance evaluation of jatropha oil-based cutting fluid in turning AISI 1525 steel alloy” CIRP *Journal of Manufacturing Science and Technology*, 31, 2020, pp. 418–430.

[28] Awode E.I., Abolarin M.S., Lawal S.A., Adedipe O. “Performance Evaluation of Jatropha Seed Oil and Mineral Oil-Based Cutting Fluids in Turning AISI 304 Alloy Steel” *International Journal of Engineering Materials and Manufacture*, 5(3), 2020, pp. 85-97.

[29] Kuram, E., Simsek, B.T., Ozcelik, B., Demirbas, E., Askin, S. “Optimization of the cutting fluids and parameters using Taguchi and ANOVA in milling” Proceedings of World Congress Engineering, 2, 2010, pp. 1–5.

[30] Carlos, A.S.B., Janaina, F.S.G., Jefferson, O.G., Jordao, G. “Performance of the jatropha vegetable-base soluble cutting oil as a renewable source in the aluminum alloy 7050-T7451 milling” CIRP Journal of Manufacturing Science and Technology, 7, 2014, pp. 210–221.