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PARAMETERS OPTIMISATION OF ENERGY CONSUMPTION IN TURNING OF AISI 304 ALLOY STEEL

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ABSTRACT

The need to reduce energy consumption in production processes becomes paramount due to environmental effect of electrical energy sourced from fossil fuel. This research addresses this challenge in orthogonal turning of AISI 304 Alloy Steel. Orthogonal turning operations were carried out in dry and wet conditions using mineral oil based and vegetable oil based cutting fluids. While turning, the effect of input parameters which include cutting speed, feed rate and depth of cut on the energy consumption and surface roughness were studied and empirical models to enhance minimum energy consumption and surface roughness were proposed. Minitab 17 statistical software via RSM was used for experimental design. Multi-response optimisation was also carried out using GRA. The result shows the optimum cutting parameters for dry environment as cutting speed of 396.46 rev/min, feed rate of 1.17mm/rev and depth of 0.5mm. For wet turning with mineral oil based cutting fluid, the results are 600 rev/min cutting speed, 0.33mm/rev feed rate and 0.01mm depth of cut. Wet turning with vegetable oil based cutting fluid shows optimal combined process parameters of 600 rev/min cutting speed, 0.5mm/rev feed rate and 0.25mm depth of cut. ANOVA shows that in dry turning, depth of cut has the most significant effect of 83.11%, in wet turning with mineral oil based cutting fluid, cutting speed has the most significant effect of 38.87% while wet turning with vegetable oil based cutting fluid, feed rate shows the most significant effect of 52.44%

Keywords: *Machining, Turning, Vegetable oil, mineral oil, surface roughness, energy consumption and grey relational analysis.*

1. INTRODUCTION

Manufacturing sector is a key industry that relies on the use of energy in driving value addition through manufacturing processes. Machining, which is one of the existing manufacturing methods is the process of removing material from a workpiece in form of chips. Machining process is usually necessary where light tolerances on dimension and fine surface finish is required. Turning is a machining operation where the workpiece is primarily rotated and then moved against the cutting tool to facilitate cutting. The need for reduction of energy consumption of manufacturing processes becomes very paramount in view of rising concern arising from the depletion of fossil fuels and the climate change associated with such sources for generation of electricity [1]. Also, it is important to ensure minimal surface roughness in machining processes in order to enhance machining performance

Workpiece properties are a functional component of the machining energy consumption. Selecting tougher material, for example Titanium alloy gives certain advantages to the component such as high specific strength and corrosion resistance [2]. Astakhov and Xiao [3] also proved that the energy spent in a cutting system can be utilized indirectly to evaluate the cutting force while [4] revealed that monitoring and analysis of a machine tools energy

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consumption can be helpful in explaining the behaviour of the cutting processes. [5] investigated the effect of vegetable and mineral oil in water emulsion cutting fluid in turning AISI 4340 steel with coated carbide tools, In their experimental study, it was shown that palm kernel oil PKO and cotton seed oil CSO based cutting fluids are suitable for use in machining process as they reduce occupational health risks and lower costs towards waste treatment due to their higher biodegradability and better performance rate. According to [6], minimising the energy consumption for the machining process can lead to the benefits for the environment as well as contribute to the economic and social well being of the society. [7], looked at the improvement of energy efficiency for end milling operation. An energy prediction model and efficient profiling tooth path strategy were proposed. At the machine tool design phase, investigations have been carried out to synchronize the spindle acceleration/deceleration with rapid feed movement in other to lower the energy required [8]. [9], proposed a method to use the recovered energy from the spindle deceleration by applying a kinetic energy recovery system (KERS). [10], [11], and [12], researched into machine tools in operation. They investigated into energy minimization through selection of optimal process parameters. For over 100 years since Taylor published his tool life equations in 1907, the research of improving machining performance by selecting optimal process parameters have been conducted [13]. Also, relationships between outputs and inputs can be obtained by using design of experiment principles. Process outputs such as surface roughness and residual stresses can be modelled by empirical modelling since they are influenced by hard-to-model factors. [14], [15] and [16]. Therefore, despite the fact that a lot of research work have been done on orthogonal cutting, the need to reveal the energy consumption in orthogonal turning of the selected material- AISI 304 has not been noticeably researched. Reduction of energy consumption in turning will reduce production cost and also enhance green production. An energy efficient turning model will enhance optimal selection of cutting environment, cutting variables- cutting speed, feed rate and depth of cut, which will ultimately reduce to the barest minimum, the energy consumption. The model will also accomplish precise surface roughness of the machined work-piece and ultimately enhance the turning efficiency, manufacturing economy and environmental friendly manufacturing (EFM). As a result, this study will cover the development of vegetable oil based cutting fluid using jathropha oil as base stock. Mineral oil based cutting fluid will also be formulated using the commercially available mineral oil as base stock. Orthogonal turning experiment shall then be carried out on AISI 304 alloy steel in dry, which is the turning operation where cutting fluid is not applied and wet, which is the turning operation where cutting fluid is applied. In machining, cutting fluid act as lubricant to minimise friction and heat generated between the cutting tool and workpiece as well as a coolant to take away the heat generated. The formulated mineral oil-based (cutting fluid prepared from mineral oil) and vegetable oil-based (cutting fluid prepared from vegetable oil and additives which include emulsifier, biocide, anti-corrosion and anti-oxidant) cutting fluids were used. In this study, response surface methodology (RSM) will be used and this is because it contains and imbedded factorial design with centre point augmented with a group of star points (axial points). The effects of process parameters on energy consumption and surface roughness will be studied. The cutting variables to be investigated are cutting speed, feed rate and depth of cut under different cutting environment.

2. MATERIALS AND METHODS

2.1 Materials and Equipment

2.1.1 Materials

The materials used for the machining processes include an experimental workpiece AISI 304 Alloy steel sourced from Orile-Iganmu Lagos and characterized at Midwal engineering, Lagos to ascertain the elemental composition, CNMG 1204082H tungsten coated carbide tool insert (Model: DCLNR 2020 K/Z, Widia India Tools), mineral oil-based cutting fluid and vegetable oil based cutting fluid.

2.1.2 Equipment

In this study, the equipment used include CNC lathe (PRODIS corporation, Taichung, Taiwan, Model: 2060 ENC). surface roughness was measured using a surface roughness tester (Model SRT – 6200, ±10% accuracy, Merit-mi Instruments Co., Ltd.) and hand-held digital clamp meter (Model: DT – 266, 50 – 60Hz frequency range) for measuring current and voltage.

Table 1: Factor Levels of input factors

Factor	Unit	Lower cubic point (-1)	Upper cubic point (+1)	Center point (0)	Upper Axial point (+1.64)	Lower Axial point (-1.64)
Cutting speed	rev/min	600	1200	900	1404.54	395.5
Feed rate	mm/rev	0.5	1.0	0.75	1.17045	0.330
Depth of cut	mm	0.25	0.50	1.2	0.920	0.0796

2.2 Methods

2.2.1 Design of Experiment

Experimental design was carried out in accordance with Response surface methodology (RSM)-Central composite design (CCD) $L_{20}(5)^3$ design technique using Minitab 17 statistical software. The factor levels of input factors are shown in Table 1 while the experimental design layout is shown in Table 2.

Table 2: RSM-CCD $L_{20}(5)^3$ Experimental Design Layout

Run order	Cutting speed Vc (rev/min)	Feed rate Fr (mm/rev)	Depth of cut doc (mm)
1	600	0.5	0.25
2	600	0.5	0.75
3	600	1	0.25
4	600	1	0.75
5	1200	0.5	0.25
6	1200	0.5	0.75
7	1200	1	0.25
8	1200	1	0.75
9	395.46	0.75	0.5
10	1404.54	0.75	0.5
11	900	0.32955	0.5
12	900	1.17045	0.5
13	900	0.75	0.079552
14	900	0.75	0.92
15	900	0.75	0.5
16	900	0.75	0.5
17	900	0.75	0.5
18	900	0.75	0.5
19	900	0.75	0.5
20	900	0.75	0.5

2.2.2 Machining Process

All turning experiments were conducted on a 3-jaw CNC lathe machine made by PRODIS with variable speed of 26 – 2400 rpm and 5 Hp rated power. Rhombic shaped Tungsten coated carbide tool inserts CNMG 120408RH by Widia Tools, mounted on a right hand tool model DCLNR 2020 k 12 (produced by WIDIA Tools) was used with a new cutting edge for each experiment.

The investigation of energy consumption and surface roughness were conducted on stainless steel (AISI 304) round bars of 25mm diameter by 600mm length fixed on the 3-jaw dependent chuck of the CNC lathe and then centre-drilled. The workpiece was then re-positioned on the chuck with an overhang length of 550 mm and also supported with a revolving centre positioned on the tail stock. Firm holding of the workpiece was achieved by proper tightening of the 3-jaw dependent chuck after ascertaining the concentricity of the mounted workpiece. Orthogonal turning operations were carried out at ambient temperature and the workpiece was turned at different cutting speeds, feed rates and depth of cut as specified in Table 2. The Experimental set up for turning process showing all components is shown in Plate I.

2.2.3 Measurement of current and voltage

(a) Current

For each experimental run, the clamp meter was used in measuring the current flowing through each of the 3-phase mains wire (red, yellow and blue phase wires).

The measurements were accomplished by setting the knob of the instrument to current mode and then clamp the jaws of the clamp meter around the phase wire. The current flowing through the wire then displayed on the instrument and was noted and recorded. The current flowing through red, yellow and blue phases were recorded as I_R, I_Y and I_B respectively. The experiment was conducted for wet with mineral oil based cutting fluid as well as wet with vegetable oil based cutting fluid environments respectively.

Clamp meter was also used to measure the voltage on each phase. This was accomplished by setting the knob of the instrument to voltage mode and then connected to the mains supply wire. The voltages for red, yellow and blue phases were recorded as V_R, V_Y and V_B respectively. Plate II shows the Experimental set up for measurement of current and voltage.

2.2.4 Surface roughness measurement

Surface integrity of each machined portion was measured using surface roughness tester (Model: STR-6210S, ± 10% accuracy; Guang Zhou Landtek). Measurements were taken at three locations around the circumference and along the length of the round bar workpiece and the average of the three readings evaluated and recorded for each experiment. Plate III shows the set up for measuring surface roughness of turned surface.

2.2.5 Calculation of energy consumption

The process involved in the calculation of energy consumption for each experimental run involves evaluation of power consumption and energy consumption.

The power consumption was determined by determining the apparent power, true power and finally the power consumption as shown in Equations. 1-6 [17].

Apparent power = Voltage (V) x current (I) (1)

(b) Voltage

True power $P_T = V \times I \times p.f$ (Watts) (2)

Where p.f is power factor = 0.8 [17]

The true power on each phase is thus calculated as shown in Equations 3-5:

Red phase; power $P_R = V_R \times I_R \times p.f$ (3)

Yellow phase, power $P_Y = V_Y \times I_Y \times p.f$ (4)

Blue phase, power $P_B = V_B \times I_B \times p.f$ (5)

Therefore, power consumption for each experimental run is shown in Equation. 6.

$P_i = P_R + P_Y + P_B$ (6)

Where i = run order number = 1, 2, 3 -------- 20.

Therefore, specific energy consumption for each experimental run in dry, wet with mineral oil based cutting fluid and wet with vegetable oil based cutting fluid was calculated using Equation. 7 [18].

Specific energy consumption:

$Es = \frac{P_i}{V_c \, x \, f \, x \, d}$ (J/mm^3) (7)

Where P_i = power consumption, V_C = cutting speed (mm/min), f = feed rate (mm/rev) and d = depth of cut (mm).

Plate I: Experimental set up for orthogonal turning process showing all components

Plate II: Experimental set up for measurement of current and voltage using clamp meter

Plate III: Set up for measurement of surface roughness of turned surface.

Cutting speed (V_c) was calculated using Equation. 8.

$$V_c = \frac{\pi DN}{1000} \quad (8)$$

Where D = diameter of workpiece (25mm), N = spindle speed (rev/min).

3. RESULTS AND DISCUSSIONS

3.1 Experimental results and Signal to noise (S/N) ratios

The results of the experiment carried out using the experimental design layout along with their respective signal-to noise (S/N) ratio values are shown in Table 6. It can be observed that as the value of process parameters varies, responses values also changes (specific energy consumption and surface roughness). Signal-to noise (S/N) ratios of individual responses were calculated using Equation. 9.

Smaller-the better:

$$S/N = -10\log\frac{1}{n}\left(\sum_{i-1}^{n} y_i^2\right) \quad (9)$$

Where y = responses of given factor level combination and n = number of experimental samples

3.2 Analysis of Experimental Results

3.2.1 Analysis of Variance (ANOVA)

ANOVA was conducted to study the significant effects of experimental factors. This analysis was conducted using confidence level of 95 % at significant level of 5 %. Table 7 and 8 show the degree of freedom (DOF), sum of square (SS), mean square values (MS), f-value and percentage contribution (p) of surface roughness and specific energy consumption (Es) for dry turning, wet turning with mineral oil-based and wet turning with vegetable oil-based cutting fluids

As shown in Table 7, it can be observed that the dry turning produced a percentage error of 5.78 % with depth of cut (83.11%) indicating the most significant parameter, followed by feed rate (6.42%) and cutting speed (4.69%) which is the least significant factor. It can also be observed that in wet turning with mineral oil based cutting fluid, the percentage error obtained was 0.325% while the most significant parameter was cutting speed (38.87%) followed by feed rate (31.05%) and the least significant being depth of cut (29.8). Finally in wet turning with vegetable oil based cutting fluid, the percentage error obtained was 3.6% while the most significant parameter was feed rate (52.44%) followed by depth of cut (24.14%) and the least significant being cutting speed (20.16%). All the factors have significant effect since their individual P-value are greater than 0.05%.

The ANOVA for surface roughness in dry turning shown in Table 8 showed a percentage error of 7.66 while depth of cut (43.05 %) specifies the most significant parameter, followed by feed rate (36.62 %) and cutting speed (12.67 %) being the least significant. Also, the ANOVA for surface roughness in wet turning with mineral oil based cutting fluid presented in Table 9 showed a percentage error of 4.108 while depth of cut (37.69 %) specifies the most significant parameter, followed by feed rate (34.60 %) and cutting speed (23.603 %) being the least significant. Finally, the ANOVA for surface roughness in wet turning with vegetable oil based cutting fluid presented in Table 8 showed a percentage error of 3.09 while feed rate (92.77 %) specifies the most significant parameter, followed by cutting speed (3.00 %) and depth of cut (1.14 %) being the least significant. The effects of all the factors are significant since their individual p-values are greater than 0.05%.

3.2.2 Empirical Model Equations

The empirical model equations for both specific energy consumption (Es) and surface roughness (Ra) for dry turning, wet turning with mineral oil based cutting fluid and wet turning with vegetable oil based cutting fluid along with their respective Rsq values are shown in Equations 10 to 14. The independent variables considered in this analysis include cutting speed (CS), feed rate (FR) and depth of cut (DOC).

For dry turning;

Es = 639 - 0.103 CS-184 FR – 447 DOC (10)

R-sq = 65.41%, R-sq (adj) = 53.29%

Surface roughness Ra (μm) = 2.15 - 0.00034 CS + 2.17 FR + 2.15 DOC (11)

R-sq = 74.29%, R-sq (adj) = 60.77%

For wet turning with mineral oil-based cutting fluid;

Energy consumption, Es = 390.6 – 0.1867 CS – 195.9 FR + 123.9 DOC (12)

S = 58.6928, R-sq = 67.20%, R-sq (adj) =55.11%

Surface roughness Ra (μm) = 2.83 + 0.001050 CS - 0.007 FR - 1.465 DOC (13)

R-sq = 64.80%, R-sq (adj) =50.80%

For wet turning with vegetable oil-based cutting fluid;

Specific Energy consumption Es = 377.6 - 0.0801 CS - 183.9 FR - 64.2 DOC (14)

R-sq = 72.64%, R-sq(adj) = 61.88%

Surface roughness Ra (µm) = -0.078 - 0.000438 CS + 4.022 FR + 0.085 DOC (15)

R-sq = 91.03%, R-sq(adj) = 89.34%

The Rsq values for some of the responses are slightly less than 80 %. This may be due to noise which may result from experimental uncertainty.

3.2.3 Contour and 3D Surface Plots

The contour as well as 3-D surface plots of specific energy consumption and surface roughness for dry turning, wet turning with mineral oil and wet turning with vegetable oil are shown in Figures 1 - 6.

Figure 1 – 6 show how change in cutting speed and feed rate affect the Specific energy consumption and Surface roughness when the depth of cut is kept constant at 0.499mm. The plot also indicate that as cutting speed increases, feed rate also increases and vice versa. Various colours here only indicate the contour within which the cutting variables can be selected to accomplish a pre-determined range of values of energy consumption or surface roughness. For example, from figure 1, when the value of depth of cut is held or kept constant at a value of 0.499mm, to accomplish a value of energy consumption between 150-200J/mm^3, feed rate and cutting speed should be selected from the contour covered by fairly light green colour. The 3D plots show how the changes in input parameters affect the response values in 3-dimension. Contour plot is of 2-dimension while 3D surface plot is of 3-dimension. The explanation of colour given above for contour plots also hold for 3D surface plots.

3.4 Grey Relational Analysis (GRA)

As specified by [19], GRA optimization procedure involves using the S/N ratios values shown in Table 6 to calculate the grey relational generation (GRG) of individual responses using smaller-the-better attributes (x_{ij}) as shown in Equation 15. This is followed by the conversion of GRG to grey relational coefficient (GRC) using Equation 16. The final stage of GRA was the calculation of grey relational grade using Equation 17. The results of GRA are shown in Table 9.

Smaller-the better, $(x_{ij}) = \dfrac{\overline{y}_{ij} - y_{ij}}{\overline{y}_j - \underline{y}_j}$ (i = 1, 2, 3…. m and j = 1, 2, 3…. n) (16)

Where, y_i is the response value of attribute j of alternative i and $\overline{y}_j$ = maximum value and $\underline{y}_j$ = minimum value of y.

$$GRC;\xi i(k) = \frac{\Delta \min + p\Delta \max}{\Delta xi(k) + p\Delta \max} \quad (17)$$

Where Δ min = minimum value of GRG, Δ max = minimum value of GRG and p = distinguishing coefficient is between 0 -1 but usually set at 0.5 (Agu *et al.*, 2019).

Grey relational grade= $\dfrac{Sum\ of\ Individual\ GRC}{Total\ numbers\ of\ \mathrm{Re}\, sponses}$ (18)

The results of GRG, GRC and Grey relational grades for both dry and wet cutting fluid are shown in Table 9.

The resulting factor effects of the experimental factors obtained using the GRA-grades as shown in Table 9 are shown in Tables 10. The main effect plots obtained using Table 10 are shown in Figures 7-9.

As shown in Figure 7, it can be observed that the optimal level of parameters for both responses in dry turning are cutting speed of 395.46 rev/min, feed rate of 1.17045mm/rev and depth of cut of 0.5mm. From Figure 8, the optimal level of parameters in wet turning with mineral oil based cutting fluid are cutting speed of 600 rev/min, feed rate of 0.32955mm/rev and depth of cut of 0.007955mm.

From Figure 9, the optimal level of parameters in wet turning with vegetable oil based cutting fluid are cutting speed of 600 rev/min, feed rate of 0.5mm/rev and depth of cut of 0.25mm

3.5 Confirmation test

The regression models - Equations 10-15 for cutting parameters which include cutting speed, feed rate and depth of cut were obtained from regression analysis using design expert statistical software. The calculated results from the models, the experimental values and the percentage error are presented in Table 11.

Table 6: Experimental Results and S/N Ratios for dry, wet turning with mineral oil and wet turning with vegetable oil

Run order	dry turning				wet turning with mineral oil				wet turning with vegetable oil			
	Es (J/mm^3)	S/N for Es (dB)	R_a (µm)	S/N for Ra (dB)	Es (J/mm^3)	S/N for Es (dB)	R_a (µm)	S/N for Ra (dB)	Es (J/mm^3)	S/N for Es (dB)	R_a (µm)	S/N for Ra (dB)
	318.031	-2.542	1.34	-50.049	233.195	-35.280	2.73	-10.291	305.53	-47.950	1.41	-3.918
	118.012	-11.618	3.81	-41.439	354.035	-48.048	1.25	-11.005	107.903	-35.945	1.15	-12.506
	270.897	-14.776	5.48	-48.656	53.523	-48.704	3.93	-8.498	154.826	-45.858	3.74	-8.432
	60.038	-17.975	7.92	-35.569	245.08	-34.571	1.57	-11.888	62.698	-37.491	4.22	-8.165
	100.100	-12.547	4.24	-40.009	39.908	-29.244	2.85	-4.028	94.644	-42.056	1.33	-11.687
	247.802	-12.361	4.15	-47.882	272.384	-42.955	2.66	-12.790	249.738	-41.798	1.57	-10.103
	49.257	-12.869	4.40	-33.849	140.521	-32.021	4.36	-9.097	122.994	-39.522	3.22	-2.477
	124.748	-12.403	4.17	-41.921	47.153	-41.936	2.70	-10.604	41.136	-41.965	3.41	-8.432
	195.166	-14.236	5.15	-45.808	252.588	-41.883	5.55	-9.855	196.292	-41.879	2.64	-9.188
	88.941	-14.420	5.26	-38.982	27.152	-41.725	4.27	-10.501	74.082	-41.912	2.18	-8.498
	293.122	-13.715	4.85	-49.341	180.877	-45.148	3.43	-10.706	276.336	-48.829	1.085	-0.709
	85.785	-12.568	4.25	-38.668	28.987	-50.981	1.59	-1.938	126.703	-49.703	3.84	-2.984
	864.208	-6.319	2.07	-58.732	75.242	-28.676	2.86	-12.609	76.547	-37.394	2.78	-6.769
	68.385	-11.364	3.70	-36.699	58.074	-47.354	3.27	-8.723	74.913	-40.661	2.56	-1.214
	132.500	-14.066	5.05	-42.444	124.973	-41.775	3.39	-10.397	124.144	-41.822	2.88	-8.432
	136.032	-14.420	4.87	-38.982	124.214	-41.932	3.11	-10.655	124.624	-41.822	2.66	-9.367
	132.300	-13.715	5.15	-49.341	121.964	-33.470	3.35	-8.627	123.338	-32.284	2.64	-10.630
	132.178	-12.568	4.88	-38.668	122.672	-41.933	3.31	-9.966	123.335	-41.893	2.94	-9.188
	131.010	-6.319	4.76	-58.732	124.907	-37.529	3.41	-9.127	124.352	-37.679	2.88	-8.881
	134.500	-11.364	5.48	-36.699	124.921	-47.786	3.15	-3.918	125.381	-43.797	2.64	-11.457

Table 7: ANOVA for Specific energy consumption

Factors	DOF	dry turning				wet turning with mineral oil				wet turning with vegetable oil			
		SS	MS	F	P(%)	SS	MS	F	P(%)	SS	MS	F	P(%)
CS (rev / min)	4	28150	7037.5	1.42	4.69	62548	15637	209.5	38.9	19035	4758.8	10.80	20.16
FR (mm / rev)	4	38545	9636.3	1.94	6.42	49978	12494.5	167.4	31.1	49525	12381.3	28.11	52.44
DOC (mm)	4	498967	124741.8	25.2	83.1	47886	11971.5	160.40	29.8	22799	5699.8	12.94	24.14
Error	74	34684.34	4954.91		5.78	522.48	74.64		0.325	3083.4	440.5		3.26
Total	80	600346.34	31597.18		100	160934.5	8470.24		100	94442.4	4970.7		100

Table 8: ANOVA for Surface roughness

Factors	DOF	dry turning				wet turning with mineral oil				wet turning with vegetable oil			
		SS	MS	F	P (%)	SS	MS	F	P (%)	SS	MS	F	P (%)
CS(rev/min)	4	4.20	1.05	40.36	12.67	3.033	0.758	10.056	23.603	0.463	0.116	1.697	2.998
FR(mm/rev)	4	12.14	3.03	47.19	36.62	4.446	1.112	14.741	34.60	14.321	3.580	52.510	92.770
DOC (mm)	4	14.27	3.57	49.24	43.05	4.843	1.211	16.057	37.69	0.176	0.044	0.646	1.141
Error	74	2.54	0.36		7.66	0.528	0.0754		4.108	0.477	0.068		3.092
Total	80	33.14	1.74		100	12.850	0.6763		100	15.437	0.812		100.000

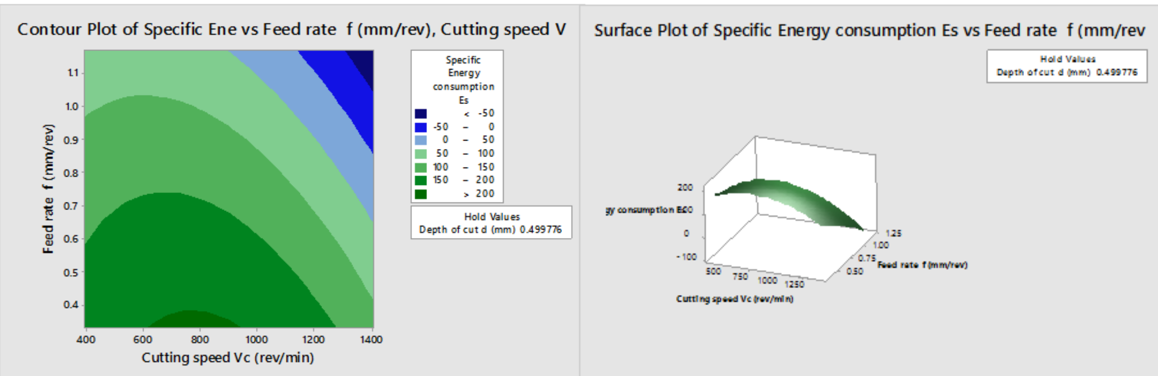

Figure 1: Contour and 3D Surface plots for specific energy consumption (dry turning)

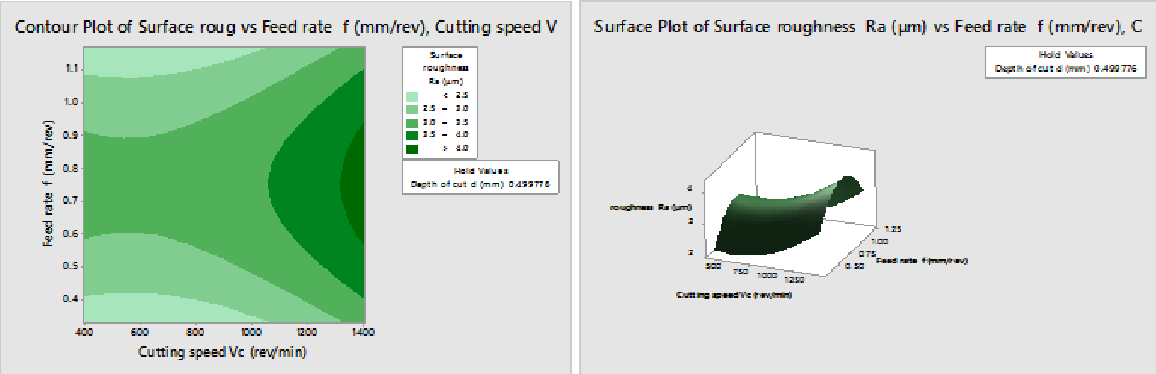

Figure 2: Contour and 3D surface plots for surface roughness (dry turning)

Table 9: Results of Grey Relational Analysis

Run order	Dry Turning					Wet turning with mineral oil based cutting fluid					wet turning with vegetable oil based cutting fluid				
	GRG		GRC		Grade	GRG		GRC		Grade	GRG		GRC		Grade
	Es	Ra	Es	Ra		Es	Ra	Es	Ra		Es	Ra	Es	Ra	
	0.651	0.000	0.589	0.333	0.461	0.296	0.783	0.415	0.697	0.556	0.899	0.272	0.832	0.407	0.620
	0.305	0.588	0.418	0.548	0.483	0.869	0.850	0.792	0.769	0.780	0.210	1.000	0.388	1.000	0.694
	0.595	0.793	0.553	0.707	0.630	0.898	0.615	0.830	0.565	0.698	0.779	0.655	0.694	0.591	0.643
	0.069	0.000	0.349	1.000	0.675	0.264	0.932	0.405	0.881	0.643	0.299	0.632	0.416	0.576	0.496
	0.248	1.648	0.399	0.587	0.493	0.025	0.196	0.339	0.383	0.361	0.561	0.931	0.532	0.878	0.705
	0.564	0.636	0.534	0.599	0.557	0.640	1.017	0.582	1.035	0.808	0.546	0.796	0.524	0.711	0.617
	0.000	0.669	0.333	0.602	0.468	0.150	0.671	0.370	0.603	0.487	0.416	0.150	0.461	0.370	0.416
	0.324	0.639	0.425	0.581	0.503	0.594	0.812	0.552	0.727	0.640	0.556	0.655	0.530	0.591	0.561
	0.481	0.758	0.490	0.674	0.582	0.592	0.742	0.551	0.660	0.605	0.551	0.719	0.527	0.640	0.583
	0.206	0.770	0.386	0.685	0.536	0.585	0.802	0.546	0.717	0.632	0.553	0.660	0.528	0.595	0.562
	0.623	0.724	0.570	0.644	0.607	0.738	0.822	0.657	0.737	0.697	0.950	0.000	0.909	0.333	0.621
	0.194	0.650	0.383	0.588	0.485	1.000	0.000	1.000	0.333	0.667	1.000	0.193	1.000	0.383	0.691
	1.000	0.245	1.000	0.398	0.699	0.000	1.000	0.333	1.000	0.667	0.293	0.514	0.414	0.507	0.461
	0.115	0.572	0.361	0.539	0.450	0.837	0.636	0.755	0.579	0.667	0.481	0.043	0.491	0.343	0.417
	0.345	0.747	0.433	0.667	0.548	0.587	0.793	0.548	0.707	0.627	0.548	0.655	0.525	0.591	0.558
	0.206	0.770	0.386	0.685	0.536	0.594	0.817	0.552	0.732	42	0.543	0.734	0.525	0.653	0.589
	0.623	0.724	0.570	0.644	0.607	0.215	0.627	0.389	0.573	0.481	0.000	0.841	0.333	0.759	0.546
	0.194	0.650	0.383	0.588	0.485	0.594	0.752	0.552	0.669	0.610	0.552	0.719	0.527	0.640	0.584
	1.000	0.245	1.000	0.398	0.699	0.397	0.674	0.453	0.605	0.529	0.310	0.693	0.420	0.619	0.520
	0.115	0.572	0.361	0.539	0.450	0.857	0.186	0.777	0.380	0.579	0.661	0.911	0.596	0.849	0.722

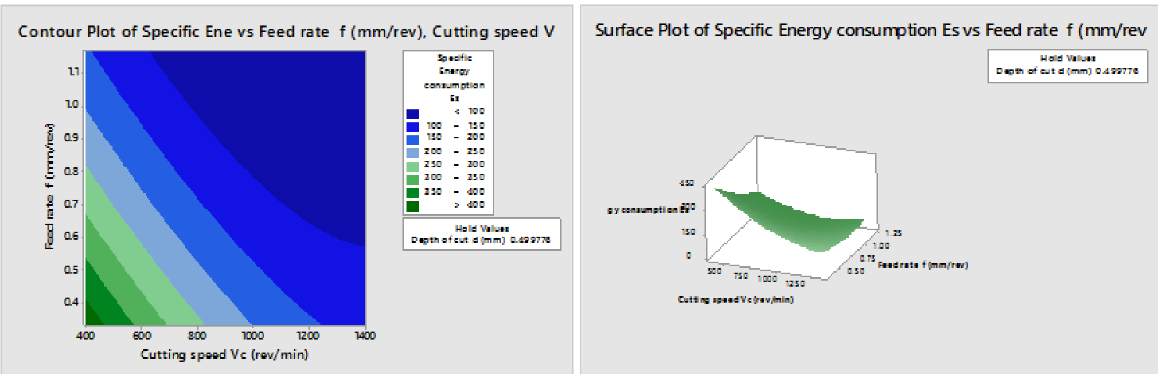

Figure 3: Contour and 3D Surface plots for specific energy consumption (mineral oil based cutting fluid)

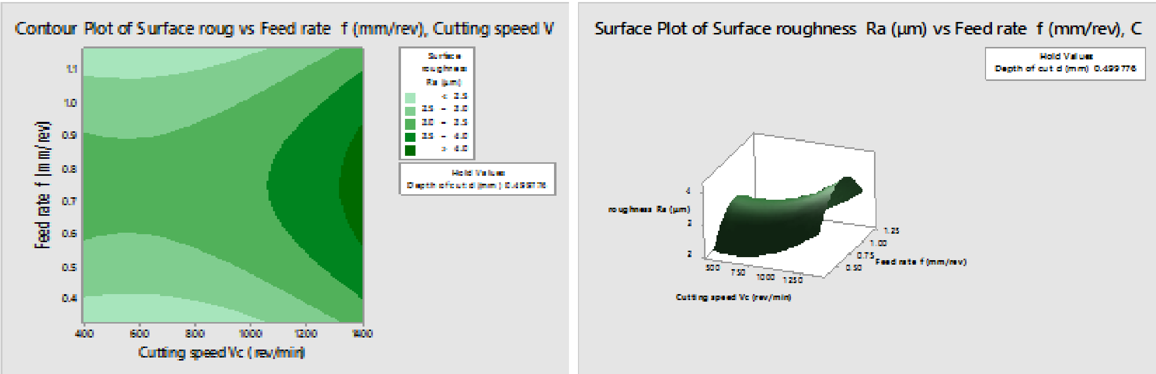

Figure 4: Contour and 3D Surface plots for surface roughness (mineral oil based cutting fluid)

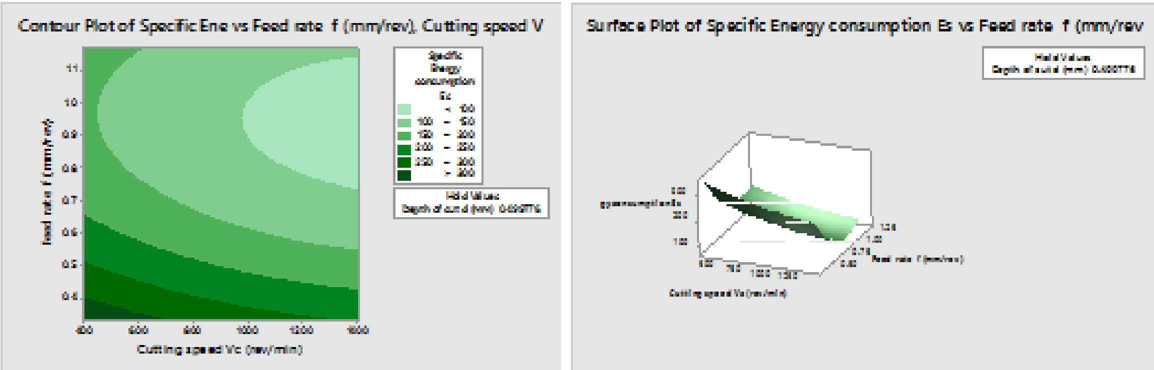

Figure.5: Contour and 3D surface plot for specific energy consumption (vegetable oil based cutting fluid)

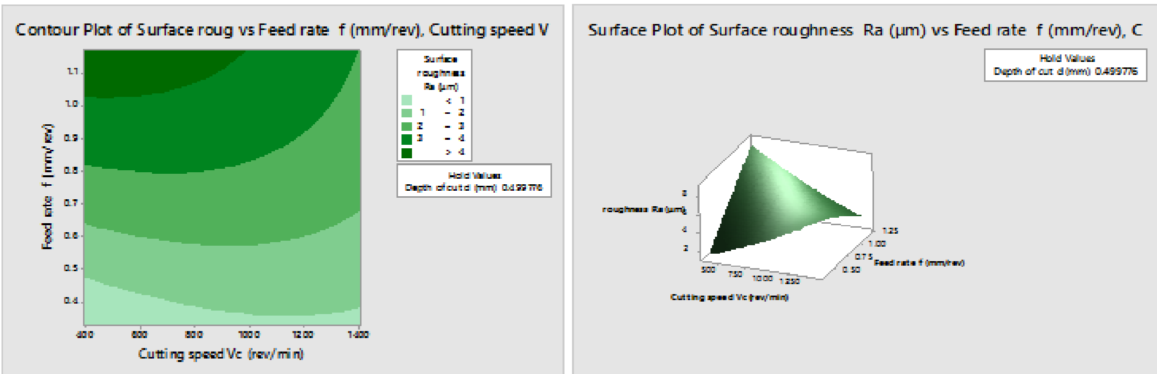

Figure. 6: Contour and 3D surface plot for surface roughness (vegetable oil based cutting fluid)

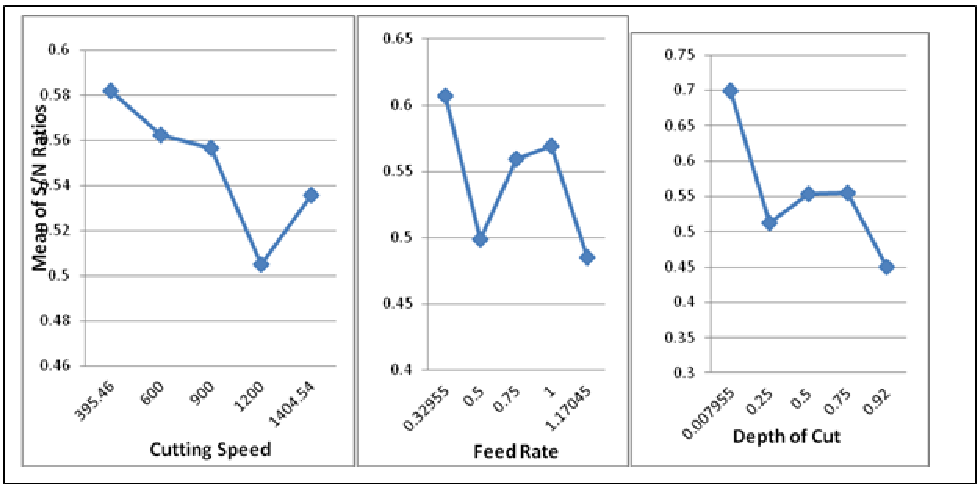

Figure 7: Main effect plots for dry turning

Table 10: Factor effects of Grey Relational Grade

Parameter	Level 1	Level 2	Level 3	Level 4	Level 5
Dry turning					
Parameter	Level 1	Level 2	Level 3	Level 4	Level 5
Cutting Speed	0.582	0.562	0.557	0.505	0.536
Feed rate	0.607	0.499	0.559	0.569	0.485
Depth of cut	0.699	0.513	0.554	0.554	0.450
Mineral oil based cutting fluid					
Parameter	Level 1	Level 2	Level 3	Level 4	Level 5
Cutting Speed	0.605	0.669	0.617	0.574	0.632
Feed rate	0.697	0.627	0.604	0.617	0.667
Depth of cut	0.667	0.525	0.607	0.718	0.667
Parameter	Level 1	Level 2	Level 3	Level 4	Level 5
Cutting Speed	0.583	0.613	0.571	0.575	0.562
Feed rate	0.330	0.659	0.554	0.529	0.691
Depth of cut	0.080	0.596	0.598	0.592	0.417

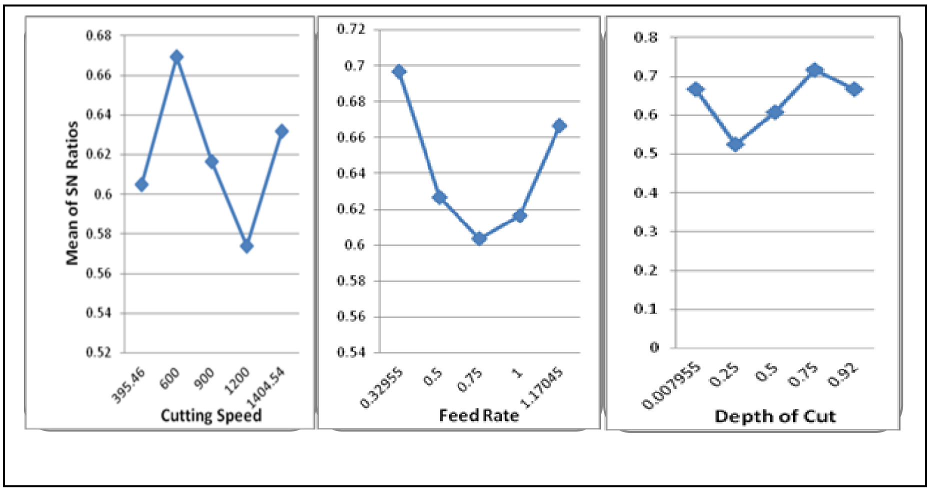

Figure 8: Main effect plots for wet turning with mineral oil based cutting fluid

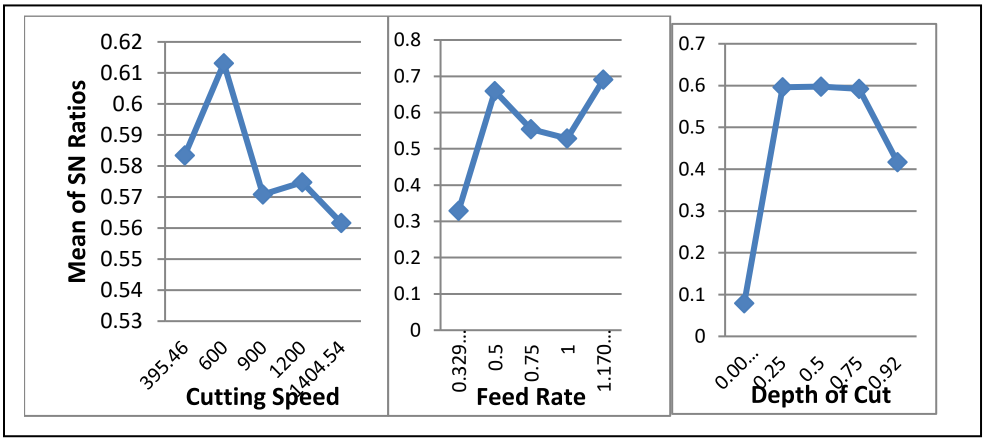

Figure 9: Main effect plot for vegetable oil based cutting fluid

$$Percentage\ error\ (E) = \frac{Experimental\ (Ex)\ value - calculated\ (Cc) value}{Experimental\ (Ex) value}\ x\ 100 \quad (19)$$

For energy consumption and surface roughness in the three cutting environments, the errors obtained between the calculated values and experimental values are less than 10% which are statistically acceptable. This agrees with [20].

Table 11: Confirmation test and percentage error

Cutting Environment	Response	Calculated value	Experimental value	Percentage Error (%)
Dry	Specific energy consumption (J/mm^3)	527.18	520.28	1.31
	Surface roughness(μm)	1.47	1.44	2.08
Wet with mineral oil based cutting fluid	Specific energy consumption (J/mm^3)	306.94	310.56	1.18
	Surface roughness(μm)	2.36	2.42	2.54
Wet with vegetable oil based cutting fluid	Specific energy consumption (J/mm^3)	141.50	138.76	1.96
	Surface roughness (μm)	4.30	4.28	2.51

4. CONCLUSIONS

i. This study has captured determination of optimal process parameters in orthogonal turning of AISI 304 alloy steel as well as empirical modelling of energy consumption and surface roughness in orthogonal turning of AISI 304 alloy steel in dry and wet environments. From the results obtained, the following conclusions can be drawn; From this analysis, it is revealed that depth of cut has the highest significant effect (83.11%) on energy consumption during dry cutting while feed rate has the highest impact (52.44%) in the machining performance when using the vegetable oil based cutting fluid.

ii. The optimal multi-response turning parameters obtained using the Grey rotational analysis showed that optimal performance can be accomplished during dry cutting when using cutting speed of 395.46rev/mm, feed rate of 1.17mm/rev and depth of cut of 0.5mm while in wet turning with mineral oil based cutting fluid, optimal parameters obtained are cutting speed of 600rev/mm, feed rate of 0.33mm/rev and depth of cut of 0.01mm. Finally, in wet turning with vegetable oil based cutting fluid, optimal parameters obtained are cutting speed of 600rev/mm, feed rate of 0.5mm/rev and depth of cut of 0.25mm.

iii. The best multiple performance was obtained with vegetable oil-based cutting fluid with reduction in energy consumption from 527.18J/mm^3 in dry turning to 141.50J/ mm^3.

4.1 Recommendations for further studies

The following recommendations for further studies are made;

i the quality of energy consumption and surface roughness during orthogonal turning of AISI 304 alloy steel in dry and wet environments with the same cutting conditions and different cutting tools should be studied.

ii Investigation should be carried out to establish and optimize the relationship between energy consumption, material removal rate (MRR) and surface roughness during orthogonal turning of AISI 304 alloy steel.

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