PAPER • OPEN ACCESS

Experimental study and Analysis of Variance of Material Removal Rate in High Speed Turning of AISI 304L Alloy Steel

To cite this article: O. Ogundimu *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **413** 012030

Experimental study and Analysis of Variance of Material Removal Rate in High Speed Turning of AISI 304L Alloy Steel

O. Ogundimu[1], S. A. Lawal[1*] and I. P. Okokpujie[2]

[1]Department of Mechanical Engineering, School of Infrastructure, Process Engineering and Technology, Federal University of Technology, Minna- Nigeria
[2]Department of Mechanical Engineering, Covenant University, P.M.B 1023, Ota, Ogun State, Nigeria
[*]Corresponding author's email: lawalsunday@futminna.edu.ng

Abstract- Material removal rate is one of the challenges encounters in the manufacturing process, due to the transformation of a raw solid material into desired shapes. This investigation involved studying the effects of the three variables (cutting speed, feed rate and depth of cut and their interaction) for material removal rate during turning of AISI 304L stainless steel with cemented carbide inserts cutting tool. Response surface methodology was employed in the experimental design and total number of 20 experiments runs were conducted using central composite design. The level of importance and performance characteristics of the machining parameters on MRR was determined by using analysis of variance (ANOVA). It was observed that the cutting speed had the most significant effects on the MRR (66.27%) followed by the depth of cut (21.55%), while feed rate (8.25%) had the least effect on MRR. The result also showed that the cutting speed and the depth of cut has good interactions during the turning operation.
Keywords: Turning operation; Material removal rate; Response surface methodology (RSM); Analysis of variance

1 Introduction

The reason for metal cutting process usually known as machining is to manufacture a preferred shape, dimension and finish of an element by eliminating the excess materials in the form of chips from raw chunk of work piece [1-3]. Today industry requires the production of less expensive and good quality products in short time [4-6]. The issue of Surface finishing, tool wear rate and material removal rate (MRR) are the major response parameters which attention is given to by most industries. Material removal rate is vital parameter that greatly influences production rate and cost [7-13]. Therefore, it is necessary to assess the MRR before the cutting process is started. MRR is a useful factor in the manufacturing, which will contribute to the minimization of cost of manufacturing and reduces the idle time to attain a preferred surface quality.

Ashish et al [1] studied surface roughness, tool wear and material removal rate in CNC turning of EN24 alloy steel and found out that the higher the machining rate the better surface finish are desirable for better performance of any machining process. In turning procedure, it is expected to have high metal removal rate in order to obtain optimum quality at reduced time and cost, the process of trying to remove this unwanted part of the work piece, it can lead to the damage of the cutting tool and the work piece as a result of vibration. Nwoke, et al., [14]; Okonkwo et al., [15] carried out studies on chatter vibration frequency on AISI 4340 alloy during turning operation. The result shows that there is need to reduce vibration in turning operation in order to have high material removal rate and good surface finishing.

Turning operation is one of the leading, highly proficient predictable machining procedures. Normally the work piece is rotating on a spindle and the cutting tool is fed into it radially, axially or both ways concurrently to obtain the required shape or sides. Lawal, et al., [16] work on vegetable and mineral oil-in-water in turning operation of AISI 4340 alloy steel and found out that vegetable oil when applied in machining process reduces surface roughness, tool wear, vibration and increases the rate of metal removal. Authors agreed that vegetable oil will bring significant improvement on MRR and will also help during the investigation of the creep response on different materials [17-20].

Tejas *et al*. [21] work on the investigation and prediction of milling procedure on vertical milling machine by using RSM. The machining factors were examined to establish their importance on mild steel by carrying out experiments using response surface methodology to obtain material removal rate (MRR) and surface roughness (SR), while investigating the effects of spindle speed, depth of cut and feed on mild steel. The experimental results were evaluated using ANOVA and the importance of parameters upon performance measures was achieved. The results revealed that depth of cut and feed rate has superior effect on MRR

Jaganjeet and Sanjeev [22] carried out an investigation on the effects of WEDM process factors for optima cutting quality for the machined components. In this work the effects of numerous process variables of WEDM, such as pulse on time, pulse off time, Servo voltage, peak current, Wire feed, and Wire tension, were study to know their influence on material removal rate of H13 Steel. And the instrument use for the surface roughness measurement is MarSurf PS1. Taguchi L18 Orthogonal Array was employed and the results of the testing were evaluated using MINITAB software. Material removal rate is very significant in machining process, because if not properly study it will affect the surface produce during the operation which can lead to high surface roughness, high wear rate of the cutting tools and the production output of the industry will be affected [23-30].

Moreover, the accomplishments of most researchers in related to the current study are recognized. Development in assessment, experimental examination of dry, wet and MQL in turning operation on material removal rate were reviewed. However, there is need to study MRR using ANOVA to determine the extent the cutting variables will have on the MRR and the interaction between the three variables has with the response parameters.

2 Material and Method

The work piece material used in this research study was AISI 304L stainless steel. It is a commonly used steel grade which has a minimum of 18% chromium and 8% nickel. Cemented carbide cutting tool was applied in the researcher, and Lactuca LT 3000 cutting fluid was also used.

This experiment was conducted using DOE via response surface methodology (RSM). Minitab 16 software was used to analyze the data obtained from the experiment. The selection of the factors values depended on the response investigating and the manufactural. RSM was used in the experimental plan, applying central composite design (CCD). By taking all the factorial angle points, some of the central duplicates and all the axial points, central composite design required between 20 to 23 experimental runs depending on the number of the central duplicates considered, the experimental plan entail of three parameters at three levels such as cutting speed, feed rate and depth of cut as shown in Table 1. The experimental analysis was carry out to assess the effect of cutting speed (N), feed rate (f) and depth of cut on the material removal rate (MRR), and a total number of twenty (20) experiment were run according to central composite design as shown in Table 2.

Table 1: Process variables and Levels

Variables	Unit	Matrix levels		
		-1	0	**+1**
Cutting speed	(rpm)	600	1200	1800

Feed rate	(mm/rev)	0.2	0.25	0.3
Depth of cut	(mm)	0.4	0.6	0.8

Table 2: Design matrix of variables

Runs	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
1.	1200	0.25	0.6
2.	1200	0.165	0.6
3.	1200	0.25	0.6
4.	600	0.3	0.4
5.	190.9	0.25	0.6
6.	1200	0.25	0.6
7.	600	0.2	0.4
8.	1200	0.25	0.6
9.	1800	0.3	0.4
10.	600	0.2	0.8
11.	600	0.3	0.8
12.	1200	0.25	0.6
13.	1200	0.25	0.936
14.	2209	0.25	0.6
15.	1200	0.334	0.6
16.	1200	0.25	0.263
17.	1800	0.3	0.8
18.	1800	0.2	0.8
19.	1800	0.2	0.4
20.	1200	0.25	0.6

2.1 Experimental procedure for turning operation

The experimental analysis was carried out in CNC lathe machine and the specification are model SPT-32; Mas –Czech Republic having maximum cutting speed of 4000 rpm, rapid oblique of 15,000 mm/min, 28 KW motor drive, diameter of 490 mm, length of 1500 mm and cemented carbide cutting tool (CNMG 120408-PM) were employed in the turning operation. The experiment was carried out under flood cutting condition with Lactuca LT 3000 conventional cutting fluid.
The dimensions of work piece used were 40 x 750 mm. To achieve the material removal rate, the work piece diameter is measured before and after each experimental run. The results are then substituted into equation (1) and the material removal rate gotten for each experimental operation

$$MRR = \frac{\pi}{4} \times \left(D_i^2 - D_f^2\right) \times F \times N \qquad (1)$$

Where D_i = Initial diameter, mm, D_f = final diameter, mm, f = Feed rate, mm/rev, N=Spindle speed, rpm [3].

3 Result and Discussion

The design matrix and the result from experiment with the three cutting variables such as cutting speed, feed rate and depth of cut are shown in Table 3 respectively.

Table 3: Experimental results for the material removal rate

Runs	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	D1 (mm)	D2 (mm)	MRR (mm^3/min)
1	600	0.2	0.4	40	39.2	5971.54
2	1800	0.2	0.4	39.2	38.4	17552.71
3	600	0.3	0.4	38.4	37.6	8595.39
4	1800	0.3	0.4	37.6	36.8	25243.33
5	600	0.2	0.8	36.8	35.2	10857.34
6	1800	0.2	0.8	35.2	33.6	31124.39
7	600	0.3	0.8	33.6	32	14838.37
8	1800	0.3	0.6	32	30.4	42343.64
9	190.92	0.25	0.6	40	38.8	3544.78
10	2209	0.25	0.6	38.8	37.6	39764.93
11	1200	0.16	0.6	37.6	36.4	13390.72
12	1200	0.33	0.6	36.4	35.2	26722.64
13	1200	0.25	0.263	35.2	34.68	8561.94
14	1200	0.25	0.936	34.68	32.80	29891.25
15	1200	0.25	0.6	32.80	31.6	18208.67
16	1200	0.25	0.6	31.6	30.4	17530.08
17	1200	0.25	0.6	40	38.8	22280.18
18	1200	0.25	0.6	38.8	37.6	21601.59
19	1200	0.25	0.6	37.6	36.4	209.23
20	1200	0.25	0.6	36.4	35.2	20211.42

3.1 Analysis of Variance for MRR

A response material removal system was designed and analyzed using Minitab 16 software, Table 4 and 5 shows the Analysis of Variance (ANOVA) result used to analyzed the effect of cutting variables on the material removal rate and their interactions, lack-of-Fit and residual error on the MRR. Table 5 can also be used to predicted the MRR when the need arises.

Table 4: The material removal rate ANOVA for AISI 304L Alloy Steel

Source	DF	Seq SS	Adj SS	Adj MS	F
Regression	9	1189155910	1189155910	132128434	1.04
Linear	3	146553375	146553375	48851125	0.38
Cutting speed	1	11491378	11491378	11491378	0.09
Feed rate	1	99779069	99779069	99779069	0.79
Depth of cut	1	35282928	35282928	35282928	0.28
Square	3	551593797	551593797	183864599	1.45
Cutting speed*Cutting	1	223385	2855184	2855184	0.02
Feed rate*Feed rate	1	98453745	60220465	60220465	0.47
Depth of cut*Depth of cut	1	452916667	452916667	452916667	3.57
Interaction	3	491008737	491008737	163669579	1.29
Cutting speed*Feed rate	1	344910273	344910273	344910273	2.72
Cutting speed*Depth of cut	1	35048834	35048834	35048834	0.28
Feed rate*Depth of cut	1	111049630	111049630	111049630	0.88
Residual Error	10	1268939042	1268939042	126893904	
Lack-of-Fit	5	698108363	698108363	139621673	1.22
Pure Error	5	570830678	570830678	114166136	
Total		19	2458094951		

Table 5: The Predictable regression coefficients for MRR using data in uncoded units

Term	Coef
Constant	14696.9
Cutting speed	69.6793
Feed rate	-423798
Depth of cut	87932.5
Cutting speed*Cutting speed	0.00123641
Feed rate*Feed rate	817675
Depth of cut*Depth of cut	140151
Cutting speed*Feed rate	218.870
Cutting speed*Depth of cut	17.4426
Feed rate*Depth of cut	372575

Figure 1-4 showed the interaction and the effects of the three variables on the material removal rate, it can be seen that the most interactive parameters were cutting speed and depth of cut. From Table 4, the cutting speed was the most significant parameters follow by the depth of cut, this also means that at the increase of the cutting speed, the MRR increase and at increase of the feed rate the MRR decreases, why the depth of cut increases the MRR increases. This result is in line with the observation made by Jaganjeet and Sanjeev [22]. Therefore, with a good combination and interactions between the cutting speed and the depth of cut will lead to a more preferred material removal rate.

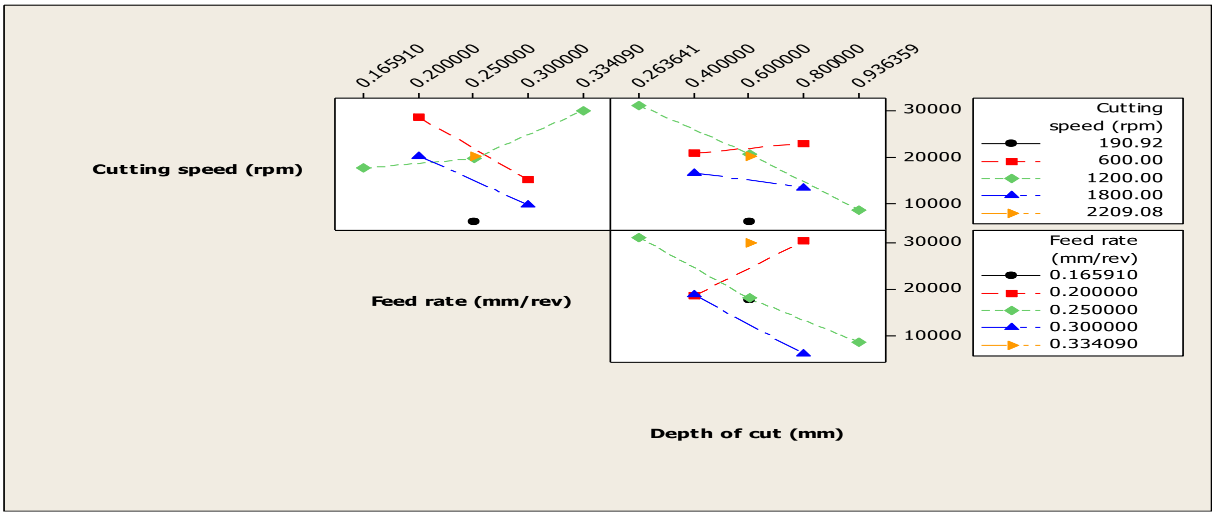

Figure 1: Interaction plot for MRR and the three cutting variables

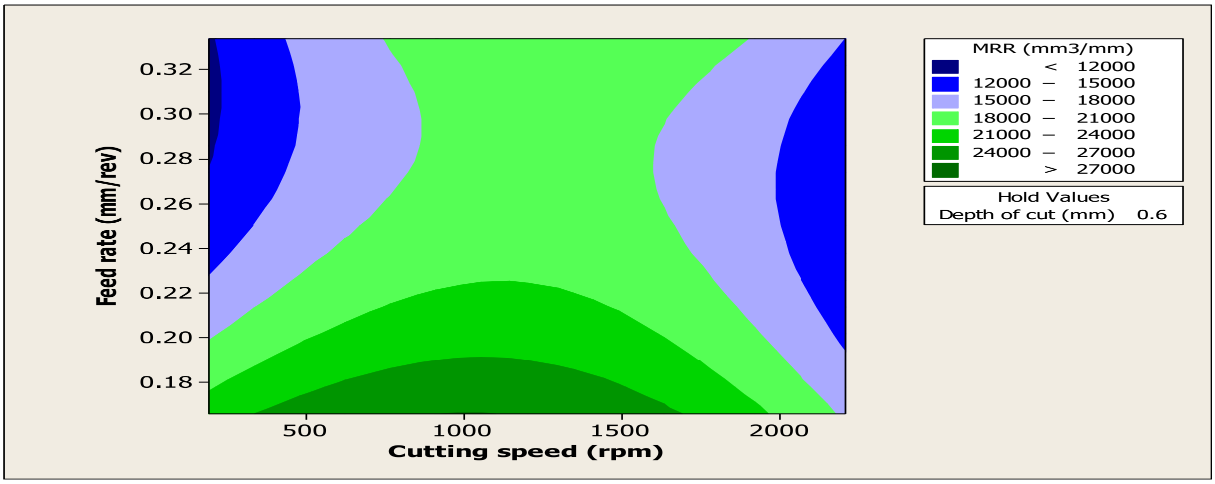

Figure 2: Contour plot for MRR vs. cutting speed and feed rate while depth of cut is constant at 0.6mm

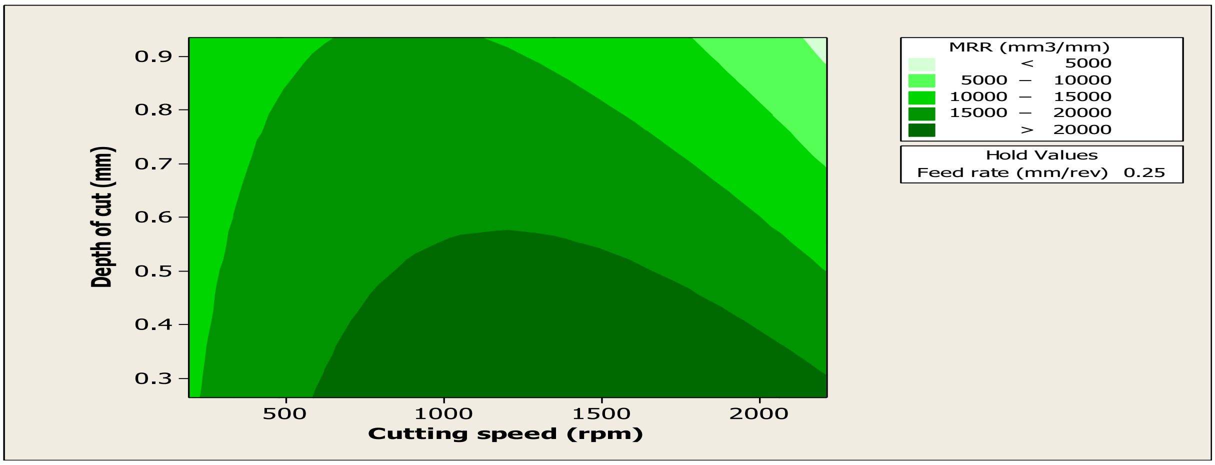

Figure 3: Contour plot for MRR vs. cutting speed and depth of cut while feed rate is constant at 0.25 mm/rev.

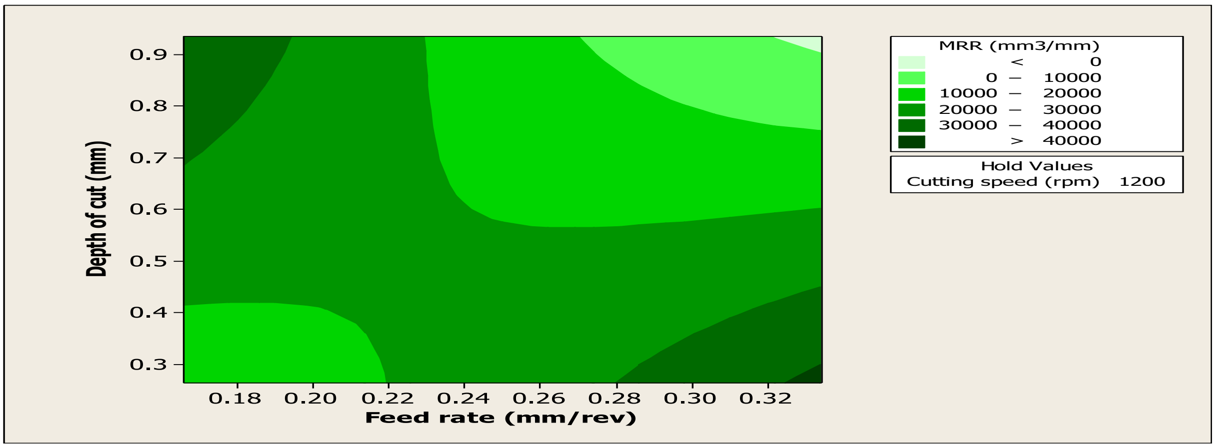

Figure 4: Contour plot for MRR vs. feed rate and depth of cut while cutting speed is constant at 1200 rmp.

4. Conclusions

The material removal rate could be effectively predicted by using predictable regression coefficients for the uncoded factors such as: cutting speed, depth of cut feed rate as the independent variables. In analyzing the individual parameters, it was found that cutting speed has the most significant effect on MRR with 66.27%, followed by depth of cut with 21.55% and feed rate has the least significant effect on MRR with 8.25%. In terms of interactions the cutting speed and the depth of cut has good level of interactions with each other than the combination of feed rate in other to achieve good process for the material removal rate.

References

[1]. Ashish, B., Bhardwaj, J., Maninder, S., and Sandeep, K. (2013). Optimization of Different Performance Parameters i.e. Surface Roughness, Tool Wear Rate & Material Removal Rate with the Selection of Various Process Parameters such as Speed Rate, Feed Rate, Specimen Wear, Dept. of cut in CNC Turning of EN24 alloy Steel – An Empirical Approach. *The International Journal of Engineering and Science IJES*. 2(1), 103-113.

[2]. Ezugwu, C. A., Okonkwo, U. C., Sinebe, J. E., & Okokpujie, I. P. (2016). Stability Analysis of Model Regenerative Chatter of Milling Process Using First Order Least Square Full Discretization Method. *International Journal of Mechanics and Applications*, *6*(3), 49-62.

[3]. Dhabale, R., and Vijay Kumar, (2015). Optimization of material removal rate of Almg1sicu in turning operation using genetic Algorithm, WSEAS Transactions on Applied and theoretical mechanics, 10(1), 95-101.

[4]. Okokpujie, I., Okonkwo, U., & Okwudibe, C. (2015). Cutting parameters effects on surface roughness during end milling of aluminium 6061 alloy under dry machining operation. *International Journal of Science and Research*, *4*(7), 2030-2036.

[5]. Ekinovic, S., and Ekinovic, E. (2000). High Speed Machining, Masinstvo, 4 (1), 15 – 50

[6]. Okokpujie, I. P., Ikumapayi, O. M., Okonkwo, U. C., Salawu, E. Y., Afolalu, S. A., Dirisu, J. O., ... & Ajayi, O. O. (2017). Experimental and Mathematical Modeling for Prediction of Tool Wear on the Machining of Aluminium 6061 Alloy by High Speed Steel Tools. *Open Engineering*, *7*(1), 461-469.

[7]. Prajapati, N.K., Patel, S. M. (2013). Optimization of Process Parameters for Surface Roughness and Material Removal Rate for Stainless steel 316 on CNC Turning Machine. *International Journal of Research in Modern Engineering and Engineering Technology*, 1(3), ISSN: 2320-6586.

[8]. Okokpujie, I. P., Ajayi, O. O., Afolalu, S. A., Abioye, A. A., Salawu, E. Y., Udo, M., ... & Ikumapayi, O. M. (2018). Modeling and Optimization of Surface Roughness In End Milling of Aluminium Using Least Square Approximation Method and Response Surface Methodology. *International Journal of Mechanical Engineering and Technology (IJMET)*, *9*(1), 587-600.

[9]. Okokpujie, I. P., Ohunakin, O. S., Bolu, C. A., & Okokpujie, K. O. (2018). Experimental data-set for prediction of tool wear during turning of Al-1061 alloy by high speed steel cutting tools. *Data in brief*, *18*, 1196-1203.

[10]. Lawal, S. A., Choudhury, I. A., & Nukman, Y. (2015). 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*, *96*(1), 21-28.

[11]. Lawal, S. A., & Ndaliman, M. B. (2014). Surface Roughness Characteristics in Finish Electro-Discharge Machining Process.

[12]. Okonkwo, U. C., Okokpujie, I. P., Sinebe, J. E., & Ezugwu, C. A. (2015). Comparative analysis of aluminium surface roughness in end-milling under dry and minimum quantity lubrication (MQL) conditions. *Manufacturing Review*, *2*, 30.

[13]. Afolalu, S. A., Salawu, E. Y., Okokpujie, I. P., Abioye, A. A., Abioye, O. P., Udo, M., ... & Ikumapayi, O. M. (2017). Experimental Analysis of the Wear Properties of Carburized HSS (ASTM A600) Cutting Tool. *International Journal of Applied Engineering Research*, *12*(19), 8995-9003.

[14]. Nwoke, O. N., Okonkwo, U. C., Okafor, C. E., & Okokpujie, I. P. (2017). EVALUATION OF CHATTER VIBRATION FREQUENCY IN CNC TURNING OF 4340 ALLOY STEEL MATERIAL. *International Journal of Scientific & Engineering Research*, *8*(2), 487-495.

[15]. Okonkwo Ugochukwu, C., Nwoke Obinna, N., & Okokpujie Imhade, P. (2018). Comparative Analysis of Chatter Vibration Frequency in CNC Turning of AISI 4340 Alloy Steel with Different Boundary Conditions. *Journal of Covenant Engineering Technology (CJET) Vol*, *1*(1).

[16]. Lawal, S. A., Choudhury, I. A., & Nukman, Y. (2014). 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*, 610-618.

[17]. Lawal, S. A., Ajani, E. A., Namessan, N. A., Ugheoke, B. I., & Egbe, E. A. P. (2017). Experimental evaluation of coated carbide insert on alloy of steel materials during high speed turning process. *Arid Zone Journal of Engineering, Technology and Environment*, *13*(3), 325-335.

[18]. Lawal, S. A., Choudhury, I. A., & Nukman, Y. (2012). Application of vegetable oil-based metalworking fluids in machining ferrous metals—a review. *International Journal of Machine Tools and Manufacture*, *52*(1), 1-12

[19]. Nwoke, O. N., Okokpujie, I. P., & Ekenyem, S. C. (2017). INVESTIGATION OF CREEP RESPONSES OF SELECTED ENGINEERING MATERIALS. *Journal of Science, Engineering Development, Environment and Technology (JOSEDET)*, *7*(1), 1-15.

[20]. Orisanmi, B. O., Afolalu, S. A., Adetunji, O. R., Salawu, E. Y., Okokpujie, I. P., Abioye, A. A., ... & Abioye, O. P. (2017). Cost of Corrosion of Metallic Products in Federal University of Agriculture, Abeokuta. *International Journal of Applied Engineering Research*, *12*(24), 14141-14147.

[21]. Tejas, C. P., Lalit, S. P. and Bhavesh, C. P. (2014). Analysis and prediction of milling process on vertical milling centre (VMC) by using response surface methodology (RSM). *International Journal for Innovative Research in Science and Technology*, *1(7): 205-212*.

[22]. Jaganjeet Singh and Sanjeev Sharma (2013). Effects of Process Parameters on Material Removal Rate and Surface Roughness in WEDM of H13 Tool Steel. International Journal of Current Engineering and Technology, Vol.3, No.5 pp 1852-1857.

[23]. Okokpujie, I. P., & Okonkwo, U. C. (2015). Effects of cutting parameters on surface roughness during end milling of aluminium under minimum quantity lubrication (MQL). *International Journal of Science and Research*, *4*(5), 2937-2942.

[24]. Azeta, J., Okokpujie, K. O., Okokpujie, I. P., Osemwegie, O., & Chibuzor, A. (2016). A Plan for Igniting Nigeria's Industrial Revolution. *International Journal of Scientific & Engineering Research*, *7*(11), 489.

[25]. Salawu, E. Y., Okokpujie, I. P., Afolalu, S. A., Ajayi, O. O., & Azeta, J. (2018). INVESTIGATION OF PRODUCTION OUTPUT FOR IMPROVEMENT. *International Journal of Mechanical and Production Engineering Research and Development*, *8*(1), 915-922.

[26]. Imhade P. Okokpujie, E.Y. Salawu, O. N. Nwoke, U. C. Okonkwo, I. O. Ohijeagbon, and Kennedy Okokpujie, "Effects of Process Parameters on Vibration Frequency in Turning Operations of Perspex Material," Lecture Notes in Engineering and Computer Science: Proceedings of The World Congress on Engineering 2018, 4-6 July, 2018, London, U.K., pp700-707.

[27]. Afolalu, S. A., Abioye, A. A., Dirisu, J. O., Okokpujie, I. P., Ajayi, O. O., & Adetunji, O. R. (2018, April). Investigation of wear land and rate of locally made HSS cutting tool. In *AIP Conference Proceedings* (Vol. 1957, No. 1, p. 050002). AIP Publishing.

[28]. Salawu, E. Y., Okokpujie, I. P., Ajayi, O. O., & Agarana, M. C. (2018). Analytical Technique for the Determination of Hoop Stress and Radial Stress on the Tooth Spur Gear under Vertical Loading in a Food Packaging Machine.

[29]. Afolalu, S. A., Abioye, O. P., Salawu, E. Y., Okokpujie, I. P., Abioye, A. A., Omotosho, O. A., & Ajayi, O. O. (2018, April). Impact of heat treatment on HSS cutting tool (ASTM A600) and its behaviour during machining of mild steel (ASTM A36). In *AIP Conference Proceedings* (Vol. 1957, No. 1, p. 050003). AIP Publishing.

[30]. Afolalu, S. A., Okokpujie, I. P., Salawu, E. Y., Abioye, A. A., Abioye, O. P., & Ikumapayi, O. M. (2018, April). Study of the performances of nano-case treatment cutting tools on carbon steel work material during turning operation. In *AIP Conference Proceedings* (Vol. 1957, No. 1, p. 050001). AIP Publishing.