Measurement of Surface Roughness on a Transmission Shaft using CNC and Conventional Lathes Machining

Temitayo M. Azeez, Omolayo M. Ikumapayi, Ojo P. Bodunde, Simeon A. Babalola, Motunrayo O. Ogundayomi

Abstract: The growth of machining science has evolved over the years; its integrity is dependent on the aesthetics and material properties of finished products. The global trend of machining operations has been dependent on energy intensity and cost. This energy has also been linked with the surface roughness and integrity of the finished part. In developing countries like Nigeria where CNC machining is gradually finding its way into the manufacturing sector, it is appropriate at this time to evaluate the impact of surface roughness and surface integrity on machine component from CNC and conventional lathe. This research therefore aimed at investigating the surface roughness obtained during a Teflon turning operation on the CNC and the conventional machine tool. In this study arithmetical mean roughness value (Ra) was measured and recorded for both CNC machined part and conventional lathe at three different orientation and seven points on each orientation. It can be concluded that the surface roughness obtained at different orientation when turning Teflon on the CNC is smoother than that obtained with the conventional machine tool as the arithmetical mean roughness value (Ra) measured from all points at different orientation lower in CNC than conventional Lathe.

Index Terms: Machining, Surface Roughness, Teflon, CNC, Conventional Lathe, Turning

1.0 INTRODUCTION

Modern Machining Industries have some challenge among which is achieving high dimensional accuracy, higher rate of production, less wear rate on the cutting tool, excellent performance on the produced products, low cost of production and excellent surface finish. The ability to control the process for excellent quality assurance of the final product is fundamentally essential [1]. This research aimed at comparing the surface roughness of products from a computer numerical control (CNC) Lathe and conventional Lathe machines. The machining operation is carried out on lathe machine. There are two categories of lathe machines, they are the computer numerical control (CNC) and conventional, that is traditional lathe machine. It is worth mentioning that conventional lathe machine is a typical family member of lathe machine which has been used from the ages past and will continue to be used in the years to come because it cannot be completely wipe away as a result of its functionality. Similar to speed lathe, it has some fundamental parts such as headstock, bed, tailstock and the like. Nevertheless, the headstock in conventional lathe is more robust when it comes to construction and it contains some other mechanism which are used for driving spindle at multiple speeds. One of the functions of the transmission shaft is to transmit power between the machine parts that are absorbing power to the source. Examples of transmission shafts are line shafts, counter shafts, overhead shafts and all factory shafts. It is expected that the following shafts experience twisting or bending since most of the shafts are load carrying especially machine parts such as gears and pulleys. For the benefit of this research work, only Teflon is considered for investigation. It is expected that this material be used for a number of articles formation having different combination of properties such as chemical, mechanical, thermal, electrical as well as friction-resisting which may be unmatched with articles of any other materials. Couple with its commercial use and other excellent properties has made Teflon resins an outstanding and unbeatable engineering materials for use in most of the industries as well as in defence applications. Teflon can also be integrated with other reinforcement agents as well as other additives or fillers to improve its effective performance.

Machining process is the most common process in the fabrication of machine elements and parts. Machining process usually causes highly tensile stresses within the machined surface. The machining of plastics materials has an induced high temperature during cutting operation, this do not deform materials alone but alone affects the surface quality of the workpiece. The ability to obtain the desired surface integrity is very important for the functional and aesthetics maintenance of a manufactured part [2]. Teflon material is one of the plastic families that has been widely used in the production and manufacturing industries. The Teflon possesses excellent combination of mechanical and physical properties. To utilize the useful properties of Teflon it is crucial to study surface integrity of machined Teflon. Surface integrity is a means of evaluating and assessing surface topography via some selected properties such as superficial and in-depth evaluation to ensure its performance align with engineering surface integrity. Karayel [3] predicted with artificial neural network to study surface roughness in CNC. His predicted model with ANN was so close to the value measured experimentally. It was

- ***Temitayo M. Azeez*** *is currently pursuing his PhD degree at the Department of Mechanical Engineering, and he is a Lecturer at the department of Mechanical and Mechatronics, Afe Babalola University, Ado Ekiti, Nigeria PH-+2348036377697. E-mail: Azeeztemitayo221@abuad.edu.ng*
- ****Omolayo M. Ikumapayi*** *is a PhD research scholar at the Department of Mechanical Engineering Science, University of Johannesburg, South Africa, PH-+27838098288.. E-mail: ikumapayi.omolayo@gmail.com*
- ***Ojo P. Bodunde*** *is a PhD research scholar at the Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, New Territories, Hong Kong, PH-+85254276785. E-mail: philipbodunde@gmail.com*
- ***Simeon A. Babalola*** *currently pursuing his PhD degree at the Department of Mechanical Engineering, and he is a Lecturer at the department of Mechanical and Mechatronics, Afe Babalola University, Ado Ekiti, Nigeria PH-+2347066594902. E-mail: babalolasa@abuad.edu.ng*
- ***Motunrayo O. Ogundayomi*** *is a Bachelor degree holder in Mechanical Engineering , Afe Babalola University, Ado Ekiti, Nigeria*

revealed that surface roughness increases with increase in feed rate and also depth of cut on surface roughness is irregular and as such not significance since it has a variable character. It is expedient to say that the quality of a surface produced are determine by the machining processing parameters such as changes in the conditions of machine tool or workpiece or the set-up of the process and it can also be influenced by the managerial decisions. Wide range of the parameters affect the surface roughness of a product. It is a known fact that the market value of any machined parts and the productivity of any machine tool is a factor of surface quality achieved by such machine [4]. Thus, one of the quality indicators of any product is surface roughness. Nowadays, quality is one of the key factors that affect the customer's level of satisfaction in a business or manufacturing industries. On this note, surface roughness analysis has been used in most industrial sector as a yard stick to determine surface quality of a produced samples, parts or components. It is therefore of great important to ensure excellent and functional mechanical components with unbeatable surface quality [5]. This influences some properties such as fatigue strength, corrosion resistance, wear rate, frictional coefficient, as well as lubrication of the machined parts [6]. The characteristics of any machined surfaces have significant influence on the capability of that material to withstand several conditions such as corrosion, temperature, stresses, friction and the like [7]. The demand for high quality products with good surface finish increasing day by day due to newer applications emanating from various manufacturing and production industries such as die and mould production companies, automobile, and as such manufacturers and producers are made to increase their productivity by simply improve the surface quality of their products for them to remain in a competitive market. Many works have been done on surface roughness of various materials among which are selected literatures below. Kartal et al. [8] carried out surface roughness analysis as well as macro surface investigation on the machined Al-6082 T6 alloy using AWJT. Many factors attributed to the smoother surfaces during this investigation such parameters as lowering the standoff distance, increasing the abrasive flow rate and spindle speed as well as decreasing nozzle feed rate. It was established that increased spindle speed as well as that of abrasive flow rate resulted to a better surface quality. Fabre et al. [9] also carried out surface roughness analysis in broaching using optimisation method. This study investigated how process parameters such as lubrication and cutting speed; tool design such as tooth angles, rise per tooth as well as substrate material affect the surface integrity of the final products. It was revealed that surface roughness is dependent on the random process theory (RPT) as well as cutting speed values and this attests to the fact that lowest mean roughness values were achieved for low cutting speed and high PRT. It has been established that increase in cutting speed, improves roughness of surface even under any dry cutting conditions. Zhang et al. [10] presented a general review on surface roughness of ultra-precision machining (UPM) and the review covers tool design geometry, machine tool, material properties, tool wear, chip formation, vibration as well as environmental conditions etc. that alter the surface roughness of UPM. The review also covered the mechanism on the surface roughness formation. Xu et al. [11] carried out a study of surface roughness on the machined samples of wire electrochemical micro. In this study, mass transport was enhanced by the used of anode vibration and cathode travelling in order to improve surface roughness, this is due to accumulation of electrolytic products in the machining gap which may cause a rough surface. In this study, changes in surface roughness under the influence of pulse conditions, cathode travelling and vibration were investigated experimentally and it was revealed that the values for Ra and Rmax were found to be 0.058 µm and 0.670 µm respectively. Zhang and Shetty [12] studied the prediction of surface roughness in machined surfaces via least squares support vector machine (LS-SVM)-based approach. It was revealed through the experimental results that proposed LS-SVM algorithm has a higher coefficient of 0.0439 which is far better than the one produced by ANOVA and ANN which gives 0.1917and 0.7266 respectively. Kumaran et al. [13] applied regression analysis to predict surface roughness in CFRP composites and integrated with unidirectional (UD) in a woven fabric surface made from abrasive water jet machining. It was revealed that a better surface finish was achieved with a lower travel speed, higher jet pressure and standoff distance. It can be inferred from the experimental results that UD with fabric surface CFRP has a reduction in roughness when compared with the composite of the UD CFRP. Venkatesan et al. [14] studied surface roughness on the aluminium alloy hybrid composites and response surface method was used to optimise the process. In this study, Al_2O_3.TiN, TICN, TiN were the layer coated carbide insert used and they are designated for fabricated CNMG 120408 FR. It was revealed that surface roughness increases with increase in feed rate and more so, cutting force, depth of cut and feed rate play significant role in achieving surface integrity. It was observed that larger percentage of reinforcement gives raise to poor surface finish and subsequently consumes higher cutting energy. Vallejo et al. [15] used a design of experiment (DOE) for response surface methodology (RSM) to model surface roughness in machining operation. The model showed an excellent performance with an average error of 14.3 % between the predicted value (Ra) and measured values for all the cutting tools conditions. Kumar et al. [16] investigated surface roughness analysis on the machined AISI 4303 steel by means of Minimum Quantity lubrication (MQL). The following were the parametric data used during the machining operation nose radius, cutting speed, workpiece hardness and feed rate. Second order regression analysis was the mathematical model developed. The final analysis of ANOVA Variance indicated that MQL has an improved surface quality as against turning in dry and wet conditions. Rao et al. [17] used RSM to study surface roughness (SR) on Niobium alloy C-103 via optimization method. The authors developed various machinability model which serve as functional relationship between responses of the surface and cutting variables parameters. It was revealed that feed rate played an importance role in surface roughness and that increases in feed rate, increases SR at the same time depth of cut and cutting speed play no active role. Nevertheless, it was observed that there is an interactive relationship between depth of cut and cutting speed. Kumar et al. [18] worked on surface roughness of Inconel 718 at different machining conditions. It was revealed that the turning operation of Inconel 718 with carbide tools has proven to have excellent surface integrity with the use of MQL with an approximately 12 to 17% improvement as compared with dry and wet conditions. It was concluded that the following parameters influenced the surface roughness feed rate and approaches angle. Kant and Sangwan [19] studied how to minimized power consumption and the influence of surface roughness on machining. In this study, multi-objective model was used to predict power consumption and surface roughness with the adoption of grey relational analysis coupled with principal component analysis and response surface methodology in order to obtain optimum machine parameters. In was revealed that, reduction in power consumption and improved surface roughness can be achieved via increasing the feed rate, depth of cut as well as cutting speed. It was observed that there is a reduction in the power consumption by 6.59 % and an improvement in surface roughness by 2.65 % as against experimental values. Prakash Rao et al. [20] studied the effect of turning operation on the matrix of Al6061-flyash in a ratio of (0, 5, 10 and 15 % Vol of FA) when using Poly Crystalline Diamond (PCD) inserts and K10 grade carbide. It was operated under the following operational parameters cutting speeds of 300m/min to 600m/min in step of 100m/min; feed arte of 0.06mm/revolution to 0.24mm/revolution in step of 0.06mm/revolution and a depth of cut was maintained at 1.2 mm which is approximately equal to 3 times the nose radius of the cutting tool. It was concluded in this research that lower surface roughness was noticed with PCD inserts and that there is 10 % filler material noticed when turning composites than K 10 grade tungsten carbide insert.

2.0 Material Preparation and Selection Criteria

2.1 Materials Selection

The material obtained for the machining trials of a transmission shaft is Teflon of ϕ62 mm x 300 mm and the machining of the Teflon material was carried out on both CNC Lathe Machine and Conventional Lathe Machine. The Teflon material was later cut into two for each machining experiment at ϕ60 mm x 140 mm. Machining operations was carried out on various workpiece materials cutting tools, and machine tools available. The machining process entails a five-step turning of a shaft both on the CNC and conventional lathe. The model design of the transmission shaft and the machined sample of the transmission shaft are presented in Figure (1a –b). The machining on both CNC and conventional lathes used the following turning parameters, feed rate of 200 mm/min, cutting speed of 585 rev/min, and soluble oil is used for cutting fluid as shown in Table 1b. Each of the steps was subjected to surface roughness analysis as depicted in Figures (2a - c) and the results have been categorized into section A, B and C. For each section, seven (7) surface roughness measurements were taken and the averages were reduced based on the surface readings. Some factors are considered in the selection of the material used in this study such as corrosion resistance, heat resistance, strength availability, rigidity, cost effectiveness as well as flexibility also put in mind the physical properties as listed in Table 1a. Teflon material was chosen to for this research work because of the following:

i. It does not generate as much heat as the mild steel.
ii. It does not produce too much noise.
iii. It does not need coolant for machining

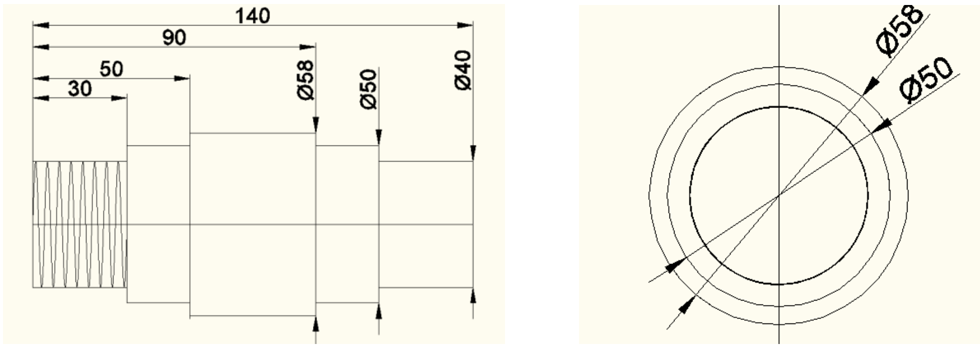
2.2 SRT-6100 Surface Roughness Tester

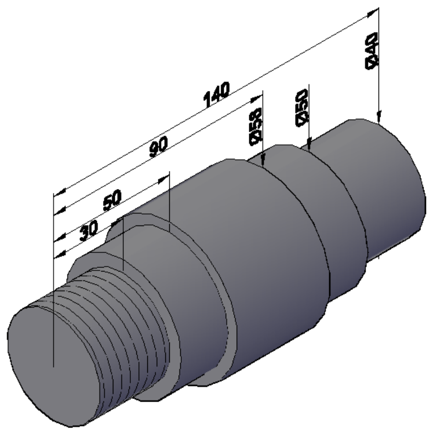
Surface roughness tester is the machine that is used to measure the roughness of a surface with the aid of probes. The SRT-6100 surface roughness tester is handy, light in weight, and easy to carry as shown in Figures (2a - c). It is also complex and advanced in its operational sequence however; it is user friendly. This instrument is compatible with four different standard ANSI, DIN, JIS and ISO. During the surface roughness analysis, a built-in probe containing sensor is used to analysis the surface roughness testing. The probe is made to touch the workpiece and then display the value after measurement. The results usually display on LCD screen attached to the machine.

Table 1: *Properties of Teflon used and the materials/Equipment*

(1a) Properties of Teflon used	
Properties	**Values**
Young's modulus	0.5 Gpa
Density	2200 kg/m^3
Bulk resistivity	1016 Ω·m
Thermal expansion	112-125. 10-6 K
Dielectric constant	ε = 2.1, tan(δ) < 5 (-4)
Melting point	600K
Yield strength	23 Mpa
Thermal diffusivity	0.124 mm^2/s
Coefficient of friction	0.05-0.10
Dielectric constant (60 Hz)	ε = 2.1, tan(δ) < 2(-4)
Dielectric strength (1 MHz)	60 MV/m

(1b) Materials and Equipment		
Cutting tool parameter	**Conventional lathe**	**CNC lathe**
Tool material	Carbide	Carbide
Tool shape	Knife edge	Knife edge
Machining parameters		
Cutting speed	585 rev/min	585 rev/min
Feed rate	200 mm/min	200 mm/min
Cutting fluid	Soluble oil	Soluble oil
Workpiece properties		
Working material	Teflon	Teflon
Workpiece length	140mm	140mm
Workpiece diameter	60 mm	60mm
Cutting condition		
Types of chip formation	Swarf	Swarf





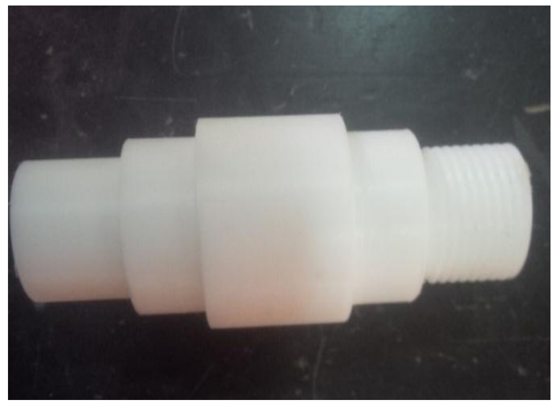


Figure 1a: *Model Design of Transmission Shaft*

Figure 1b: *Machined Transmission Shaft*

Figure 2a: *Test on Surface A*

Figure 2b: *Test on Surface B*

Figure 2c: *Test on Surface C*

2.3 Programme used to machine the transmission shaft on the CNC lathe machine

The machine program used for the model design on the CNC lathe machine for unthreaded portion of the transmission shaft and threaded portion of the transmission shaft are presented below:

I. Model Programme for the Unthreaded Portion

1. 002016;
2. G90 ;
3. M3 S585;
4. G0 X0 Z0;
5. G1 X-46 Z-320
6. G1 X-49 M8 F20
7. G1 Z-410
8. G0 X-46 Z-320
9. G1 X-50
10. Z-370
11. G0 X-46 Z-320;
12. G1 X-52;
13. Z-370;
14. G0 X-46 Z-320;
15. G1 X-54;
16. Z-370;
17. G0 X-46 Z-320;
18. G1 X-56;
19. Z-370;
20. G0 X-46 Z-320;
21. G1 X-59;
22. Z-350;
23. G0 X-46 Z-320;
24. G1 X-60;
25. Z-350;
26. G0 X-46 Z-320;
27. G1 X-64;
28. Z-350;
29. G0 X-46 Z-320;
30. G1 X-64;
31. Z-350;
32. G0 X-46 Z-320;
33. G1 X-66;
34. Z-350;
35. G0 X-46 Z -320;
36. G1 X-67;
37. Z-350;
38. G0 X-46 Z-320;
39. G0 X0 Z0
40. M9
41. M5

II. Model Programme for the Threaded Portion

1. 002016;
2. G90;
3. M3 S585;
4. G0 X0 Z0;
5. G1 X-46 Z-320;
6. G1 X-49 M8 F20;
7. Z-410;
8. G0 X-46 Z-320;
9. G1 X-50;
10. Z-370;
11. G0 X-46 Z-320;
12. G1 X-52;
13. Z-370;
14. G0 X-46 Z-320;
15. G1 X-54;
16. Z-370;
17. G0 X-46 Z-320;
18. G1 X-56;
19. Z-370;
20. G0 X-46 Z-320;
21. G1 X-59;
22. Z-350;
23. G0 X-46 Z-320;
24. G1 X-60;
25. Z-350;
26. G0 X-46 Z-320;
27. G1 X-64;
28. Z-350;
29. G0 X-46 Z-320;
30. G1 X-64;
31. Z-350;
32. G0 X-46 Z-320;
33. G1 X-66;
34. Z-350;
35. G0 X-46 Z -320;
36. G1 X-67;
37. Z-350;
38. G0 X-46 Z-320;
39. G0 T0303 S155;
40. G0 X-73 Z-312;
41. G92 X-71 W-30 F3;
42. X-72;
43. X-73;
44. X-74;
45. X-75;
46. X-76;
47. X-77.4;
48. X-80;
49. G0 X-73 Z-312;
50. G0 X0 Z0;
51. T0202;
52. M9;
53. M5;

Table 2: Surface Roughness Measurement, Ra (μm)

Test	Ra_1(μm)	Ra_2(μm)	Ra_3(μm)	Ra_4(μm)	Ra_5(μm)	Ra_6(μm)	Ra_7(μm)	Average
CNC_A	0.769	0.811	0.800	0.695	0.714	0.819	0.844	0.779
Conv_A	0.992	0.814	1.151	1.052	1.067	0.893	0,963	0.987
CNC_B	1.082	1.062	1.007	0.834	1.067	1.047	1.047	1.021
Conv_B	1.087	1.107	1.072	0.794	1.146	1.186	1.002	1.056
CNC_C	0.729	0.734	0.690	0.635	0.635	0.628	0.536	0.642
Conv_C	1.313	1.261	1.266	1.199	1.074	1.028	0.892	1.145

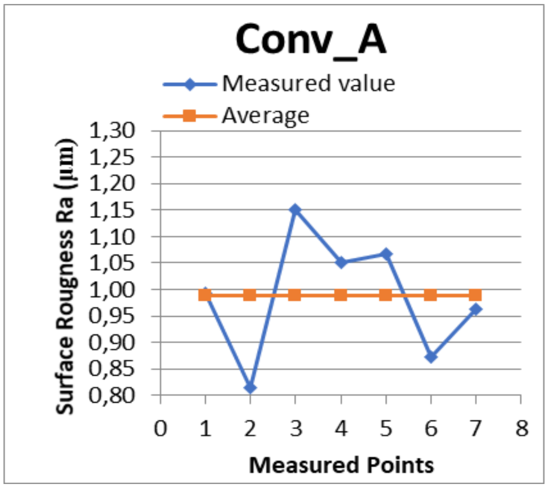


Figure 3a: Graph of Conv_A

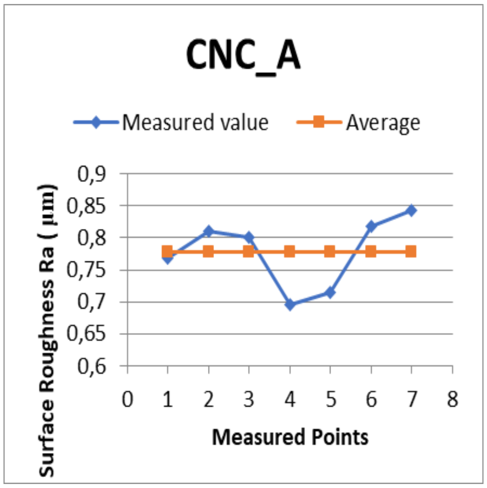


Figure 3b: Graph of CNC_A

Comparing Figure 3a and 3b, results show that measurement of surface roughness machined with CNC gives better surface roughness than the conventional lathe machining as all the seven (7) points are very close to the measured values unlike the measured values of conventional lathe.The plotted measured value of Figure 3b i.e. CNC machine values show a better surface finish than the measured value of Figure 3a i.e. Conventional Lathe Machine values. More so, the average value of Figure 3b is between 0.75 and 0.8 which gives a better surface finish than the average value in Figure 3a which is between 0.95 and 1.00 surface roughness.

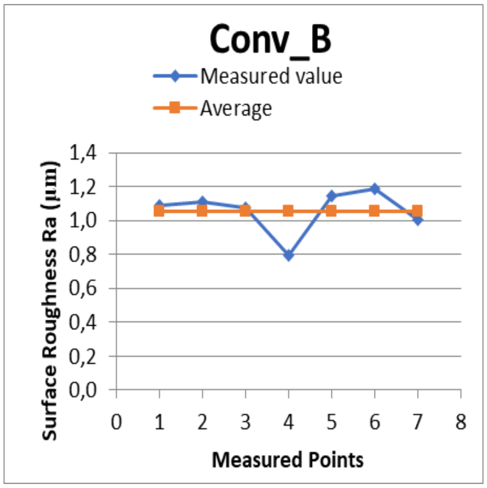


Figure 3c: Graph of Conv_B

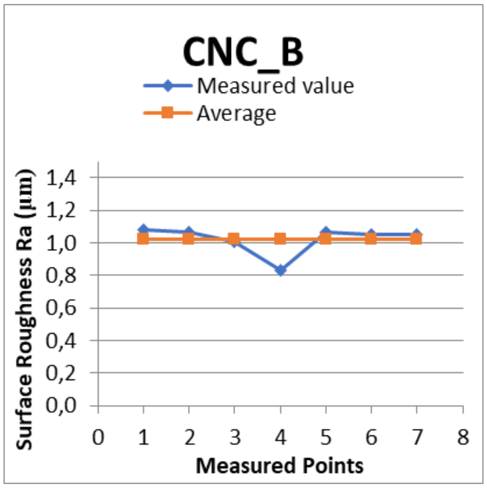


Figure 3d: Graph of CNC_B

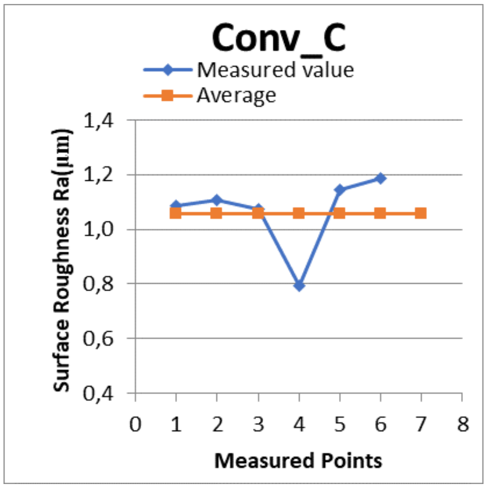


Figure 3e: Graph of Conv_C

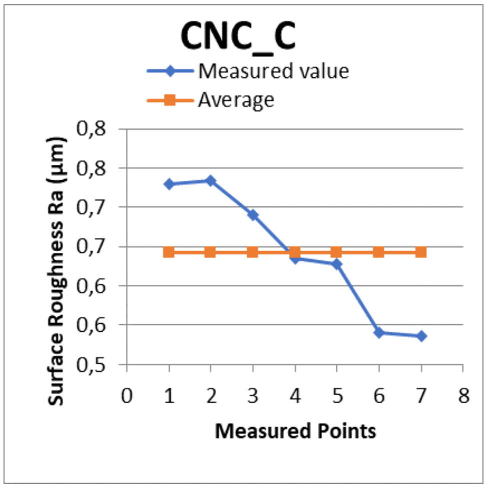


Figure 3f: Graph of CNC_C

RESULT AND DISCUSSION

The result of surface roughness measurement is presented in Table 2; Surface roughness at seven different points on a position (A, B and C) were taken with their average. The measurements were taken at different orientations (A, B and C) of the machined Teflon material with both CNC and Conventional lathe machine. Comparing average measurement of surface roughness at position A, one could see that CNC machining gives better surface roughness with lower average value, likewise in position B. In position C, Conventional Lathe Machining has lower average measurement value compare to CNC lathe machining which gives better surface. Based on the tests carried out, Figures (3a – f) show the surface roughness from the materials from the computer numerical control (CNC) and conventional lathe machines. The results show that surface roughness on CNC machining is better than the conventional lathe machine. The data points of the measured values are very close to the average values of the CNC while that of the conventional deviate further away as evidence in Figures (3a – f). The surface finish of the CNC machined part is better compared with the conventional machines.

CONCLUSION

i. From the analysis conducted of which surface roughness tests were done, the results obtained have proved that for CNC machining of Teflon plastic material under a coolant cutting environment, the surface roughness falls within the acceptable range found in literature.
ii. It can be deduced from the experimental results that arithmetical mean roughness value (Ra) is lower in CNC lathe than in conventional lathe regardless of the orientation of measurements.
iii. In the first orientation "A", the average Ra for CNC lathe was found to be 0.779 µm while that of conventional lathe was 0.987 µm, this implies that turning operation on the conventional lathe is not as smooth as that of CNC.
iv. In the second orientation "B", 1.021 µm and 1.056 µm were the values for Ra in CNC lathe and conventional lathe respectively. It was observed that, the surface integrity from both machining is very close as the values for Ra shows a close margin.
v. In the third orientation "C", it was revealed that CNC lathe has an average value of Ra to be 0.642 µm while that of conventional lathe was 1.145 µm, in this case, there is much gap between the two values and as such CNC still proven to have better and smoother surface topography when compare to conventional lathe.

CONFLICT OF INTEREST

The authors declared that there is no known conflict of interest that can hinder the publication of this paper in this journal.

ACKNOWLEDGMENT

Appreciation goes to the Technicians that work on both the convectional and CNC lathe machines at the Central Engineering Workshop and Production Engineering Laboratory, Afe Babalola University, Ado Ekiti, Nigeria.

REFERENCES

[1] Ikumapayi, O. M. and Akinlabi, E. T. (2019) "Experimental data on surface roughness and force feedback analysis in friction stir processed AA7075 – T651 aluminium metal composite " Data Br.,, 23, 103710, 1- 14. https://doi.org/10.1016/j.dib.2019.103710
[2] Todd, Robert H.; Allen, Dell K.; Al ting, Leo (1994), Manufacturing Processes Reference Guide, Industrial Press Inc., p. 153, ISBN 0-8311-3049-0.
[3] Karayel, D. (2009) Prediction and control of surface roughness in CNC lathe using artificial neural network. Journal of materials processing technology, 2 0 9: 3125–3137.
[4] Okokpujie, I. P. et al.,. (2018)"Modeling and optimization of surface roughness in end milling of aluminium using least square approximation method and response surface methodology," Int. J. Mech. Eng. Technol., 9 (1), 587–600.
[5] Benardos, P. G., Vosniakos, G. C. (2003). Predicting surface roughness in machining: a review. Int Journal of Machine Tool Manufacture; 43:833–44.
[6] Feng, C.X.J., Wang, X. (2002). Development of empirical models for surface roughness prediction in finish turning. Int. J. Adv. Manuf. Technol. 20, 348–356.
[7] Basheer, C., Dabade, U. A., Suhas, S. J., & Bhanuprasad, V. V. (2008). Modeling of surface roughness in precision machining of metal matrix composites using ANN. Journal of Materials Processing Technology, 197: 439-444.
[8] Kartal, F.; Yerlikaya, Z.; Gökkaya, H. (2007). Effects of machining parameters on surface roughness and macro surface characteristics when the machining of Al-6082 T6 alloy using AWJT. Measurement, 95: 216–222. http://dx.doi.org/10.1016/j.measurement.2016.10.007
[9] Fabre, D.; Bonnet, C.; Rech, J.; Mabrouki, T. (2006). Optimization of surface roughness in broaching. CIRP Journal of Manufacturing Science and Technology. 1-13 http://dx.doi.org/10.1016/j.cirpj.2016.10.006
[10] Zhang, S.J.; To, S. ; Wang, S.J.; Zhu, Z.W. (2015). A review of surface roughness generation in ultra-precision machining. International Journal of Machine Tools & Manufacture, 91: 76–95. http://dx.doi.org/10.1016/j.ijmachtools.2015.02.001
[11] Xu, K.; Zeng, Y.; Li, P.; Zhu, D. (2015). Study of surface roughness in wire electrochemical micro machining. Journal of Materials Processing Technology, 222: 103–109. http://dx.doi.org/10.1016/j.jmatprotec.2015.03.007
[12] Zhang, N.; Shetty, D. (2016).An effective LS-SVM-based approach for surface roughness prediction in machined surfaces. Neurocomputing, 198: 35–39. http://dx.doi.org/10.1016/j.neucom.2015.08.124
[13] Kumaran, S. T. ; Ko, T. J.; Uthayakumar, M. ; Islam, Md. M. (2017). Prediction of surface

roughness in abrasive water jet machining of CFRP composites using regression analysis. Journal of Alloys and Compounds, 724: 1037-1045. http://dx.doi.org/10.1016/j.jallcom.2017.07.108

[14] Venkatesan, K.; Ramanujam, R.; Joel, J.; Jeyapandiarajan, P.; Vignesh, M.; Tolia, D.J.; Krishna, R. V. (2014).Study of Cutting force and Surface Roughness in machining of Al alloy Hybrid Composite and Optimized using Response Surface Methodology. 12th global congress on manufacturing and management, GCMM 2014. Procedia Engineering 97: 677 – 686.

[15] Vallejo, A.J.; Morales-Menendez, R. and Ram´ırez-Mendoza, R. (2009). Surface Roughness Modelling in Machining Processes. Proceedings of the 13th IFAC Symposium on Information Control Problems in Manufacturing, Moscow, Russia, 325 – 330.

[16] Kumar, S.; Singh, D.; Kalsi, N. S. (2017). Analysis of Surface Roughness during Machining of Hardened AISI 4340 Steel using Minimum Quantity lubrication. 5th International Conference of Materials Processing and Characterization (ICMPC 2016). Materials Today: Proceedings, 4: 3627–3635.

[17] Rao, K. S.; Rao, C.S. P.; Bose, P.S.C.; Rao, B. B.; Ali, Md. A.; Kumar, K. K. (2017). Optimization of Machining Parameters for surface roughness on turning of Niobium alloy C-103 by using RSM. 5th International Conference of Materials Processing and Characterization (ICMPC 2016). Materials Today: Proceedings 4: 2248–2254.

[18] Kumar, S.; Singh, D.; Kalsi, N. S. Experimental Investigations of Surface Roughness of Inconel 718 under different Machining Conditions. 5th International Conference of Materials Processing and Characterization (ICMPC 2016). Materials Today: Proceedings 4: 1179–1185, (2017).

[19] Kant, G. and Sangwan, K.S. (2014). Prediction and optimization of machining parameters for minimizing power consumption and surface roughness in machining. Journal of Cleaner Production, 83: 151-164.

[20] Prakash Rao C.R.; Bhagyashekar M.S.; Narendraviswanath. (2014). Effect of Machining Parameters on the Surface Roughness while Turning Particulate Composites. 12th Global Congress On Manufacturing And Management, (GCMM 2014). Procedia Engineering, 97: 421 – 43.