

Effect of Cutting Parameters on Surface Roughness of Stainless Steel during Turning Operation

¹Ipilakyaa, T. D., ²Gbashi, S. M., ³Omenka, I. K., ⁴Okwori, E. A. and ⁵Uche, R. B.

^{1, 2, 3, 4, 5}Department of Mechanical Engineering, University of Agriculture Makurdi, Nigeria.
ipilakyaa@yahoo.com

ARTICLE INFO

Article history:

Received: 15th May, 2019

Received in revised form:

30th May, 2019

Accepted: 12th December, 2019

Published: 30th December, 2019

Keywords

Cutting speed, Depth of cut, Feed rate, Surface roughness, Turning operation.

ABSTRACT

This paper examines the effect of cutting parameters (speed, feed rate and depth of cut) on the surface roughness of stainless steel and proposes a model equation that defines the relationship between surface roughness and the cutting parameters. A full factorial experiment was used to scrutinize the cutting characteristics of stainless steel using High Speed Steel Tool (HSS) while regression analysis was used to develop the model equation. The specimen was turned on a manual lathe machine (Harrison M300) under different levels of constraints and the surface roughness was established using an SRT-6223 Digital Surface Profile Gauge Roughness Tester. Results of the study indicate significant improvement in surface finish of stainless steel at higher cutting speeds, lower feed rates and lower depths of cut. In addition, feed rate was found to have greater influence on surface roughness of stainless steel than depth of cut. Optimum cutting speed, feed rate and depth of cut were found to be 69.74 m/min, 0.08 mm/rev. and 1.0 mm respectively, which produced the least surface roughness of 1.4 μm . According to the non-linear regression equation, the optimum surface roughness was 1.6 μm .

© 2018TAJET. All rights reserved

Introduction

Control of surface roughness has long been established as a vital consideration in the machining of engineering materials. Surface integrity has a significant impact on product performance, longevity, reliability, aesthetics and market value [1].

The various mechanical, physical, thermal and chemical effects induced during processing of materials have an important influence on the surface of a manufactured part. The quality of machined parts may be affected significantly as the properties of the machined surface are altered by dry machining [2]. A surface generally has properties and behavior that are considerably different from those of the bulk of the part. Although the bulk material generally determines a component's overall mechanical properties, the component's surfaces directly influence several important properties and characteristics of the manufactured part [3].

Regardless of the method of production, all surfaces have their own set of characteristics, referred to as surface integrity. Surface texture is the repetitive or random deviation from the nominal surface that forms the three-dimensional topography of the surface. Surface texture includes: roughness (nano and micro roughness), waviness (macro roughness) lay, and flaws. Surface roughness is a material property, used to identify surface texture in terms of well-defined and measurable quantities. It is a predominant characteristic in evaluating surface quality of a machined component [4]. Surface

roughness is measured by the vertical deviation of a real surface from its horizontal ideal form. If those deviations are relatively large, the surface is rough; if they are relatively small, the surface is smooth [5]. Surface roughness most commonly refers to the variations in the height of the surface relative to a reference plane. It is measured either along a single line profile or along a set of parallel line profiles.

The surface roughness of a finished component is closely related to the functional performance of the component during its service life. Machined components during their useful life are significantly influenced by surface roughness which affects several properties such as; corrosion resistance, fatigue strength, wear resistance, coefficient of friction, ability to distribute and hold a lubricant, load bearing capacity, heat transmission, and coating [6].

There are many different roughness parameters in use but R_a (arithmetical mean deviation of the assessed profile) is by far the most common, though this is often for historical reasons and not for particular merit, as the early roughness meters could only measure R_a .

Turning is a machining process carried out on a lathe machine in which unwanted material is removed by using a tool bit which is advanced into the rotating work piece. Turning can also be defined as a chip removal operation where the piece of metal to be machined is rotated and the cutting tool is advanced against it [7]. Turning is used to produce rotational, typically axi-symmetric parts that have many features such as holes,

grooves, threads, tapers, various diameter steps, and even contoured surfaces. Parts that are fabricated completely through turning often include components that are used in limited quantities such as custom designed shafts and fasteners.

Lathe is one of the most reliable production machines used by the manufacturing industry in producing its products. The product quality of the lathe process is determined by the degree of roughness of the surface. In the process of cutting metal using lathe, the result of roughness is determined by three main parameters, namely movement of work piece/spindle main motion, feed motion and depth of cut [8]. Therefore, the control of machined surface roughness is essential [9], and appropriate process parameters (depth of cut, feed rate and speed of cut) have to be selected to reach the desired surface quality of machined parts.

The important cutting parameters to be considered are the cutting speed, feed rate and depth of cut. These parameters affect the surface integrity of the machined material. The cutting speed (surface speed) is defined as the speed at which the work piece material is moving past the cutting tool. The cutting speed of a cutter bit is defined as the number of feet of work-piece surface, measured at the circumference, that pass the cutter bit in 1 minute. The cutting speed is expressed in meter per minute (m/min).

Feed rate refers to the cutting tool and it is the rate at which the tool advances along its cutting path. It is the term applied to the distance the cutter bit advances for each revolution of the work piece. It is specified in millimeters per revolution.

Depth of cut is the thickness of the layer being removed in a single pass from the work piece or the distance from the uncut surface of the work to the cut surface expressed in millimeters. The depth of cut regulates the reduction in the diameter of the work piece for each longitudinal traverse of the cutter bit. Figure 1 shows the various cutting parameters on a turning operation process on a work piece.

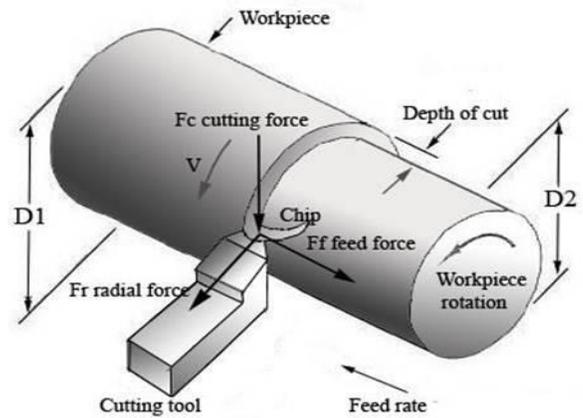


Fig. 1: Work piece showing the various cutting parameters

Stainless steel is a steel alloy with highest percentage contents of iron, chromium and nickel with minimum of 10.5% chromium content by mass and a maximum of 1.2% carbon by mass. Stainless steels are most notable for their corrosion resistance, which increases with increasing chromium content. They exhibit extraordinary corrosion resistance due to the formation of a thin layer of Cr_2O_3 on the surface. Stainless steels are categorized into Ferritic (composed of ferrite), Martensitic, Austenitic, Precipitation-Hardening and Duplex stainless steels. Stainless steel is used in architecture (buildings and bridges), chemical and petrochemical industries (pipes), food and beverage industries (cookware), transportation sector, energy, culinary, jewelry and other applications.

A number of important investigations have been carried out on determining the relationship between cutting parameters and mechanical properties of engineering materials. Abdallah [10] recognized the importance of achieving dimensional accuracy, good surface finish and maximum material removal rate in the machining process; and optimized the cutting parameters viz. feed rate, cutting speed and depth of cut for superior surface finish and maximum material removal rate of an aluminum alloy 6061. Surface roughness and material removal rate were found to be maximum at 11.6% and 14%, and minimum at 4.4% and 3.7% respectively. Cutting parameters including cutting speed, feed rate and depth of cut were found to affect the machining process at 45%, 36% and 19% respectively for minimum surface finish of 0.256 microns with an error percentage of 4.4%.

Al-Ahmari [11] developed empirical models for tool life, surface roughness and cutting force for turning operations. Process parameters including cutting speed, feed rate, depth of cut and nose radius were used to develop the machinability model using Response Surface Methodology (RSM) and neural



networks (NN). Abhang and Hameedullah [12], carried out experimental work to optimize cutting parameters including feed rate, depth of cut and lubricant temperature in the turning operation of EN-31 steel alloy by using tungsten carbide inserts. The work aimed at explaining and demonstrating the systematic procedure of Taguchi parameter design. The study determined the optimal combination of cutting parameters using the signal-to-noise ratio and the significance level of each cutting parameter using ANOVA analysis. The study established that better surface finish can be obtained with a cooling lubricant at higher depths of cut.

Feng and Wang [13] researched on prediction of surface roughness in finish turning operation. An empirical model was developed by considering working parameters: work piece hardness (material), feed rate, cutting tool point angle, depth of cut, spindle speed and cutting time. Data mining techniques, nonlinear regression analysis with logarithmic data transformation were employed in developing the empirical model.

Doniavi *et al.* [14] used response surface methodology (RSM) to develop an empirical model for the prediction of surface roughness in turning operations. The authors showed that the feed rate influenced surface roughness remarkably. With increase in feed rate, surface roughness was found to be increased. With increase in cutting speed, the surface roughness decreased. The analysis of variance was applied which showed that the influence of feed and speed were more in surface roughness than depth of cut.

Paul [15] experimentally investigated the effect of cutting speed, feed and depth of cut on the surface finish, tool wear and cutting force in a continuous dry turning of hardened alloy steel, AISI 4340 having hardness: 48(48-52) HRC using the Taguchi design of experiments. It was observed that for tool wear, feed had significant influence and depth of cut was the least influential of all. Optimal conditions were obtained at cutting speed (140 m/min), feed (0.125 mm/rev), and depth of cut (0.8 mm).

Kirby *et al.* [16] developed the prediction model for surface roughness in turning operation. The regression model was developed by a single cutting parameter and vibrations along three axes were chosen for in-process surface roughness prediction system. By using multiple regression and Analysis of Variance (ANOVA), a strong linear relationship among the parameters (feed rate and vibration measured in three axes) and the response (surface roughness) was found. The study demonstrated that spindle speed and depth of cut may not

necessarily need to be fixed for an effective surface roughness prediction model.

Materials and Methods

Turning operations were performed on a Harrison M300 Lathe machine with center height 167 mm, capacity between centers 635 and motor power of 1.6 kW. The spindle speed of the lathe was between 40 to 2500 rpm and the cutting tool used was High Speed Steel. The tool was selected because of its high resistance to abrasion, wear and ability to withstand high cutting speeds and temperatures. These characteristics allow relatively higher machining speeds and improved performance over plain High Carbon steel. The work piece was Stainless Steel with a diameter of 60mm and a length of 170mm. Surface integrity was measured using SRT-6223 Digital Surface Profile Gauge Roughness Tester. This device has a range of 0-800 μm , an accuracy of $\pm 5 \mu\text{m}$ and is incorporated with an LCD display. The tester is a handheld gauge for fast and accurate measurement of the peak-to-valley height of the surface profile. Turning operation were performed with the cutting speed range of between 7.54-69.74 m/min; feed rate range of 0.05-0.2 mm/min and depth of cut of between 0.5 mm – 1.8 mm. Experimental samples were obtained by varying cutting speeds while keeping depth of cut and feed rate constant; varying feed rate while keeping depth of cut and cutting speed constant and finally varying depth of cut while keeping cutting speed and feed rate constant. The corresponding surface roughness for each of the samples was measured using the surface roughness tester. The minimum surface roughness results in reference to cutting speed, feed rate, and depth of cut were determined and estimations of the optimal surface roughness value (R_a) for least surface roughness were also determined. Regression analysis was used to develop a model equation for the effect of cutting speed, feed rate and depth of cut on surface roughness.

Results and Discussion

Figure 2 shows the effect of cutting speed on surface roughness, Figure 3 the effect of feed rate on surface roughness while Figure 4 shows the effect of depth of cut on surface roughness. The result of the effect of cutting speed on surface roughness, presented in Figure 2 shows that surface roughness decreases with increase in cutting speed for dry machining. This is due to the decrease in the built-up edge size at higher speed which agrees with the results of Selvaraj and Palanisam [17]. In addition, the cutting process becomes more and more stable as the speed increases, and the vibration during cutting at higher speed is lower as reported by Ghani *et al.* [18].

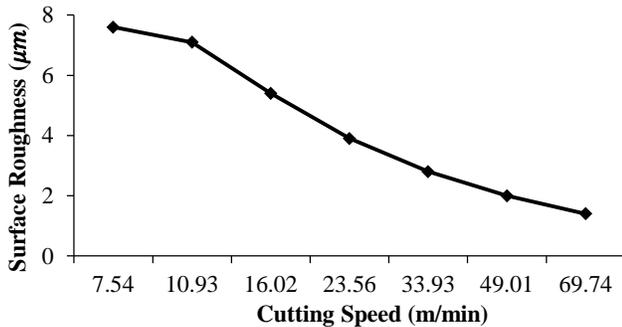


Fig. 2: Effect of Cutting Speed on Surface Roughness

Figure 3 shows the result of the effect of feed rate on surface roughness. In all the seven machining cases shown in the figure, it is seen that surface roughness is reduced by increasing the feed rate. This agrees with the theoretical relationship that exists between surface roughness and feed rate Selvaraj and Palanisam [17].

It is clear in Figure 4 that surface roughness increased with increase in depth of cut for all the seven cases investigated. Increase in surface roughness with depth of cut may be attributed to increase in machine vibration due to the increase in cutting forces at larger depths of cut [19]. Increase in surface roughness at larger depths of cut could also be linked to built-up edge formation at larger depths of cut.

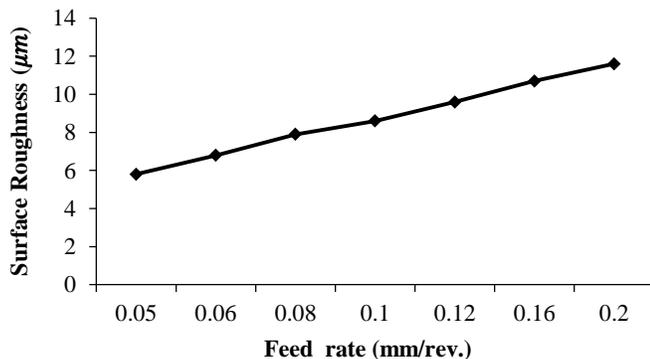


Fig. 3: Effect of Feed Rate on Surface Roughness

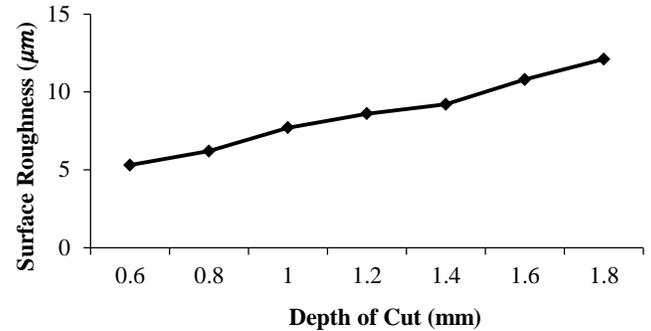


Figure 4: Effect of Depth of Cut on Surface Roughness

A multiple regression analysis was carried out at 95% confidence.

For multiple regression equation, the model is given as

$$Y = A_0 + A_1X_1 + A_2X_2 + A_3X_3 + A_{\dots}X_{\dots} \quad (1)$$

where Y is the dependent variable, and A_1, A_2, A_3, A_{\dots} are the coefficients of the X_1, X_2, X_3, X_{\dots} independent variables respectively.

However, for the regression equation for the effect of cutting speed, feed rate and depth of cut on surface roughness, surface roughness (R_a) becomes the dependent variable and cutting speed (v), feed rate (f) and depth of cut (d) become the independent variables. Therefore, equation (1) after substituting coefficient and intercept values and terms, the least – squares regression equation for surface roughness becomes:

$$\log R_a = 2.034 - 0.708 \log v + 0.475 \log f + 0.717 \log d \quad (2)$$

Hence,

$$R_a = 108.143 \left[\left(\frac{f^{0.475} * d^{0.717}}{v^{0.708}} \right) \right] \quad (3)$$

Equation 2 is the only linear equation that satisfies a least – squares criterion. That means this equation fits the data from which it was created better than any other linear equation. Equation 3 becomes the non-linear regression equation.

The coefficient of multiple determination measures the proportion of variation in the dependent variable (R_a) that can be predicted from the set of independent variables (v, f, d) in the regression equation. The coefficient of multiple determination is rounded up to 0.983. For the sample, this means that about 98.3% of surface roughness can be explained by the cutting parameters (cutting speed, feed rate and depth of cut). Also, having an F-test value greater than the significant F



value or p-values, it further suggests that the regression equation fits the data well.

Comparing Figures 2, 3 and 4, it can be concluded that the optimum combination of cutting parameters for minimum surface roughness is obtained at cutting speed 69.74 m/min (370 rpm), feed rate of 0.08 mm/rev. and depth of cut 1.00 mm which gives surface roughness of 1.4 μm .

Conclusion

From the experimental investigations carried out, results from figures 2, 3 and 4 indicate significant improvement in surface finish of stainless steel at higher cutting speeds, lower feed rates and lower depths of cut. In addition, feed rate was found to have greater influence on surface roughness of stainless steel than depth of cut. Optimum cutting speed, feed rate and depth of cut were found to be 69.74 m/min (370 rpm), 0.08 mm/rev. and 1.0 mm respectively, which produced the least surface roughness of 1.4 μm .

References

- [1] Waseem, A. Jianfei, S and Wuyi, C. (2015). Effect of Machining Parameters on Surface Integrity in High Speed Milling of GH4169. *Journal of Material and Manufacturing Processes*, 31(4): 620 – 627.
- [2] Shaikh A. H. and Ambekar S. D. (2016). Effect of Cutting Parameters on Surface Finish, Toolchip Interface Temperature and Machining Time in the Turning of OHNS 01 Grade Steel. *International Journal of Scientific Research and Development*, 4(8): 37 - 44.
- [3] Hamdi, H., (2008). Workpiece Surface Integrity. In: Paulo, J. D., ed. *Machining: Fundamentals and Recent Advances*. 3rd Edition. New York: Springer, 59 - 91.
- [4] Rao P. N. (2000). *Manufacturing Technology, Metal Cutting and Machine Tools*. 3rd Edition. USA: McGraw-Hill Companies.
- [5] Hassan A. E., (2014). *Fundamentals of Machining Processes*. 4th Edition. USA: CRC Press, Taylor and Francis Group.
- [6] Natarajan C., Muthu S. and Karuppuswamy P. (2011). Investigation of Cutting Parameters of Surface Roughness for Non-ferrous Material using Artificial Neural Network in CNC Milling. *Journal of Mechanical Engineering Research*, 3(1):1-14.
- [7] Kanase T. S. and Jadhav D. B. (2013) Enhancement of Surface Finish for CNC turning Cutting Parameters by using Taguchi Method. *Indian Journal of Researches*, 3(2): 23 – 34.
- [8] Thomas C., Katsuhiko M., Toshiyuki O., and Yasuo Y. (2012). *Metal Machining Theory and Applications*. 5th Edition. New York-Toronto: John Wiley & Sons Inc.
- [9] Asilturk I. and Akkus, H., (2011). Determination of the Effect of Cutting Parameters on Surface Roughness in Hard Turning using the Taguchi Method. *International Journal of Advanced Manufacturing Technology*, 12(4): 234-245.
- [10] Abdallah A., (2014). Optimization of Cutting Parameters for Surface Roughness in CNC Turning Machining with Aluminum Alloy 6061 Material. *IOSR Journal of Engineering (IOSRJEN)*, 4(10): 220-302.
- [11] Al-Ahmari A. M. A., (2007), Predictive Machinability Models for a Selected Hard Material in Turning Operations. *Journal of Materials Processing Technology*, 190(3): 305–311.
- [12] Abhang L. B. and Hameedullah M., (2012). Optimization of Machining Parameters in Steel Turning Operation by Taguchi Method. *International conference on Modelling, Optimization and Computing, Procedia Engineering*, 38(1): 40-48.
- [13] Feng C. X. and Wang X. (2002), Development of Empirical Models for Surface Roughness Prediction in Finish Turning. *International Journal of Advanced Manufacturing Technology*, 20(5): 348–356.
- [14] Doniavi A., Eskanderzade M. and Tahmasebian M. (2007). Empirical Modeling of Surface Roughness in Turning Process of 1060 Steel using Factorial Design Methodology. *Journal of Applied Sciences*, 7(17): 2509-2513.
- [15] Paul B. K. (2014). Optimization of Cutting Parameters in Hard Turning of AISI 4340 Steel. *International Journal of Innovative Research in Advanced Engineering*, 1(8): 2349-2163.
- [16] Kirby E. D., Zhang Z. and Chen J. C. (2004). Development of an Accelerometer Based Surface Roughness Prediction System in Turning Operation using Multiple Regression Techniques. *Journal of Industrial Technology*, 20(4): 1-8.
- [17] Selvaraj D. P. and Palanisam C. (2010). Influence of Cutting Speed, Feed Rate and Bulk Texture on the Surface Finish of Nitrogen Alloyed Duplex Stainless Steels during Dry Turning. *Journal of Material Engineering*, 2(3): 453-460.
- [18] Ghani A. K., Choudhury I. A. and Husni S.N. (2002). Study of Tool Life, Surface Roughness and Vibration in Machining Nodular Cast Iron with Ceramic Tool. *Journal of Materials Processing Technology*, 127(1): 113-123.



[19] Helmi A. Y. and Hassan E. (2008). Machining Technology: Machine Tool Operations. 2rd Edition. USA: CRC Press, Taylor and Francis Group. Asuquo, L. and

Bobo-Jama, S. A. (1991). Foundry Technology, 23-31, ABIC Books and Equipment Ltd, Enugu-Nigeria.