Effect of Machining Parameters on the Surface Roughness for Different Type of Materials

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Abstract. Surface roughness ($R_a$) is an important parameter in determining the quality of surface finishing of any products obtained from the machining process. Surface roughness can be affected by several factors such as machining parameters, workpiece material properties, cutting tool parameters and machine tool conditions. In this study, the effects of machining parameters such as feed rate and cutting speed on the surface roughness was investigated for aluminium, mild steel and brass materials during the turning process using CNC Lathe machine. The experimental $R_a$ values obtained were compared with the theoretical values with discrepancy ranging from 1.14 % to 113.71 %. From the study, it can be concluded that the surface roughness of materials will increases as the feed rate increases and decrease when higher cutting speed is applied.

1. Introduction

Surface roughness is a measurement of finished surface area where it indicates the state of machined surface. A better surface finishing is one of the desired requirements in industry as it improves fatigue strength and minimizes friction [1]. The parameters that affect the surface roughness can be classified into primary and natural surface roughness effects. Primary surface roughness effect is contributed by cutting tool geometry, feed rate and cutting speed while natural surface roughness effect is contributed by the machine tool and uncontrolled variation in machining process such as tool wear, dynamic unbalance of machining system and chip formation [2-3].

Surface roughness plays an important role in determining how a real object will interact with its environment. There are various factors that will affect the surface roughness of a workpiece such as cutting speed, feed rate and tool nose radius. Figure 1 shows the example of machined components and the affected surface roughness parameters during the machining process.
The theoretical values of $R_a$ can be calculated using the general exponential modelling Equations (1) and (2) as follows [5]:

$$R_a = 1.22 \times 10^5 M f^{1.004} V_C^{-1.252}$$ (1)

$$M = r^{-0.714} (BHN)^{-0.323}$$ (2)

Where, $R_a$ = average surface roughness ($\mu$m)

$V_C$ = cutting speed (m/min)

$f$ = feed rate (m/min)

$r$ = tool nose radius (m)

BHN = hardness of material

For the turning process, cutting speed ($V_c$) is related to workpiece diameter $D$ and the revolution rate $N$ [6]. This relation is given by Equation (3) as follows:

$$V_c = \pi DN$$ (3)

Previous studies that related to this matter have been carried out over the years. Rajesh et. al., [7] studied the effect of machining parameters such as cutting speed, feed rate and depth of cut (DOC) on Al alloy composite. Experiment was conducted using CNC Turning machine with carbide and polycrystalline diamond (PCD) cutting tools. It can be concluded that the surface roughness of Al alloy is less than Al alloy composite and the optimum machining parameters of cutting speed, feed rate and DOC are 180 to 220 m/min, 0.1 to 0.3 mm/rev and 0.5 to 1.5 mm respectively. A proper combination of cutting speed, feed rate and DOC is very important to achieve good machinability because in conventional machining process, these are the most influential machining parameters [8].

Nexhat Qehaja et. al., [9] conducted a research on the effect of machining parameters and machining time on the surface roughness of cold rolled steel using production lathe machine. Statistical method revealed that the feed rate has the most influence on the surface roughness, followed by nose radius and cutting time. Study on the effect of cutting speed, feed rate, DOC and types of coolant on the surface roughness of stainless steel has been carried out by Sutar and Gujar using CNC Milling machine [10]. Among these parameters, it was found that the most significant parameter is type of coolant, followed by cutting speed, feed rate and DOC.

Dinesh et. al., [11] conducted a study to observe the effect of machining parameters on surface roughness for titanium alloy using 3-axis CNC Milling machine. The result shows that the surface roughness increased with increasing of feed rate and depth of cut but decreased with increasing of cutting speed under wet condition. In addition to the feed rate and DOC, Catherine et. al., [12] have studied the effect of spindle speed, step over and plunge rate on the surface roughness of machined polyurethane (PU) block. Step over is how far between the previous and the next cut is, whereas
plunge rate is the speed at which the tool moves in the z direction [13]. The study has proved that the step over and silicon content are the most significant parameters that contribute to the surface quality of PU block.

Numerous studies on the effect of machining parameters to the surface roughness has been conducted but the equipment and the material used are different. Also, there are rarely studies that compare the theoretical and experimental roughness values. Thus, there are no discussion behind the percentage difference values. In this study, the effect of machining parameters such as cutting speed and feed rate to the surface roughness of aluminium, brass and mild steel materials will be investigated. Such study on these materials has only been conducted by Suker et. al., [14] but there is no detail discussion on the theoretical and experimental results. In this study, each sample was prepared using Traditional Lathe machine while turning process was done using CNC Lathe machine. Roughness values of each sample is determined through Surfcom-130A surface and roughness tester machine. Both results in terms of theoretical and experimental will be compared and discussed in this study.

2. Methodology

2.1 Workpiece preparation

Each workpiece was set up on the Traditional Lathe machine, as shown in Figure 2. Firstly, the facing process is carried out where the metal was removed from the end of each workpiece with spindle rotation of 540 rpm until flat surface is obtained [15]. After drilling the centre point, the facing process was continue on the other end of each workpiece. Then, the hardness of each workpiece was determined using Rockwell hardness tester based on HRB scale. By referring to the hardness conversion chart, HRB was converted to BHN value and the results acquired were compared with the mechanical properties of hardness (HRB) to obtain the specific classification of materials.

2.2 Turning process

For the turning process, the cutting speed, feed rate, cutting and machine tools are firstly determined. Before setting up the workpiece on the CNC Lathe machine, each workpiece was divided into five sections. Figure 2 shows the CNC Lathe machine used in this study. Turning process was performed with five different values of feed rate which is 0.12 mm/rev, 0.16 mm/rev, 0.2 mm/rev, 0.24 mm/rev and 0.28 mm/rev. The turning process was repeated with different cutting speed value of 75.40 m/min, 113.10 m/min, 150.81 m/min, 188.50 m/min, and 226.19 m/min.

2.3 Determining the roughness value of workpiece

The roughness values of each workpiece for all the five sections were determined by setting up the workpiece on the Surfcom-130A surface and roughness tester with the maximum level of Rₐ is 400 μm. The experimental values of surface roughness obtained were then compared with the theoretical values form the calculation.

Figure 2. (a) Traditional Lathe machine (left) and (b) CNC Lathe machine (right)
3. Results and discussion

3.1 Feed rate

Theoretical value calculations (this formula applies to all types of workpiece) are shown as follows:

Spindle rotation = 1200 rpm

\[ V_c = \pi DN = \pi \times \left(\frac{24}{1000}\right) \times 1200 = 90.48 \text{ m/min} \]

By combining both equation (1) and (2),

\[ R_a (\text{Theoretical}) = 1.22 \times 10^5 \times r^{-0.714} \times (BHN)^{-0.323} \times f^{1.004} \times V_c^{-1.252} \mu m \]

Percentage of error = \( \frac{\text{experimental} - \text{theoretical}}{\text{theoretical}} \times 100 \% \)

Table 1 shows the effect of feed rate on the surface roughness for aluminium material. The feed rate used in this study are 0.12 mm/rev, 0.16 mm/rev, 0.20 mm/rev, 0.24 mm/rev and 0.28 mm/rev. This feed rate values applies to the mild steel and brass materials as well. The cutting speed is fixed at 90.48 m/min. The highest percentage differences between theoretical and experimental value of surface roughness for the aluminium is 59.11 % at 0.24 mm/rev feed rate.

**Workpiece A1 – Aluminium (A16061)**

| Diameter of workpiece (mm) | 24.00 |
| Cutting speed, \( V_c \) (m/min) | 90.48 |
| Spindle rotation, \( N \) (rpm) | 1200 |
| Tool nose radius, \( r \) (mm) | 0.80 |
| Workpiece Brinell hardness value, BHN | 143 |
| Depth of cut, \( a \) (mm) | 0.50 |
| Feed rate, \( f \) (mm/rev) | 0.12 | 0.16 | 0.20 | 0.24 | 0.28 |
| Theoretical roughness value, \( R_a \) (\( \mu m \)) | 1.642 | 2.191 | 2.742 | 3.292 | 3.843 |
| Experimental roughness value, \( R_a \) (\( \mu m \)) | Reading 1 | 0.738 | 0.991 | 1.242 | 1.435 | 2.342 |
| | Reading 2 | 0.801 | 0.865 | 1.258 | 1.107 | 1.853 |
| | Reading 3 | 0.749 | 0.926 | 1.134 | 1.496 | 2.048 |
| | Average | 0.763 | 0.927 | 1.211 | 1.346 | 2.081 |
| Percentage of error (%) | 53.53 | 57.69 | 55.84 | **59.11** | 45.85 |

Figure 3 shows the graph of surface roughness against feed rate for aluminium material. The differences between theoretical and experimental values can be clearly seen from this figure.
Table 2 shows the effect of feed rate on the surface roughness for mild steel material. The highest percentage differences between theoretical and experimental value of surface roughness is 30.03% at feed rate 0.28 mm/rev.

**Workpiece B1 – Mild steel**

| Diameter of workpiece (mm) | 24 |
|---------------------------|----|
| Cutting speed, V<sub>c</sub> (m/min) | 90.48 |
| Spindle rotation, N (rpm) | 1200 |
| Tool nose radius, r (mm) | 0.8 |
| Workpiece Brinell hardness value, BHN | 135 |
| Depth of cut, a (mm) | 0.5 |
| Feed rate, f (mm/rev) | 0.12 | 0.16 | 0.20 | 0.24 | 0.28 |
| Theoretical roughness value, R<sub>a</sub> (µm) | 1.728 | 2.232 | 2.880 | 3.354 | 3.916 |
| Experimental roughness value, R<sub>a</sub> (µm) | |
| Reading 1 | 1.706 | 1.590 | 2.229 | 3.168 | 2.586 |
| Reading 2 | 2.156 | 2.376 | 2.583 | 2.886 | 2.881 |
| Reading 3 | 1.859 | 2.191 | 3.000 | 2.751 | 2.754 |
| Average | 1.907 | 2.052 | 2.604 | 2.935 | 2.740 |
| Percentage of error (%) | 10.36 | 8.06 | 9.58 | 12.50 | **30.03** |

Figure 3. Graph of surface roughness against feed rate for Aluminium (Al6061).

Figure 4 shows the graph of surface roughness against feed rate for mild steel material.
Table 3 shows the effect of feed rate on the surface roughness for brass material. The highest percentage differences between theoretical and experimental value of surface roughness is 51 % at 0.12 mm/rev feed rate.

**Workpiece C1 – Brass (C2700)**

Table 3. Effect of feed rate on surface roughness for Brass (C2700).

| Diameter of workpiece (mm) | 24 |
|---------------------------|----|
| Cutting speed, \( V_c \) (m/min) | 90.48 |
| Spindle rotation, \( N \) (rpm) | 1200 |
| Tool nose radius, \( r \) (mm) | 0.8 |
| Workpiece Brinell hardness value, \( BHN \) | 156 |
| Depth of cut, \( a \) (mm) | 0.5 |
| Feed rate, \( f \) (mm/rev) | 0.12 | 0.16 | 0.20 | 0.24 | 0.28 |
| Theoretical roughness value, \( R_a \) (μm) | 1.596 | 2.131 | 2.666 | 3.201 | 3.737 |
| Experimental roughness value, \( R_a \) (μm) | 2.439 | 2.381 | 2.113 | 2.684 | 3.494 |
| Reading 1 | 2.489 | 2.618 | 2.143 | 2.621 | 3.549 |
| Reading 2 | 2.303 | 2.541 | 2.266 | 2.548 | 3.270 |
| Reading 3 | 2.410 | 2.513 | 2.174 | 2.618 | 3.438 |
| Average | 2.410 | 2.513 | 2.174 | 2.618 | 3.438 |
| Percentage of error (%) | 51.00 | 17.93 | 18.45 | 18.21 | 8.00 |

Figure 5 shows the graph of surface roughness against feed rate for brass material.
3.2 Cutting speed

Table 4 shows the effect of cutting speed on the surface roughness for aluminium material. For this case, the feed rate is fixed at 0.20 mm/rev. Cutting speed used in this experiment is 75.4 m/min, 113.1 m/min, 150.81 m/min, 188.5 m/min and 226.19 m/min, which applies to all materials. The highest percentage differences between theoretical and experimental value of surface roughness is 82.82% at 188.5 m/min cutting speed.

Theoretical value calculations (this formula applies to each workpiece) are shown as follows:

Spindle rotation = 1000 rpm

\[ V_c = \pi DN = \pi \times \left( \frac{24}{1000} \right) \times 1000 = 75.40 \text{ m/min} \]

**Workpiece A2 – Aluminium (A16061)**

| Workpiece Brinell hardness value, BHN | 143 |
|--------------------------------------|-----|
| Feed rate, f (mm/rev)                | 0.20 |
| Spindle rotation, N (rpm)            | 1000 | 1500 | 2000 | 2500 | 3000 |
| Cutting Speed, \( V_c \) (m/min)     | 75.40 | 113.10 | 150.81 | 188.50 | 226.19 |
| Theoretical roughness value, \( R_a \) (\( \mu \)m) | 3.445 | 2.073 | 1.446 | 1.094 | 0.871 |
| Experimental roughness value, \( R_a \) (\( \mu \)m) | Reading 1 | 3.572 | 1.823 | 1.707 | 2.184 | 1.031 |
|                                      | Reading 2 | 2.765 | 2.085 | 1.271 | 1.476 | 1.281 |
|                                      | Reading 3 | 2.809 | 2.198 | 2.142 | 2.342 | 1.068 |
|                                      | Average   | 3.049 | 2.035 | 1.707 | 2.000 | 1.127 |
| Percentage of error, %               | 11.49 | 1.83 | 18.05 | **82.82** | 29.39 |
Figure 6 shows the graph of surface roughness against cutting speed for aluminium material.

![Figure 6. Graph of surface roughness against cutting speed for Aluminium (Al6061).](image)

Table 5 shows the effect of cutting speed on the surface roughness for mild steel material. The highest percentage differences between theoretical and experimental value of surface roughness is 90.08 % at 226.19 m/min cutting speed.

**Workpiece B2 – Mild steel**

| Workpiece Brinell hardness value, BHN | 135 |
|---------------------------------------|-----|
| Feed rate, f (mm/rev)                | 0.20|
| Spindle rotation, N (rpm)            | 1000| 1500| 2000| 2500| 3000|
| Cutting Speed, $V_c$ (m/min)         | 75.40| 113.10| 150.81| 188.50| 226.19|
| Theoretical roughness value, $R_a$ (µm) | 3.509| 2.112| 1.473| 1.114| 0.887|
| Experimental roughness value, $R_a$ (µm) | Reading 1 | 4.598| 2.576| 2.646| 1.669| 1.583|
|                                       | Reading 2 | 4.103| 2.283| 2.337| 2.109| 1.767|
|                                       | Reading 3 | 4.610| 2.673| 2.762| 1.626| 1.708|
|                                       | Average   | 4.437| 2.511| 2.582| 1.801| 1.686|
| Percentage of error, %               | 26.45| 18.89| 75.29| 61.67| **90.08**|

Figure 7 shows the graph of surface roughness against cutting speed for mild steel material.

![Figure 7. Graph of surface roughness against cutting speed for Mild steel (low carbon steel).](image)
Table 6 shows the effect of cutting speed on the surface roughness for brass material. The highest percentage differences between theoretical and experimental value of surface roughness is 113.71 % at 226.19 m/min cutting speed.

**Workpiece C2 - Brass**

Table 6. Effect of cutting speed on surface roughness for Brass (C2700).

| Workpiece Brinell hardness value, BHN | 156 |
| Feed rate, f (mm/rev) | 0.20 |
| Spindle rotation, N (rpm) | 1000 | 1500 | 2000 | 2500 | 3000 |
| Cutting Speed, \( V_c \) (m/min) | 75.40 | 113.10 | 150.81 | 188.50 | 226.19 |
| Theoretical roughness value, \( R_a \) (µm) | 3.349 | 2.016 | 1.406 | 1.063 | 0.846 |
| Experimental roughness value, \( R_a \) (µm) |  |
| Reading 1 | 2.527 | 1.742 | 2.053 | 1.561 | 1.731 |
| Reading 2 | 2.684 | 2.057 | 2.358 | 1.957 | 1.877 |
| Reading 3 | 2.009 | 2.318 | 1.885 | 1.589 | 1.815 |
| Average | 2.407 | 2.039 | 2.099 | 1.702 | 1.808 |
| Percentage of error, % | 28.13 | 1.14 | 46.29 | 60.11 | 113.71 |

Figure 8 shows the graph of surface roughness against cutting speed for brass material.
Based on graphs of surface roughness against feed rate (Figure 3, 4 and 5), the slopes are in positive gradient. This shows that, as the feed rate increases, the surface roughness will also increase which is similar to the trend shows in [16]. This is due to the increased in heat generated that leads to the tool wear. High feed rate also causes the chatter to increase as discussed in [17]. However, the effect of feed rate on chatter is not as critical as spindle rotational speed [18]. In addition, the tool life will decrease, and tool will become dull as the feed rate increases. This can cause the tip of the tool to become larger and rub over the surfaces of workpiece which subsequently inducing the residual stresses, and eventually may cause surface wearing and tearing [19]. In industry, high productivity is always a priority and thus feed rate has to be maximized as much as possible because a maximum material removal rate is desired [20]. This has to be done while maintaining acceptable surface roughness value.

Based on the results in Table 1, 2 and 3, there is a significant difference between theoretical and experimental value for the surface roughness. In Table 1, the percentage of error is between 45.85 % to 59.11 %, in Table 2, the percentage of error is between 8.06 % to 30.03 %, whereas in Table 3, the percentage error is between 8.0 % to 51.0 %. Deviation between theoretical and experimental roughness value may cause by the errors occurred during the roughness measuring process such as operator skills, worn or dirty stylus tip and error in calibration.

By comparing the graphs between the three different material used, for the feed rate of 90.48 m/min, brass (2.410 µm) has highest roughness value, then followed by mild steel (1.907 µm) and aluminium (0.763 µm). In theoretical, brass (156 BHN) which has higher hardness value should have higher roughness value than aluminium (143 BHN) and mild steel (135 BHN). However, the results show that mild steel has higher roughness value than aluminium. This happen due to mild steel has lower elastic recovery rate than aluminium. The presence of elastic recovery will decrease the surface roughness [21]. Thus, the result of roughness value for mild steel is higher than aluminium.

From the experimental roughness values obtained, there are deviations from the theoretical values. The deviations for different workpiece machined at different feed rate ranges from 8.0 % to 59.11 %. This may cause by backlash as the machine uses gear working principle. Backlash may occur during the switching of cutting speed, feed rate and movement of the working table that contributes to the inconsistency of feed rate. The feed rate should be a constant variable, thus the fluctuating feed rate will cause deviation from the theoretical values. Besides, it is no cutting fluid is used while cutting the workpiece. When the workpiece is being cut, the friction between the tool and workpiece increased and increased the temperature of the cutting zone and workpiece. This will increase the thermal distortion of the workpiece and generally increased the surface roughness of the workpiece. On the
other hand, it is always variation in z value of the measuring roughness machine. The tester is difficult to be adjusted to zero value due to sensitivity of the measuring machine. It may also due to the presence of dust. Since the measurement of the surface roughness is in micro meter, the presence of dust might affect the measurement of roughness.

Based on the graphs of surface roughness against cutting speed in Figure 6, 7 and 8, the slopes are in negative gradient. This shows that, as the cutting speed increase, the surface roughness will be decreased. This attribute is due to the decrease in the built-up edge size. This built-up edge will generate burr on the machined surface and deteriorating of surface finishing. Therefore, by increasing the cutting speed, the influence of the built-up edge became negligible. Besides, as the cutting speed increase, the turning process become more stable and the vibration during the process become lower and thus a better surface produced [21-22].

Based on the results in Table 4, 5 and 6, there is a significant different between theoretical and experimental value for the surface roughness. In Table 4, the percentage of error is between 1.83% and 82.82%, in Table 5, the percentage of error is between 18.89% and 90.08%, whereas in Table 6, the percentage error is between 1.14% and 113.71%. The deviation between theoretical and experimental roughness values may cause by errors occurred during the roughness measuring process. Roughness tester is a highly sensitivity equipment, even a small residue chip or dust which remain on the surface will cause an error in result.

By comparing the graphs between the three different materials used, for the cutting speed of 75.40 m/min, mild steel (4.437 µm) has the highest roughness value, then followed by aluminium (3.049 µm) and brass (2.407 µm). Based on theory, mild steel (135 BHN) which has lower hardness value should have lower roughness value then aluminium (143 BHN) and brass (156 BHN). However, the results show that mild steel has higher roughness value than aluminium and brass. This happen because the mild steel has a lower elastic recovery rate than aluminium and brass. The presence of elastic recovery will decrease surface roughness. Besides that, the rust on the surface of the mild steel will also affect the roughness value and cause of highest roughness value among these three materials. In general, during turning process of workpiece with high hardness, the temperature of cutting area will increased. According to this temperature, there is thermal softening in cutting area (between tool edge and surface of workpiece) that made the plastic deformation for chips become easier. The hard particles in workpieces will affect the tool wear and this made the surface roughness increases [23].

4. Conclusion
As a conclusion, the feed rate and cutting speed used in metal machining process such as turning process by Lathe machine will give a large effect to the surface finish especially the surface roughness of the products. From this experiment, we can conclude that, the roughness value will increase when the feed rate increases, while the roughness value will decrease as the cutting speed increases. From the graphs, there are some deviations of roughness value between the experimental results and theoretical results. The roughness values that obtained from this experiment is still not acceptable because there are too much of deviations with the theoretical roughness value. This is due to some factors that may affect the accuracy of the roughness value which includes collision between workpieces in storage, rusting and cleanliness of workpiece surface.

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Reference

[1] Yalcinkaya S and Sahin Y 2017 13th Int. Conf. on Tribology (Galati, Romania) Vol 174
[2] Vinod M, Neha K, Keshva N, Karanvir S and Ramagopal V S 2015 Experimental investigation on uncontrollable parameters for surface finish during diamond turning Materials and Manufacturing Processes Vol 30

[3] Mohammed T H, Montasser S T and Joachim B 2007 A study of the effects of machining parameters on the surface roughness in the end-milling process Jordan Journal of Mechanical and Industrial Engineering Vol 1 pp 1-5

[4] Turning Surface Roughness Calculator. Retrieved 15 August, 2018, from http://www.custompartnet.com/calculator/turning-surface-roughness

[5] Lab 6. Retrieved 26 September, 2018, from https://www.scribd.com/document/329537069/lab-6#download

[6] Cutting Data Recommendations. Retrieved 15 August, 2018, from https://www.uddeholm.com/files/Cutting_Data_Corrax_eng.pdf

[7] Rajesh K B, Sudhir K and Das S 2010 Effect of machining parameters on surface roughness and tool wear for 7075 Al alloy SiC composite Int. Journal of Advanced Manufacturing Technology (London: Springer-Verlag) vol 50 pp 459-469

[8] Bapi S, Moola M R and Sujan D 2017 MATEC Web of Conf. vol 95

[9] Nexhat Q, Kaltrine J, Avdyl B, Mirlind B and Hysni O 2015 Effect of machining parameters and machining time on surface roughness in dry turning process Procedia Engineering 100 pp 135-140

[10] Pooja A S and Gujar A J 2017 Study the effect of machining parameters on surface roughness in CNC milling of AISI 316L Int. Journal of Engineering Research and Technology (In Research Publication House) vol 10

[11] Dinesh K C, Kapil K C and Ganga S S 2015 Effect of machining parameters on surface roughness for titanium alloy Int. Journal of Engineering and Innovative Technology vol 4

[12] Catherine L D K, Raja A M, Azrina A and Sangeeth S 2014 Impact of machining parameters On the surface roughness of machined PU block Int. Journal of Chemical, Molecular Nuclear, Materials and Metallurgical Engineering (World Academy of Science, Engineering and Technology) vol 8

[13] Speeds and Feeds. Retrieved 26 September, 2018, from https://support.bantamtools.com/hc/en-us/articles/115001658374-Speeds-and-Feeds

[14] Suxer D S, Alsoufi M S, Alhusaini M M and Azam S A 2016 Studying the effect of cutting conditions in turning process on surface roughness for different materials World Journal of Research and Review 2 pp 16-21

[15] Frank J H Jr 2000 Home facing process. Retrieved 15 August, 2018, from http://www.mini-lathe.com/Mini_lathe/Operation/Facing/facing.htm

[16] Satheesh N K, Ajay S, Ashay S, Ananth K and Harsha S 2012 Effect of spindle speed and feed on surface roughness of carbons steel in CNC turning Procedia Engineering 38 pp 691-7

[17] Nurhaniza M, Ariffin M K M A, Mustapha F and Baharudin B T H T 2016 Analyzing the Effect of machining parameters setting to the surface roughness during end milling of CFRP-aluminium composite laminates Int. Journal of Manufacturing Engineering 2016

[18] Ten Questions About Chatter. Retrieved 26 September, 2018, from http://www.custompartnet.com/calculator/turning-surface-roughness

[19] Serope K and Steven S 2014 Manufacturing Engineering & Technology (London: Pearson) p 996

[20] Kuttolamadom M A, Hamzehlouia S and Mears M L 2010 Effect of machining feed on surface roughness in cutting 6061 aluminium SAE Int. Journal of Materials and Manufacturing 3

[21] Abdullah A B, Chia L Y and Samad Z 2008 The effect of feed rate and cutting speed to surface roughness Asian Journal of Scientific Research 1 pp 12-21

[22] Khalid A D 2016 Effect of cutting parameters on surface roughness in turning operations Al-Qadisiyah Journal for Engineering Sciences 9

[23] Ehsan D D and Ali A A 2009 Proc. of the World Congress on Engineering (London) Vol 2