Effect of Different Cutting Speed and Feed Rate on Surface Roughness in Femur Bone Drilling

P.Y.M.W. Nduruhadi\textsuperscript{a,b}, S. Sharif\textsuperscript{b}, D. Kurniawan\textsuperscript{b,∗}

\textsuperscript{a}Department of Mechanical Engineering, University of Jenderal Achmad Yani, Cimahi 40526, Indonesia
\textsuperscript{b}Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai 81310, Malaysia

Abstract

In drilling of bones, surface roughness can be used as an indication of bone cell damage induced by the machining process. In common workpieces, relationship between both feed rate and cutting speed on surface roughness to the workpiece is apparent. It is expected that such relation also exists when bone is the workpiece. On the other hand, there are various quantifications or parameters of surface roughness. So, it needs to be confirmed which parameter that can suit the surface roughness on bone machining results. This study intends to evaluate the effect of cutting speed and feed rate on surface roughness of drilled bone, as well as to identify which surface roughness parameter fits for such machined surface. A series of experimental bone drilling was done by using two input variables (i.e., cutting speed and feed rate). The cutting speeds are 6 m/min and 37 m/min and the feed rates are 0.01 mm/rev and 0.2 mm/rev. For each machined surface, surface roughness was taken in five parameters (i.e., \( R_a \), \( R_q \), \( R_k \), \( R_{pk} \), and \( R_{vk} \)). The results show that feed rate significantly affects the surface roughness while cutting speed does not. Although further detail needs to be observed, it is confirmed that \( R_a \) parameter can be used in the measurement of surface roughness of bone machining results.

Keywords: Drilling, bone, surface roughness, cutting speed, feed rate

* Corresponding author. Tel.:+6075534734; fax: +6075566159
E-mail address: denni@utm.my
1. Introduction

Surface roughness is an important indicator in the results of the machining process. In metal cutting, it is related to friction, wear, and lubrication that occurred during machining process. Commonly, low surface roughness is sought after and developed [1, 2]. Modeling and prediction of surface roughness as function of several influential factors in machining of metals are conducted as well. Still related to product quality in machining, studies on surface roughness in machining non-metals as function of machining parameters are also being practiced. An example is a study using the workpiece material of some type of wood used for furniture. It was reported that feed is proportional to the surface roughness on the machined workpiece.

In the case of surface roughness as the response in bone machining, references and studies that have been done in this area are still somewhat limited [4, 5, 6, 7]. Distinct from the intention to measure surface roughness in machined metals or non-metals, the response of surface roughness in the machining of bones is used as an indication of bone cells damage that might occur as a result of the machining process. It is known that the level of damage that occurs in the bone cells during bone machining correlates to the level of success in bone surgery and the time needed for post-surgery recovery [8, 9, 10].

In the measurement of surface roughness, there are some surface roughness parameters that can be used to represent the surface roughness of a machined workpiece surface. In metal cutting, Ra (arithmetic mean value of the roughness profile) is the most commonly used and it is sufficient to represent the results of machined surface. However, use of Ra might not necessarily be the case in the surface roughness measurement of the non-metal materials with porous surface texture and heterogeneity, such as woods and bones. In his study, Tan [3] used several parameters of surface roughness on some wood species and made comparison between them. The results showed that the Rk was more reliable compared to the parameters of Ra, Rq, and Rap, for most wood specimens, although not so for wood with a uniform surface such as pine trees. While previous studies on the surface roughness in machined bones used the parameter of Ra [4, 5, 6, 7], there is no study that use and compare several parameters of surface roughness on the machining of bone.

Therefore, this study was conducted to evaluate the influence of cutting speed and feed rate on surface roughness resulted from bone drilling. In addition, this study also intends to reveal the differences in various surface roughness parameters on the drilled bone.

2. Experimental

The study was conducted by running a series of experimental drilling processes using a DECKEL MAHO DMC 835V CNC machining center and uncoated carbide drill with diameter of 4 mm. Fresh bovine femur bone was used as the workpiece material. In addition, a jig that was prepared in advance to support the bone drilling in this experiment. Two levels of cutting speed and feed rate were chosen as the input variables; which are 6 m/min and 37 m/min for cutting speed and 0.01 mm/rev and 0.2 mm/rev for feed rate. For each of these four combinations of drilling parameters, ten holes were drilled in the workpiece. All the drilling processes were done by irrigation using saline solution at a rate of 500 ml/min. Experimental set-up and data collection in this study is shown in Fig. 1.

Surface roughness values were obtained from the measurements made on the direction of the axial hole in the wall using a cut-off length (λc) = 0.25 mm at three different measuring positions for each drilled hole. The reported values are the average of the multiple measurements (at least three times) taken. Portable surface profilometer Accretech Handysurf E-35 B was used as the measuring equipment. From the profile obtained by the surface profilometer, the surface roughness parameters calculated were Ra, Rq, Rk, Rp, and Rvk.

3. Results and discussion

Surface roughness values obtained from the bone drilling experiments are presented in Fig. 2. Considering multiple measurements taken, the standard error of each surface roughness value is also displayed. Observing the results, it appears that the drilling process that uses a combination of input variable of low feed rate (0.01 mm/rev) and high cutting speed 37 m/min was able to produce the finest surface (or the lowest surface roughness, in particular for Ra). Meanwhile, the combination of the input variable of high feed rate of 0.2 mm/rev and low cutting
speed of 6 m/min resulted the opposite. In addition, an increase in feed rate will increase the resulting surface roughness (Ra), while an increase in cutting speed does not significant effect to the surface roughness (Ra).

Effect of feed rate and cutting speed on the surface roughness obtained in this study is in agreement with the results of previous studies [5] but in contrast with previous studies of bone turning process [4, 6]. It is known indeed that theoretically the feed rate is directly proportional to the surface roughness. For metal cutting, cutting speed’s relative influence to the surface roughness is rooted from the flow of the chip build-up and scale-stab [6], which apparently is not the case for this bone drilling.

Viewed from the surface roughness parameters resulted used in this study, the parameter Ra shows the smallest value in all combinations of input variables, while the largest values of surface roughness was shown by the parameter Rk. This trend that the value of the parameter Ra gives the smallest measurement results compared to other parameters is similar to the trend in metal cutting, but is not similar to the results of a study conducted on the woods [3]. The difference in porous surface characteristics of wood and bone may be the cause of this discrepancy. Observing Fig. 2, similar effect on Ra as function of cutting speed and feed rate also applies to other surface
roughness parameters. So, basically for this particular bone drilling, selecting any surface parameter will give similar results. Although the lack of references on these various surface roughness parameters on bones, the results of this study can be used as a confirmation that to represent the surface roughness of drilled bones, Ra is adequately sufficient.

4. Conclusions

In this particular drilling of bovine femur bones, feed rate was found to be proportional to surface roughness, while cutting speed does not result significant influence. Among various surface roughness parameters, Ra is adequately representative to quantify the surface profile of the drilled bones, although further study is needed to provide more detailed observation on the machined surfaces.

Acknowledgements

Financial support from the Ministry of Education, Malaysia and Universiti Teknologi Malaysia through Fundamental Research Grant Scheme no. 4F285 is acknowledged.

References

[1] W.J.Zong, Y.H.Huang, Y.L.Zhang, T.Sun, Conservation law of surface roughness in single point diamond turning, International Journal of Machine Tools & Manufacture, 84 (2014) 58–63.
[2] Zahia Hessainia, Ahmed Belbah, Mohamed Athmane Yallese, Tarek Mabrouki, Jean-François Rigal, On the prediction of surface roughness in the hard turning based on cutting parameters and tool vibrations, Measurement, 46 (2013) 1671–1681.
[3] Tan Poh Lai, Evaluation and modeling of machined wood surface roughness and fuzziness, Ph.D Thesis, Universiti Teknologi Malaysia, 2011.
[4] P.Y.M.W. Ndaruhadi, S. Sharif, M.Y. Noordin, and D. Kurniawan, Effect of cutting parameters on surface roughness in turning of bone, Advanced Materials Research, 845 (2014) 708-712.
[5] P.Y.M.W. Ndaruhadi, S. Sharif, and D. Kurniawan, Experiment investigation of hole accuracy and surface roughness in femur bone drilling using different parameters, Advanced Materials Research, 845 (2014) 720-723.
[6] D. Kurniawan, N. Jiawkok, and M.Y. Noordin, Machining conditions effect to machining temperature and forces in orthogonal machining of bone, Advanced Materials Research, 658 (2013) 223-226.
[7] K. Alam, A.V. Mitrofanov and V.V. Silberschmidt, Measurements of surface roughness in conventional and ultrasonically assisted bone drilling, Am. J. Biomed. Sci. 1(4). (2009) 312-320.
[8] C Natali, P Ingle, J Dowell, Orthopaedic bone drills – can they be improved? Temperature changes near the drilling face, The Journal of Bone and Joint Surgery. 78 (1996) 357-62.
[9] G Augustin, S Davila, K Mihoci, T Udiljak, DS Vedrina, A Antabak, Thermal osteonecrosis and bone drilling parameters revisited, Arch Orthop Trauma Surg. 128 (2008), 71–77.
[10] SC Isler, E Cansiz, CTanyel, M Soluk, F Selvi, Z Cebi, The effect of irrigation temperature on bone healing, International Journal of Medical Sciences. 8 (2011), 704-708.