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Influence of image resolution on surface topography prediction based cutting tools measurements

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Abstract
The surface topography of machined components is of paramount importance for product functionality. The surface is responsible for friction properties, appearance, and fatigue life of the parts. For components produced by material removal processes such as metal cutting, the characteristics of the surface topography are dependent on the interactions between machine tool, cutting tool, cutting parameters, and workpiece material. When high added value parts are machined, a wrong choice of cutting tool and cutting parameters can result in expensive rework loops or the discharge of the parts. In a previous work by the authors, it was shown how the contributions related to the cutting tool microgeometry, cutting parameters and material smearing phenomena could be derived from a high-resolution measurement of the tool used to generate the surface. The measurement is used as input to a model that predicts the 3D topography of machined surfaces by accounting for the effects of the cutting edge micro-profile, the cutting edge radius, and tool run out. However, in an industrial context, instruments capable of high-resolution measurements may not be available. In this paper, the influence of the point cloud density and instrument spatial resolution is discussed. High-resolution images of cutting tools are acquired and used for simulating the surface topography achieved in ball-end milling operations. The resolution of the images is decreased and the effect on the surface topography prediction is analyzed. The results are compared with surface topography produced by the measured tools while machining tool steel. The results are used to evaluate the applicability of surface topography prediction based on on-the-machine tool profile measurement.

Machining, surface roughness model, tool measurements

1. Introduction

The surface topography of a machined component is a key aspect affecting the functionality of the component itself. In absence of dynamic effects such as chatter and machine tool errors, the topography of a machined surface is largely determined by the interaction between the material and the cutting tool generating the surface. Ball end milling is a widespread subtractive process used for the generation of free form components for the moulds and dies industry. The surface topography of those components directly affects the surface appearance and the surface frictional properties. Especially in finishing machining, where the added value of the machined component is high, the selection of wrong cutting parameters and /or wrong cutting tool may lead to the discharge of the part with considerable loss of money.

Reliable models for surface topography prediction may mitigate this issue by guiding the machine operator toward the selection of optimized process parameters and conscious tool choice. 3D simulation models of ball end milled or turned surfaces do exist [1], [2], [3], but the majority of them does not account for the material deformation occurring while cutting below the minimum uncut chip thickness (MUCT) and only a few accounts for the microgeometry of the tool [4].
The author proposed a model that, by using as input a high-resolution measurement of the cutting tool, can simulate the surface topography accounting simultaneously for contributions of tool edge microtopography, edge radius, runout, and cutting parameters. The model is extensively described in [5]. While high fidelity results were achieved, the applicability of such a model in a workshop environment is limited by resolution and capability of the available measuring instruments.

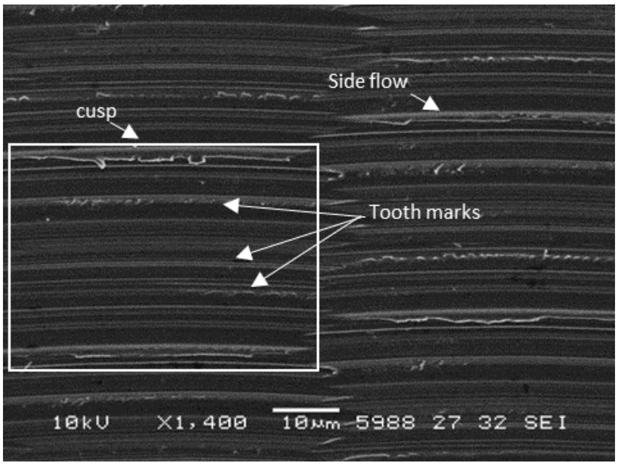

Figure 1. Surface generated machining tool steel using fz 15µm, ae 50 µm, and ap 15µm. Notice the characteristics of cusps generated by the tool-workpiece intersections, the tooth mark due to the edge microtopography, and the side flow due to the finite size of the edge radius.

2. Accurate model of surface topography

Figure 1 shows the topography of a ball end milled surface machined with one of the tools used in the experiments. The topography of an ideal ball nose end milled surface is constituted by a series of spherical cusps generated by the physical intersection between the cutting tool and the workpiece. The projected area of those cusps corresponds to the value of the feed per tooth (fz) multiplied by the step over (ae).

The actual generated surface differs considerably from the theoretical one due to the effect of the edge microtopography generating characteristic tooth marks that are transferred to every single cusp surface. Furthermore, the finite size of the cutting edge radius generates side-flow phenomena on the separation between two consecutive tooth cusps.

The accuracy of the model in predicting those two phenomena is intrinsically bounded to the accuracy and resolution with which the cutting edge profile and radius are known. In this work, the influence of the measurement resolution on the model prediction ability is discussed. Several simulations using 3D images of cutting tools in which the pixel size was artificially increased were performed and the results compared to measurements of the Sa roughness of machined surfaces.

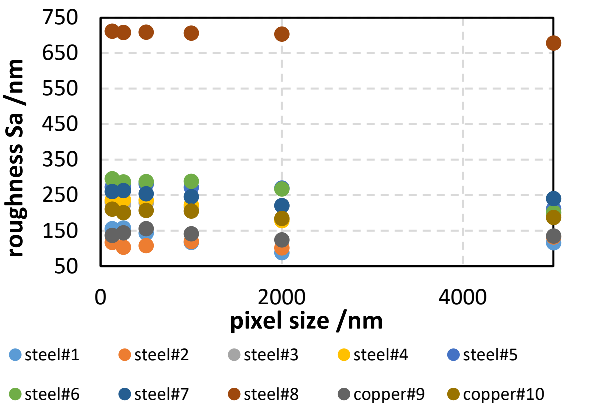

Figure 2. Surface roughness variation according to the model prediction when the pixel size of the tool measurement is increased from 126 nm to 5000 nm.

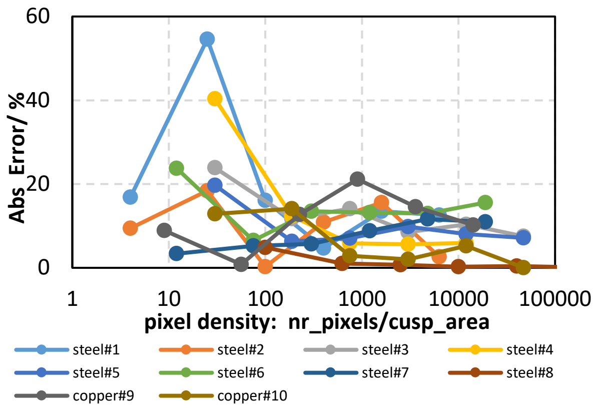

Figure 3. Percentage error on Sa roughness of the simulated surface compared to experimental results. The x-axis, in logarithmic scale, represents the number of pixels per project area of the theoretical cusps.

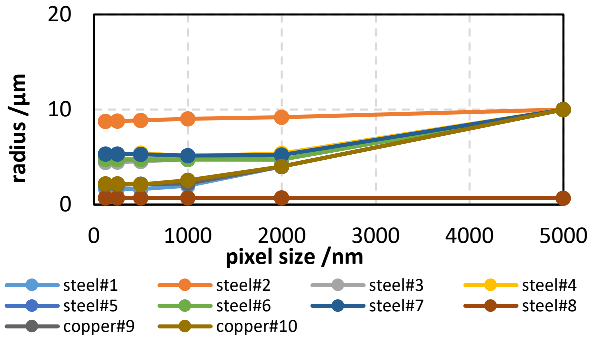

Figure 4. Variation of the cutting edge radius measurement with the increase of the pixel size of the tool measurement

3. Methodology

High-resolution images of the teeth of ten different ball end mills were acquired using a confocal microscope LEXT OLS4100 with 100x magnification objective lens and pixel size of 126 nm^2. A special fixture was used to orient the tools under the microscope to be able to acquire the specific area of the cutting edges that will generate the surface during machining. The same microscope was used to acquire the topography of machined surfaces produced using the measured tools. Machining tests were performed using tool steel and copper with ratio MUCT/cutting-edge-radius of 4% and 25 % provided in [5]. The Cutting parameters were varied according to table 1. Simulations of the surface topography were performed using the tool measurements with increased pixel size in the range from 126 nm^2 to 5000 nm^2 and compared with experimental roughness measurement of the machined surfaces

Table 1. Cutting parameters used in the experiments. fz, ae and ap represent the feed per tooth, step over and depth of cut respectively.

fz /μm	ae /μm	ap /μm	Test#
10	10	10	1,2
15	50	15	3,4,5,10
20	50	15	6,7
25	100	25	10
15	15	15	9

4. Discussion and conclusion

The decreased resolution of the tool measurement leads to a general reduction of the value of the simulated roughness, (figure 2). This trend is explained by the fact that fewer features of the tool edge micro-topography are captured by the measurement and therefore its effect is not adequately accounted for in the simulations. This effect is less evident when larger ae, fz, and ap are used for the experiment (test#8): in those conditions, the effect of the tool macro geometry prevails over the edge microtopography effect on the surface roughness calculation. Figure 2 shows that, depending on the cutting conditions, when a resolution of at least 100 pixels per projected cusp is used, the error in the predicted roughness drops below 20%. The resolution of the measurement also affects the measurement of the edge radius and, in turn, the amount of predicted side-flow. The higher the resolution the higher the value of the edge radius. This contributes to increase the relative effect of the smearing phenomena over the edge microtopography in the prediction and therefore decreasing the model reliability. For the tested cutting parameters it is shown that instrument able to generated 3D representation of the surface with a pixel size of 500 to 1000 nm^2 are sufficient to keep the prediction error below 20% for Sa roughness values between 100 to 250 nm

References

[1] He CL, Zong WJ, Zhang JJ. Influencing factors and theoretical modeling methods of surface roughness in turning process: State-of-the-art. Int J Mach Tools Manuf 2018;129:15–26.

[2] Liu K, Shreyes N M. Effect of plastic side flow on surface roughness in micro-turning process. Int J Mach Tools Manuf 2006;46:1778–85. https://doi.org/10.1016/j.ijmachtools.2005.11.014.

[3] Layegh K SE, Lazoglu I. 3D surface topography analysis in 5-axis ball-end milling. CIRP Ann - Manuf Technol 2017;66:133–6.

[4] Lavernhe S, Quinsat Y, Lartigue C, Brown C. Realistic simulation of surface defects in five-axis milling using the measured geometry of the tool. Int J Adv Manuf Technol 2014;74:393–401.

[5] Biondani FG, Bissacco G. Effect of cutting edge micro geometry on surface generation in ball end milling. CIRP Ann 2019;68:571–4. https://doi.org/10.1016/j.cirp.2019.04.017.