Available online at www.sciencedirect.com
ScienceDirect
Procedia CIRP 67 (2018) 302 – 306
www.elsevier.com/locate/procedia

11th CIRP Conference on Intelligent Computation in Manufacturing Engineering, 19-21 July 2017, Ischia Italy

Abrasive grains micro geometry: a comparison between two acquisition methods

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Abstract

One of the aspects that makes difficult grinding processes modelling is the non-deterministic nature of the cutting tool, in particular the abrasive grains of the grinding wheel have a random distribution and an undefined geometry that influences the grinding forces.
In order to develop a reliable 3D model of the grinding process the actual microgeometry of abrasive grains must be acquired. This paper compares the results of two different acquisition methods: the geometry acquired via a laser non-contact instrument is confronted with the one acquired using a computer tomography; the accuracy of the grain micro geometry provided by the two approaches is discussed.

Keywords: grinding; computer tomography; micro-geometry

1. Introduction

The grinding models proposed in literature can be classified as: (i) physical process models (analytical and numerical models), (ii) empirical process models (regression analysis, artificial neutral net models) and (iii) heuristic process models (rule based models) [1, 2, 3].

In order to achieve an experimental validation of the proposed model, the actual microgeometry of the grinding wheel surface should be taken into account. Unfortunately, due to the scale of the cutting grains a complete acquisition of the grinding surface would be nowadays impossible for the huge computational requirements necessary to completely describe the wheel surface.

To face this technological limit a previous experimental study investigated the grinding process by considering a single abrasive grain whose geometry was acquired by a stylus instrument [4]. Although the experimental study provided interesting results about the relationship between the grain geometry, the measured forces and the 3D FEM model, the filtering effect due to the stylus instrument geometry, suggested to assess other acquisition methodologies.

Actually, the conical shape of the stylus prevents the acquisition of surfaces whose slope is greater than the cone semi-aperture angle. Consequently, the cone aperture angle limits the acquisition of the grain cutting face, resulting in an artefactual geometry characterized by negative rake angles.

In order to achieve better and more accurate geometrical description of the actual abrasive grain, two acquisition methods that can overcome the stylus instrument limit are presented and discussed, precisely: computer tomography, and non-contact laser triangulation.

doi:10.1016/j.procir.2017.12.217

2. Experimental setup

2.1. Material

Among all the different types of abrasive grain materials currently available on the market this study focuses on pure aluminum oxides (Al_2O_3) grains that due to their wide range of applications in grinding processes. A grit size equal to 16 FEPA has been chosen in order to allows a better comparison within the two measuring methods.

A total of 25 grains was acquired using the Computed Tomography; 4 of these grains were randomly chosen to be measured with the non-contact laser triangulation. The limited number of samples scanned with the laser was justified by the consistency and repeatability of the obtained results as well as for the considerable duration of the acquisition procedure.

Each grain used for this study, randomly chosen from the entire stock available, has then been mounted on top of M4 steel screws using a bi-components epoxy resin (Fig 1) to be correctly hold in place during measurements.

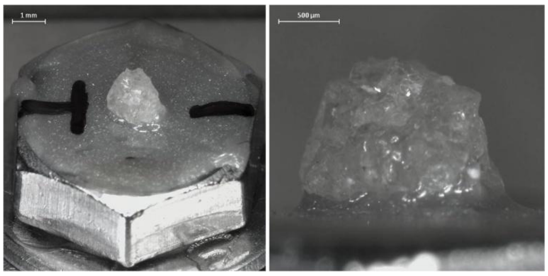

Figure 1: An aluminum oxide abrasive grain mounted on the screw.

2.2. Computer tomography

A Zeiss Metrotom 800 Computer Tomography has been use to obtain the 3D geometry of each abrasive grain. The characteristics of the machine are listed in Table 1 while Table 2 shows the scanning parameters optimized for the grain acquisitions.

Table 1: CT machine performance features

Zeiss Metrotom 800	
Tube	130kV/39W
Detector	1900 x 1512 pixels
Measuring range	Φ 125 x 150 mm
Lifting table adjustment range	290 mm
Source detector distance	800 mm

Table 2: CT scan parameters optimized for grains geometry acquisition

Scanning parameters	
Current	65 kV
Voltage	61 µA
Integration time	1000 s
Gain	8.0 x
Image averaging	2 images
Binning	1 x 1

2.3. Non-contact laser triangulation

The same grain samples have been acquired by a non-contact laser instrument, specifically a Taylor Hobson Talyscan 150 configured with the laser probe; Fig. 2 shows the positions of the laser source and linear CCD array used by the triangulation method.

The samples geometry was acquired by using a square grid with sampling step $\Delta x = \Delta y = 5$ µm.

The acquisition procedure consists of the following phases: (i) sample spraying with a white welding developer (DN R2.82: ROTRIVEL U) in order to reduce optical laser ray-grain material artefacts, (ii) six lateral view acquisitions with spacing $\Delta\alpha = 60°$, (iii) one top acquisition to integrate lateral views data.

Fig. 3 shows the dividing device for the rotation of the sample during the lateral acquisition phase.

Figures 4 and 5 display the lateral and top acquisition phases respectively. Fig. 6 shows the pseudo-colour six lateral acquisitions obtained by using the described experimental setup.

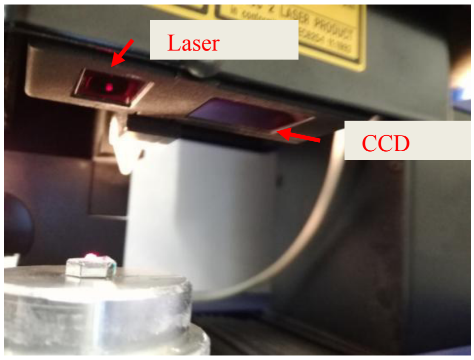

Fig. 2: Non-contact laser triangulation system

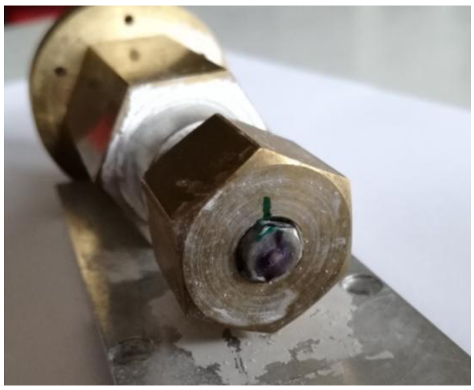

Fig. 3: Dividing device

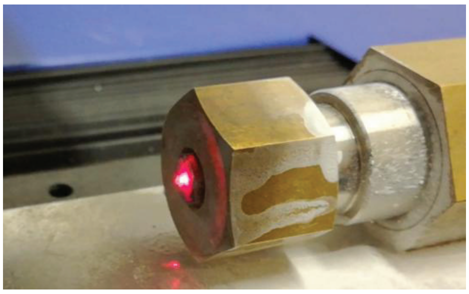

Fig. 4: Lateral acquisition phase

Fig. 5: Top acquisition phase

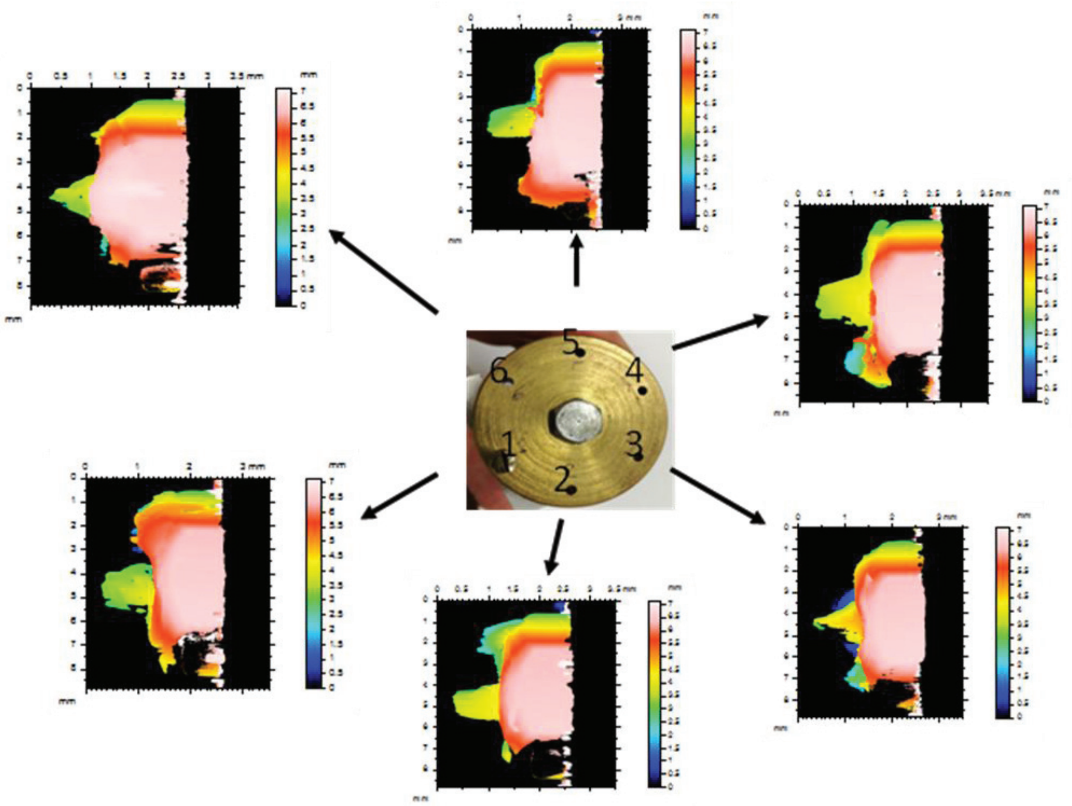

Fig. 6: Pseudo-colour six lateral acquisitions

2.4. Geometry reconstruction approach

Digital model reconstruction from the point clouds of the single grinding grain, obtained with the Taylor Hobson laser system, was done with the GEOMAGIC software platform.

For the grain digital model reconstruction, several steps are needed. First, the seven point clouds, related to the six different laser acquisitions, were improved by noise/overlap reduction and redundant points removal. Via the "N point pairs" option, the six improved point clouds were aligned by picking several tie-point pairs on each one. Then, alignment was refined by applying the iterative best-fit image alignment algorithm to the full set of 3D images to globally minimize alignment errors.

Once the aligned and improved grain point cloud was obtained, the generation of a high accurate polygonal model of the grain was created with the following main parameters: max distance: 2 μm; surface sampling step: 0.4 μm; standard deviation: 0.064 μm; smoothing level: medium, smoothing radius: 1.2, smoothing tolerance: 0.192 μm; reduction tolerance: 0.0128 μm. A polygon mesh with 3,491,802 points and 6,822,629 triangles was generated.

Since the grain surface is highly complex, the polygon model presents numerous holes/gaps that need to be filled. For automatic holes/gaps filling, the software uses a bridging distance to connect boundary perimeter points and create triangles. However, this automatic procedure could not be applied as the newly generated triangles did not blend the surrounding surfaces.

3. Acquired grains geometries

The results of the CT and laser scanning acquisition for one grain are shown in Figure 7-12. In particular:

- Fig. 7 shows the results of the CT acquisition: lateral top and oblique views;
- Fig. 8 shows the results of the laser scanning acquisition and the GEOMAGIC reconstruction: lateral top and oblique views;
- Fig. 9 displays three views of a grain resulting from the GEOMAGIC reconstruction;
- Fig. 10 shows a comparison between the acquisition made by using the CT (white colour) and the laser scanned (blue color) systems.
- Fig. 11 shows a comparison between the acquisition made by using the CT (red colour) and the laser scanned (blue color) grain.
- Fig 12 shows a comparison between the acquisition made by using the CT (red colour) and the laser scanned (white color) grain.

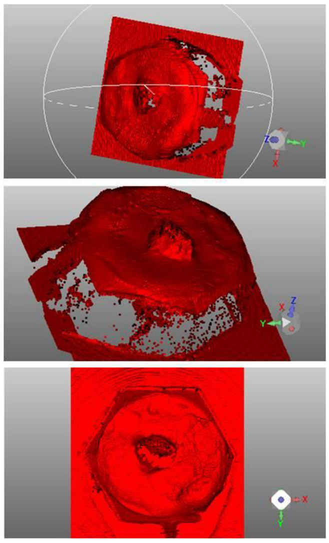

Fig. 9: Three views of a grain resulting from the GEOMAGIC reconstruction

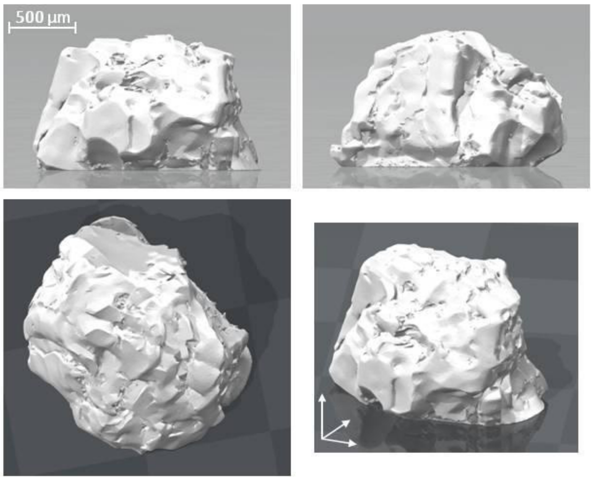

Fig. 7: 3D model of a grain acquired via CT.

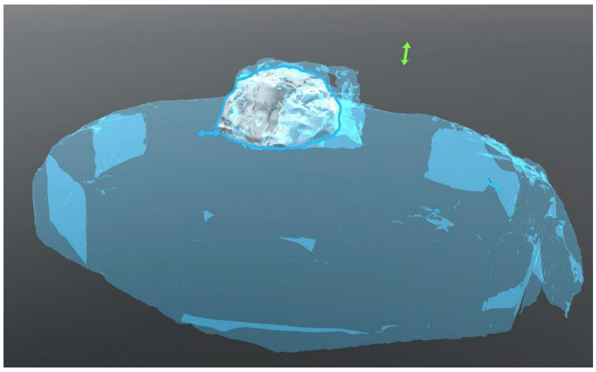

Fig. 10: Comparison between the CT-acquired grain (white colour) and the Laser scanned grain-resin-screw head assembly (transparent blue colour).

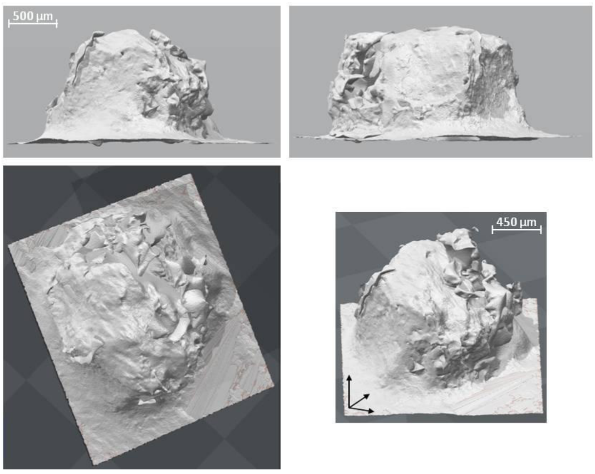

Fig. 8: 3D model of a grain reconstructed from multiple laser scan acquisitions.

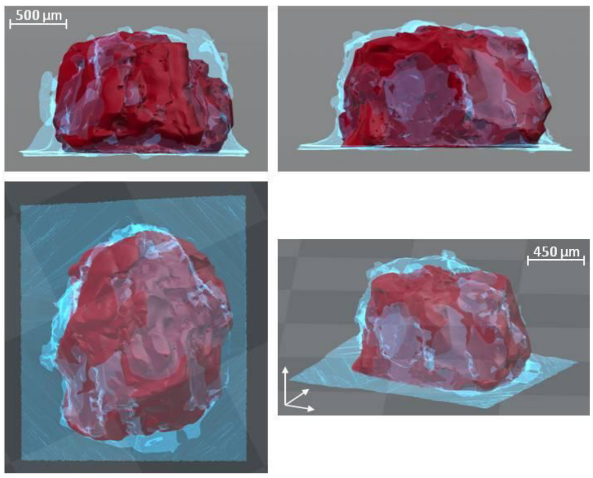

Fig. 11: Comparison between the CT-acquired grain (red colour) and the Laser scanned grain extracted from the assembly (transparent blue colour).

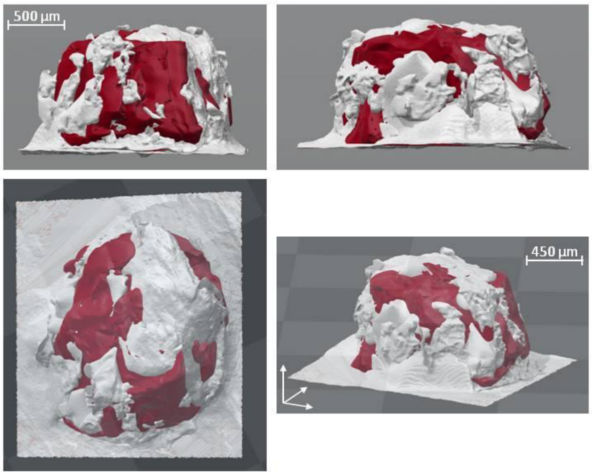

Fig. 12: Comparison between the CT-acquired grain (red colour) and the Laser scanned grain extracted from the assembly (white colour).

4. Discussion

Several differences between the two acquisition methods used in this study have been observed; the diversities regard various aspects such as the experimental setup and the output data-set obtained.

From the point of view of the sample the Computed Tomography does not need any particular preparation once the grain is mounted on a support (like the screw used in this work) provided it can be placed in the measuring chamber of the CT instrument, meanwhile in order to overcome the problem of the reflection of the measuring laser beam and the transparency of the grain material, the sample needs to be sprayed with a matt powder. The powder than acts like a filter filling some of the smaller gaps on the grain surface changing its geometry.

Regarding the measuring procedure, the CT method results to be trivial for the type of analysis requested in this study, requiring just a tuning of the scanning parameters and the definition of the volume to be acquired; on the other hand the laser scan needs multiple acquisitions in order to obtain the entire geometry of the grain making the process more complex and time consuming. With the samples used in the study the average time needed for each CT acquisition was around 1 hour and 20 minutes, with the machine working without requiring any operator intervention. In contrast the laser scans took 27 hours for the acquisition and need an operator intervention to change the sample position after each scan; furthermore the reconstruction phase by GEOMAGIC required 1.5 hours and an appropriate selection of the pair points for aligning the various views.

The highlighted differences in the scanning procedure are also reflected on the reconstruction operations needed to obtain the grain geometry.

A major difference within the two methods can be found comparing the type of output obtained from the CT and the laser scan. The Computed Tomography performs a complete acquisition of the sample including its internal structure.

The external geometry of the grain can be acquired without any filtering effect due to the mat powder and without losing the feature with negative angles; in addition the different materials which constitute the sample can be detected and isolated allowing to obtain a 3D model of the entire screw together with the grain and the resin or to isolate each of the components, screw, resin and the grain as done in this study. Moreover, the internal structure of the grain (Fig. 13) can be studied detecting porosities useful to understand the wear behavior of the grain.

On the other side the data acquired with the laser scan refers only to the external geometry of the grain affected by all the filtering and measurements errors stated above.

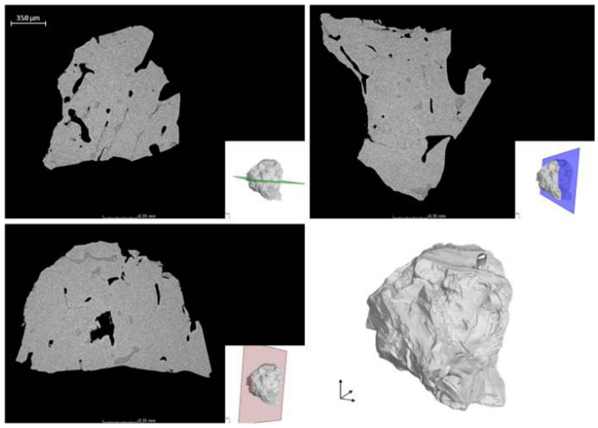

Fig. 13: Internal structure of the abrasive grain acquired using the CT machine.

5. Conclusion

The comparison between a Computed Tomography and a Laser Scan methods used to measure and obtain a 3D model of an aluminum oxide abrasive grain have been presented in this study. The obtained results indicate that the CT approach has several advantages over the laser scanning system; these advantages range from the acquisition time, to the available information on the internal structure of the grinding grain.

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