Letter to the Editor

A discussion on the capability of X-ray computed tomography for contact mechanics investigations (Feikai Zhang, Jianhua Liu, Xiaoyu Ding, Zhimeng Yang *Tribology International* **145** (2020) 106167).

Introduction

Tribology and contact mechanics communities unanimously agree that the real contact area plays a significant role in important phenomena such as wear, adhesion, friction, material transformations, etc. There have been many studies that numerically and analytically model the contact of real engineering surfaces. A recent paper by Müser *et al.* [1] reviewed different methodologies and discussed their pros and cons. Direct measurement of the real contact area always has been a challenge due to the nature of surface roughness. There have always been great interests in developing measurement tools for evaluating the real area of contact. Most developed methods use transparent surfaces and optical approaches to detect the contacting areas [2-4]. These methods have several disadvantages such as the resolution of optical instruments and inability to study non-transparent surfaces.

The advent of X-ray micro-computed tomography (µCT) in contact mechanics allows the observation and measurement of the real contact area of non-transparent objects in 3D [5, 6] with potentially high resolution. This will be a great tool for tribologists to study the mechanics of contact which can be potentially developed further by the in situ µCT synchrotron and near real-time measurement. However, due to the artefacts of the post-processing methods, careful attention needs to be paid in the selection of suitable image processing methods. Here we present some important post-processing parameters that should be considered while developing µCT methods for detection of real contact area regardless of pre-processing condition. Particular attention is given to a recently published paper in Tribology International [5] and we focus on image binarisation which is crucial in the estimation of contact area and seems in place for the benefit of Tribology International readers.

Discussion on image post-processing

First, there is a well-known trade-off between the resolution of the image and the field of view in laboratory-based µCT. Although the authors of [5, 6] clarified later in their paper, it is ambiguous to report the detail detectability of the machine as resolution, *i.e.* 0.2µm [5, 6]; which is not practical to achieve based on our experience of using the same machine.

After the image acquisition, the first step for the detection of contact is the binarisation of the grayscale raw images to distinguish the solid and void phases. A single grayscale value is needed to separate solid and void phases. Voxels lower than the threshold represent voids and voxels higher than threshold constitute solid phase. The threshold can be found using various approaches and is generally based on the statistics of the image or a physical calibration [7]. In statistical methods, global thresholding (*e.g.* Otsu method [8]) is the most commonly applied approach. The binarisation is not limited to the global threshold and readers are referred to [9] for further information on different techniques. In [5] the methodology for binarisation is not declared. After communication with the corresponding author, it became clear that a threshold value was obtained from the median value between the two peaks of the intensity histogram as given by the software of the machine.

Previous studies have highlighted the limitation of binarisation methods for the detection of contacts. For an approach consisting of a global threshold followed by more advanced segmentation method, Weis and Schröter [10] concluded that “even a minor error in the choice of the binarisation threshold can make the detection going completely wrong”. Kerckhofs *et al.* [11] quantified the accuracy of µCT concerning binarised microscopic images of matching slices. They noted that using a global threshold to analyse µCT images, 11% of the total number of voxels are visualised incorrectly.

In addition to image binarisation, connectivity assumption can introduce some degree of misrepresentations. One can assume two voxels are in contact when there is a face-to-face contact only (called 6-connectivity, as there are six faces for each voxel); or voxels are even in contact if there is a node-to-node connection (26-connectivity, including nodes, edges and faces). A slight bias was reported in [12] using a 6-connectivity for contact detection. The authors concluded, “It is likely that using a 26-connectivity relation in the contact detection phase would result in avoiding this bias, and therefore, should be considered in future studies”.

To illustrate the limitation of the methodology reported in [5], Figure 1 was borrowed from the original manuscript (with permission from Elsevier) and several values of global thresholding were used to binaries an artificially made 3D image representing two disks in contact as shown in Figure 1. In Figure 2(a), which is an artificially made image, it is assumed there is a physical gap between the disks with one voxel thickness (XZ plane showing the contact area of Fig 2(a) is zero). Very small Gaussian blur was added to the image to make sure they are closer to real µCT images. Following Otsu’s approach, the global thresholding value is 0.447 and therefore the blurred image was binarised using this value. Figure 2(b) shows the detected contact area which is the artefact of binarisation. As can be seen in Figure 2(c) and 2(d) different value of global thresholding could result in different contact area (Fig 2(c)) or even larger gap between two objects (Fig 2(d)), the gap became equal to 3 voxels.

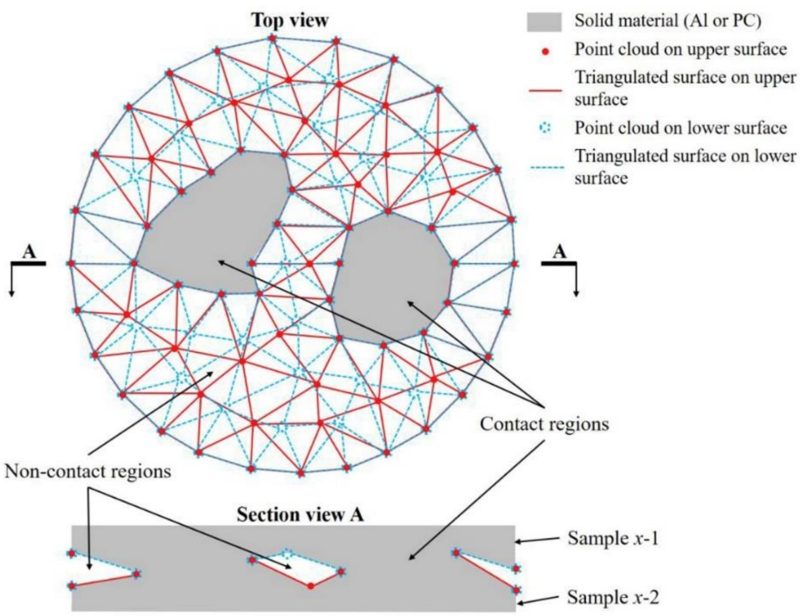
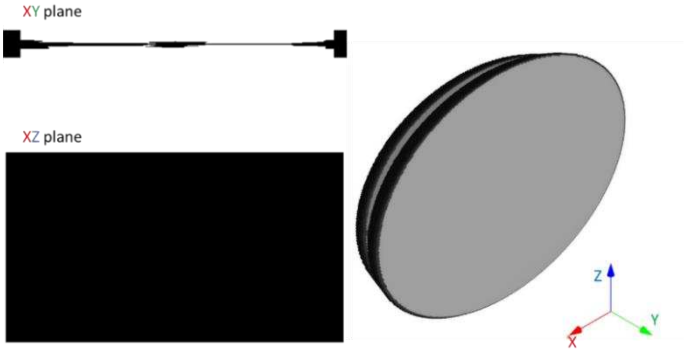
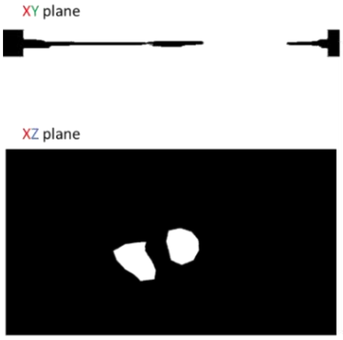


Figure 1. Sketch of the detected contact area using µCT from [4] (with permission from Elsevier).

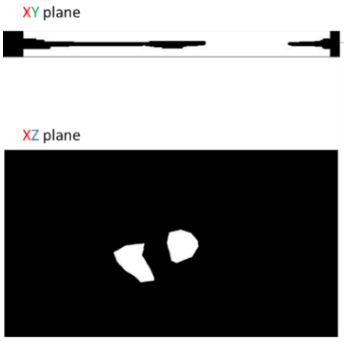
The intention of this letter is that correct detection and quantification of the contact area from µCT is not trivial and careful calibration needs to be reported regarding image post-processing. Calibration can be carried out against high-resolution topography of the surface of interest obtained by *e.g.* optical interferometry and adopting more advanced segmentation algorithms fit for purpose before bringing the surfaces in contact.



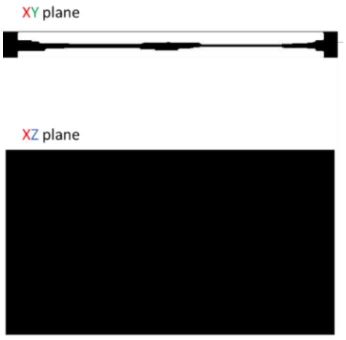
(a)



(b)



(c)



(d)

Figure 2. (a) Grayscale synthetic image; (b) Binarised image with global threshold of 0.447; (c) Binarised image with global threshold of 0.7, (d) Binarised image with global threshold of 0.8.

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