MATERIALS ANALYSIS APPLYING COMPUTER TOMOGRAPHY AND VOXEL-BASED PHOTOGRAMMETRY

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Abstract: Computerised tomography technique is an imaging method that offers, in opposite to closed range photogrammetry, a very detailed three-dimensional image of the interior object structure. As this method operates complete without destructions phenomena that proceed inside the object can be analysed by multi-temporal tomography. After a description of this measuring method, we present some image analysing procedures that based on 2D photogrammetry methods and were adapted to determine metric parameters in voxel data of material samples.

1. Introduction

Computer tomography is a completely non-destructive technique for visualising features in the interior of solid objects and for obtaining information on their three-dimensional geometries and properties. It can be used for a wide range of materials including metal, bone, ceramic and with reservations bio-material. Computerised tomography was originally developed for medical application and is nowadays also used for material research. But it differs from conventional medical scanning methods in its ability to resolve details as small as a few micrometers in size even when imaging object is made of high density materials.

"Tomos" is the Greek word for "cut" or "section" and "graphy" the word for "writing something", so that tomography describes a technique for digitally cutting an object using X-rays to reveal its interior details. A computer tomography image is typically built on slices, like slices of bread. This analogy is suitable because just as a slice of bread has a thickness, a computer tomography slice corresponds to a certain thickness of the object being scanned. Therefore whereas a typical digital image is composed of pixels (picture elements), a computer tomography image is composed of voxels (volume elements).

2. Principle of computer tomography

The grey levels in a computer tomography slice correspond to X-ray attenuation, which reflects the proportion of X-rays scattered or absorbed as they pass through each voxel. X-ray attenuation is primarily a function of X-ray energy and the density and atomic number of the material being imaged. A computer tomography image is created by directing X-rays through the slice plane from multiple orientations and measuring their resultant decrease in intensity. A specialized algorithm is then used to reconstruct the distribution of X-ray attenuation in the slice plane. By acquiring a stacked, contiguous series of computer tomography images data describing an entire volume can be obtained in much the same way as bread can be reconstructed by stacking all of its slices.

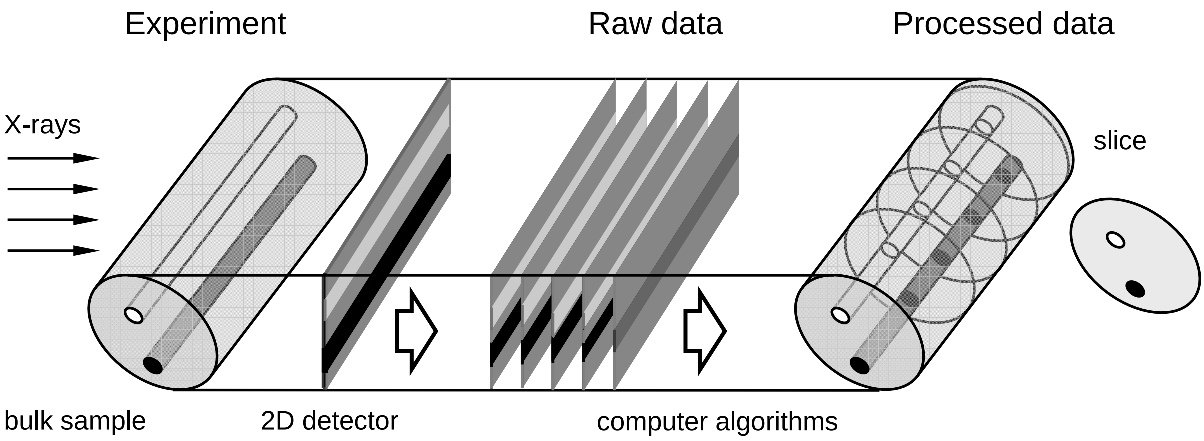

Figure 1: Principle of computer tomography

After this measuring technique was developed in medicine applications for imaging soft tissue and bone X-ray computer tomography was subsequently extended and adapted to a wide variety of industrial tasks. Because industrial computer tomography systems image only non-living objects, they can be designed to take advantage of the fact that the items being studied do not move and harmed by X-rays. The use of higher-energy X-rays, which are more effective at penetrating dense materials and smaller X-ray focal spots, providing increased resolution and longer exposure times increasing the signal-to-noise ratio [1,2].

For the acquisition of computer tomography data, we cooperate with the Institute of Materials Science (IfWW) at the University Dresden. The tomograph can be operated with maximal 225kV and penetrates even through 8cm blocks of concrete. With the 1024x1024 CCD sensor it is possible to image an object with a resolution up to 2µm respectively 2mm object size. But the typically sample size is around 5-10mm and results a resolution between 5 and 10 µm.

Figure 2: Computer tomography at the IfWW

The only preparation that is absolutely necessary for computer tomography scanning is to ensure that the object fits inside the field of view and that it does not move during the scan. Because the full scan field for computer tomography is a cylinder the most efficient geometry to scan is also a cylinder. Thus when possible it is often advantageous to have the object take on a cylindrical geometry, either by using a coring drill or drill press to obtain a cylindrical subset of the material being scanned, or by packing the object in a cylindrical container with either X-ray-transparent filler or with material of similar density. Because the contrast mainly depends on density for some applications the sample has to be treated to enhance the contrasts. Coating with high density materials (gold and copper) and placement with copper balls are examples of marking the object structure.

Calibrations are necessary to establish the characteristics of the X-ray signal as read by the detectors under scanning conditions, and to reduce geometrical uncertainties. The reconstruction of a three-dimensional density distribution requires data on the X-Ray attenuation of all pixels of all projection images. To compute the attenuation during the reconstruction the ratios of the intensities measured with and without specimen are required. To perform the calibration an X-Ray image (reference image) is acquired, before the specimen is placed in the optical path. The required data are obtained by dividing the projection images by the reference image. The superposition of noise and image data has to be considered when the calibration is performed. The noise in the reference image would cause systematic errors of the attenuation images and with that ring artefacts would appear in the image of the sample. Thus a reduction of noise in the reference image is required. To achieve this goal we acquire a series of reference images. These images are then combined in an average reference image. In addition we process a geometric correction of the imaging system. For that purpose a calibration board with around 400 holes is used to determine the distortion parameters. The correction is modelled with polynomial grad 5 or 6 [3].

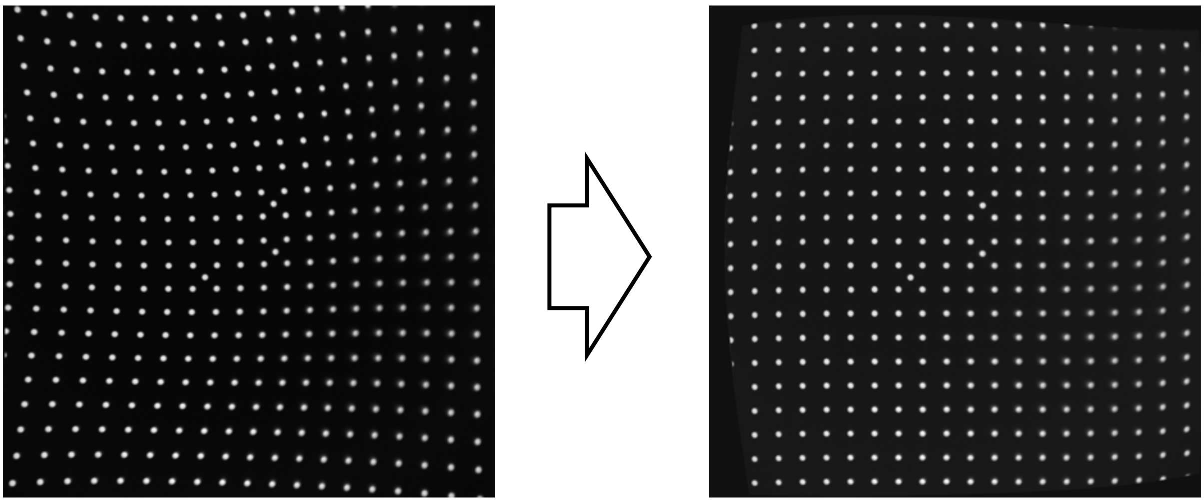

Figure 3: Correction of the imaging system

Reconstruction is the mathematical process of converting projections into two-dimensional slice images. The most widespread reconstruction technique is called filtered back projection, in which the data are first convolved with a filter and each view is successively superimposed over a square grid at an angle corresponding to its acquisition angle.

3. Sintering - Voxel based image analysing

Main focus is monitoring and understanding on the mechanisms of particle rearrangement during the sintering process by acquiring time series of computer tomography data. Applying photogrammetric image analyzing techniques extended and adapted to three-dimensional data particle constellation and motion parameters can be derived automatically from multi-temporal voxel data. To overcome the border of image resolution subvoxel image analyzing techniques have been developed and achieved an accuracy better than 1/10 voxel.

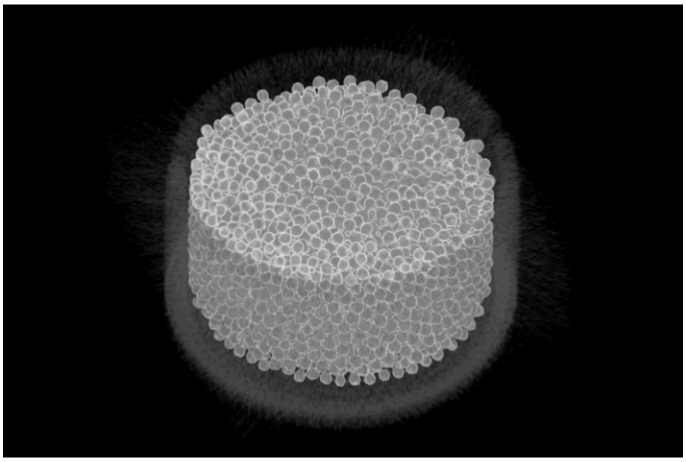

Figure 4: The sintering crucible with around 10000 copper balls

The theoretical description of sintering processes based on two particle models shows a significant discrepancy of the predicted and observed shrinkage of real powder specimens. This inconsistence is caused by particle rearrangement processes as observed in particle rows, 2D specimens and on the surface of 3D samples. Only the application of computer tomography combined with photogrammetric image analysing gives the opportunity to determine particle rearrangements inside of 3D specimens [4].

The analysis of the particle rearrangements during successive sintering stages is shown. Samples consisting of 100…120 µm copper balls were sintered. The sintering was interrupted frequently to enable the acquisition of 3D datasets of successive sintering stages by computer tomography. Photogrammetric image analysing was used to determine the particle positions, the particle contacts for each dataset. In addition each particle was tracked from the initial sintering stage to the final sintering stage. The particle rotation, the formation and breaking of contacts are presented.

The particles were filled into crucibles (Ø 2.5 mm). The number of particles obtained by 3D image analysis was around 10,000 particles. The crucibles were marked by 6 cuts to determine the orientation of the samples in each 3D image and to measure the precise voxel size. The tube voltage was set to 175 KV and the radiation was filtered by a 0.8 mm copper filter to optimize the image quality. The CCD camera resolution was set to 1024*1024 pixels and 1440 projections were acquired. The images were matched using the notches detected by image analysing as pass points for the 3D least square matching (LSM).

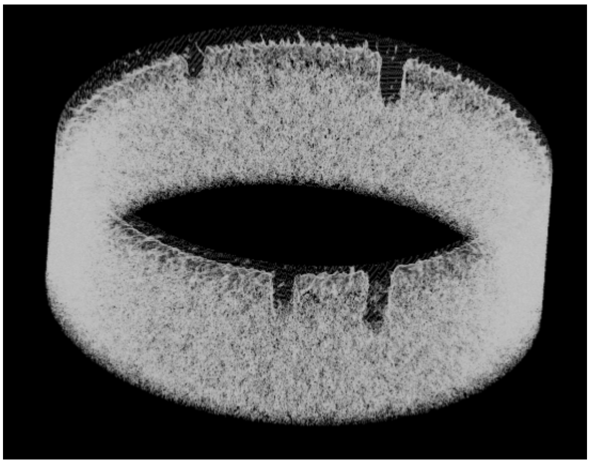

Figure 5: The sintering crucible with notes

The particle positions were estimated at first. Then the particle surface points were determined with subvoxel accuracy. An example 3D visualization based on the image analysing data is shown in figure 6. During this step the coordination partners were determined as well. By least squares method a sphere function was fitted to the surface points to determine the particle centre with an error of about 0.1 voxels. Some particles (30...40) were unsuitable (hollow particles) for the used image analysis algorithms. Thus we take into account that 0.5% or less of the particles were not detected or not tracked or the particle centre position was determined with a large error.

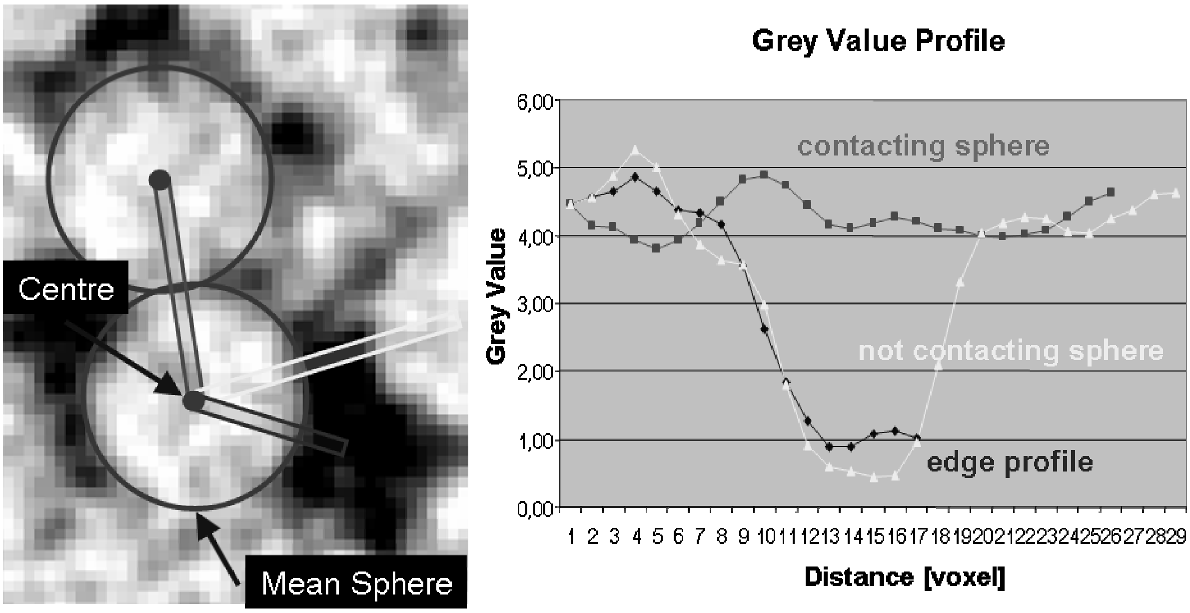

Figure 6: Surface modelling

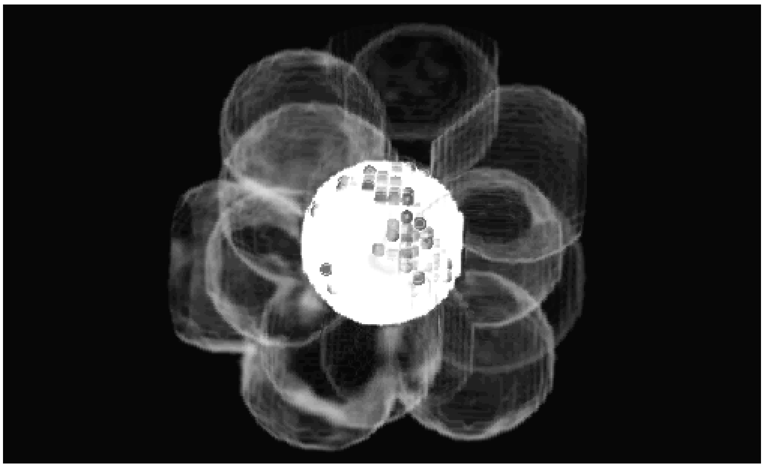

Figure 7: The sintering particle with its contact partners

4. Conclusions

In this paper we discuss the possibilities of microfocus computer tomography in materials research joined with voxel-based photogrammetry. In this large interdisciplinary field of non-destructive testing methods not only high quality three-dimensional images of the internal structure of the material can be obtained or is of interest. Furthermore quantitative and metric information can be determined with photogrammetric image analysing techniques. Several examples have been pointed out and are subject of present research projects at the Technical University Dresden.

5. Acknowledgements

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