Advanced Applications of Computed Tomography by Combination of Different Methods

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Abstract. Advanced applications of materials need sophisticated measurement methods for research, process development and quality control. X-ray Computed Tomography (CT) is a very powerful method for non-destructive testing of materials. A CT-scanner generates a series of X-ray attenuation measurements, which are used to produce computed reconstructed images of an object. In the last years 3D-CT systems with matrix detectors have become more and more popular. In this paper we outline the extended possibilities of 3D Computed Tomography by using a 450 kV-macro focus x-ray source and a 225 kV micro-focus source within one CT system as well as the advantages by applying different CT-methods for the characterisation of one specimen.
The possibility of using two different X-ray sources within one CT-device leads to considerable advantages at certain circumstances. If there are different materials in one specimen the application of two different energies can lead to a significant improvement of the contrast. Moreover, if bigger parts are scanned, the 450 kV-source can be used to get an overall image of the specimen and the 225 kV can be used to get a high resolution image of a detail. In the second section we discuss the limits of 3D-CT and apply an advanced CT-mode (region of interest CT) for the characterisation of flat parts and of selected details in large objects. With the ROI-CT-mode “zooming” is possible similar to optical microscopes and a resolution down to 1/10.000 of the part diameter can be reached. This is a much higher resolution as compared to usual 3D-CT.

Introduction

X-ray Computed tomography (CT) is a powerful radiographic non-destructive-testing and dimensional measurement-method to locate and size volumetric details in three dimensions. The CT image is derived from a large number of systematic observations at different viewing angles, and the final CT image is then reconstructed with the aid of a computer cluster. In the last years 3D-CT systems with matrix detectors become more and more popular. The main advantages of these systems are the reasonable high scanning speed and the high resolution. In usual industrial CT-systems one X-ray tube is used (mainly a 225 kV micro-focus tube or a 450 kV macro-focus tube) [1, 2]. CT-devices with two X-ray sources within one CT-system are rather seldom and therefore, not well investigated.

Due to measurement artefacts like beam hardening, scattered radiation etc.[3,4] and restricted data evaluation possibilities the industrial applications of CT are still limited and the full potential of CT is not yet used in industry and research and development. A method to get better CT-results and to reduce unwished artefacts is the application of advanced CT methods, which are optimized to the task and specimen to be investigated. In the last years in addition to usual 3D-CT, 2D-CT and spiral CT measurement modes, several other CT-measurements methods and the corresponding reconstruction algorithms were developed and tested[1,2]. In literature, there are reports about multi-energy CT[1], phase contrast CT[1], laminography[1], transversal CT[2], several kinds of region of interest-CT methods (ROI-CT) [1,2] and many other proposed CT-modes.

The major contribution of this paper is the demonstration and discussion of extended possibilities of 3D computed tomography by using a 450 kV-macro focus x-ray source and a 225 kV micro-focus source within one CT system. In addition, we show the advantages of the application of different CT-methods (3D-CT and Region of interest CT) for the characterisation of one specimen. We present CT-results from different samples from automotive and electronic industry.

1. Experimental

The X-ray tomograms were scanned at a Rayscan 250E 3D-CT-system constructed by Hans Wälischmiller GmbH with a 225 kV micro focus tube and a 450 kV macro focus tube[5]. The target material is tungsten for both tubes. The diameter of the X-ray spot for the 225 kV tube is 5-200 µm depending on the selected tube current and about 2.2 mm for the 450 kV tube. The two different X-ray tubes produce different –X-ray spectra, since the geometry, tube current and energy, windows etc. are different. The detector of the CT-device is a 1024x1024 a-Si flat panel matrix-detector Perkin Elmer RID 1640 AL1 ES with a Gadox Scintillator[7].

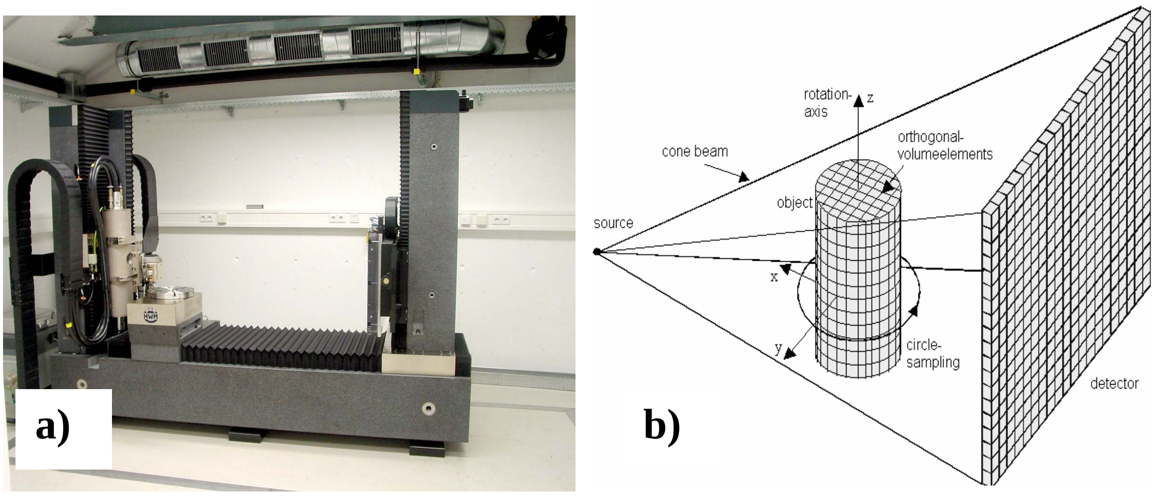

Figure 1: a) Picture of the Rayscan 250 E system showing the two X-ray-sources (225 kV and 450 kV) on the left side and the flat-panel detector on the right side. **b)** Principle of 3D-computed tomography[1].

A picture of the CT-system can be seen on Figure 1a). The CT has several measurement modes including radioscopy, 3D-CT and Region-of-Interest-CT (ROI-CT), especially for flat parts and flat regions of complex parts. The principal measurement geometry of 3D-CT is shown in Figure 1b. Table 1 summarizes the investigated parts together with the measurement parameters. The parts were selected in a way that typical applications from industry were investigated.

Table 1. Investigated samples and CT-measurement parameters

Work-piece: Material and Size	**CT-Mode and tube used**	**Voltage (kV)**	**Current (µA)**	**Resolution (µm/voxel)**	**# of pro-jections**	**Filter (mm)**
#1: Step-part (made of aluminium), 160 x 200 x 25 mm^3	3D-CT – 225 kV 3D-CT – 450 kV	220 400	430 1400	183 183	900 900	0.2 Pb+0.3 Cu 1 W+0.6 Cu
#2: Die-casted part from automotive industry (made of aluminium), 240 x 200 x 108 mm^3	3D-CT – 225 kV 3D-CT – 450 kV: ROI-CT – 225 kV	220 420 215	1000 1500 270	277 277 37	900 900 810	0.2 Pb+0.3 Cu 1 W+1.6 Cu 1 Cu
#3: Plug (made of metallic pins and a polymeric housing), 32 x 32 x 40 mm^3	3D-CT – 225 kV 3D-CT – 450 kV	200 300	240 900	52.9 127	720 540	0.3 Cu 2.2 Cu
#4: Mobile phone (made of different metals, silicon and polymers), Width: 110 x 45 x 18 mm^3	3D-CT – 225 kV ROI-CT – 225 kV	185 180	280 50	62 14	900 900	0.15 Cu 0.15 Cu+0.15 brass

2. Results and discussion

2.1 Comparison of 3D-CT measurements with a 225 kV and a 450 kV tube

Figure 2 shows 3D-CT results (cross-sectional pictures and gray-value profile along the long axis) of an Al-part (work piece #1) measured with the 225 kV-tube and the 450 kV tube. The Al-part has a rather simple geometry with various steps and some air-pores inside the material. The measurements with the micro-focus tube show much more details due to the higher resolution as compared to the results measured with the high-energy tube. However, the CT-results exhibit rather strong artefacts: the surface of the part e.g. the interface between Al and air is smeared and the grey-value within the part is rather inhomogeneous although the material density is more or less constant. These artefacts are well known and mainly caused by beam hardening and scattered radiation effects [3,4]. On the other hand the CT-results with the 450 kV-tube show much less artefacts, the grey values within the material and the air are rather constant, but the resolution is much lower. Therefore, details can not be recognised so clearly.

The next examples are CT-results from a complex industrial Al-work piece from automotive industry. Fig. 3 compares CT-cross section of measurements with the 225 kV-tube and the 450 kV-tube. Similar to the CT-investigations on work piece #1 the CT-results with the 225 kV-tube have a higher resolution and show more details, whereas the CT results with the 450 kV exhibit less artefacts.

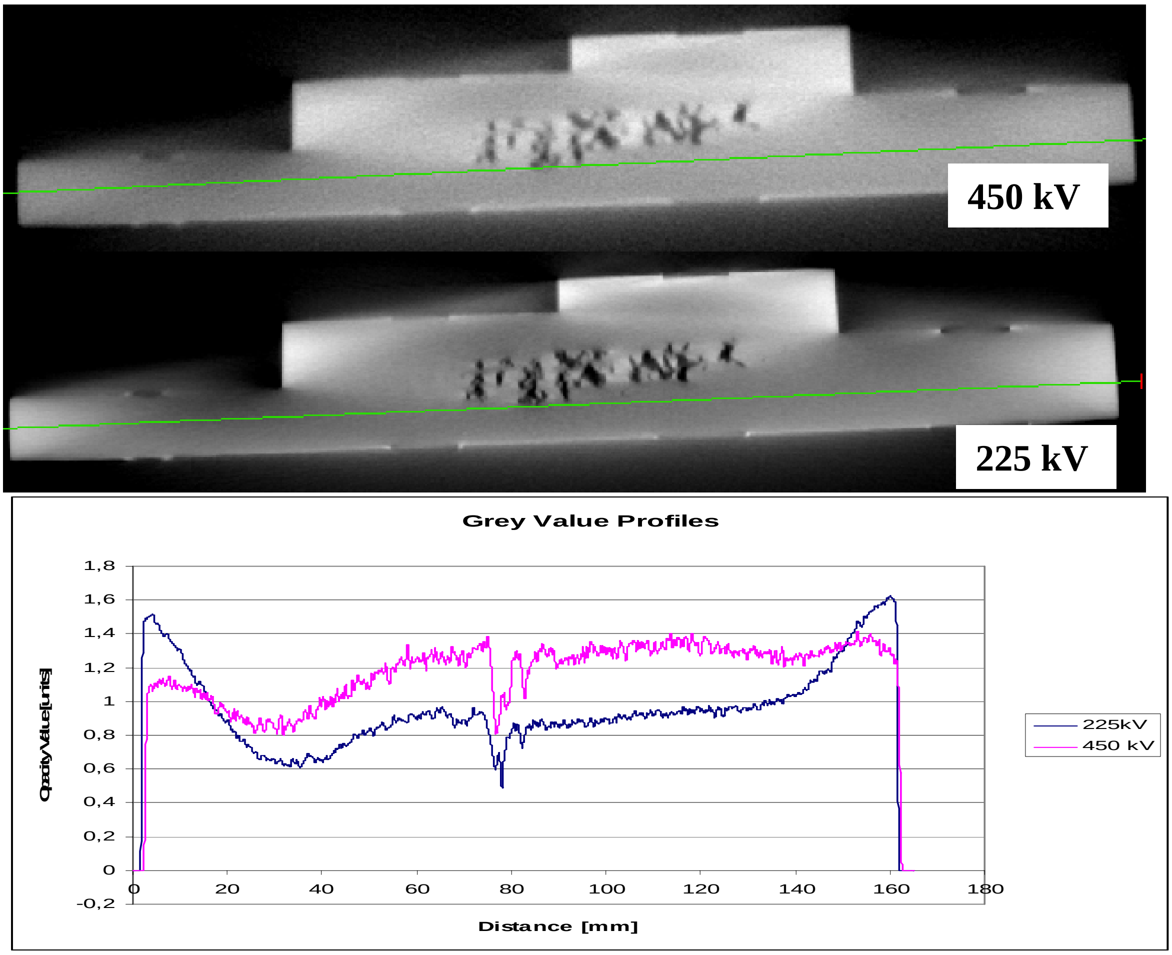

Figure 2: CT-cross sectional pictures of an Al-part (work piece #1) including shrink-holes. The part was scanned with a 450 kV-micro focus tube (upper picture) and a 225 kV tube (lower picture). The picture on the bottom is a comparison of the gray-value line profile along the long axis of the part measured with the 225 kV and the 450 kV tube.

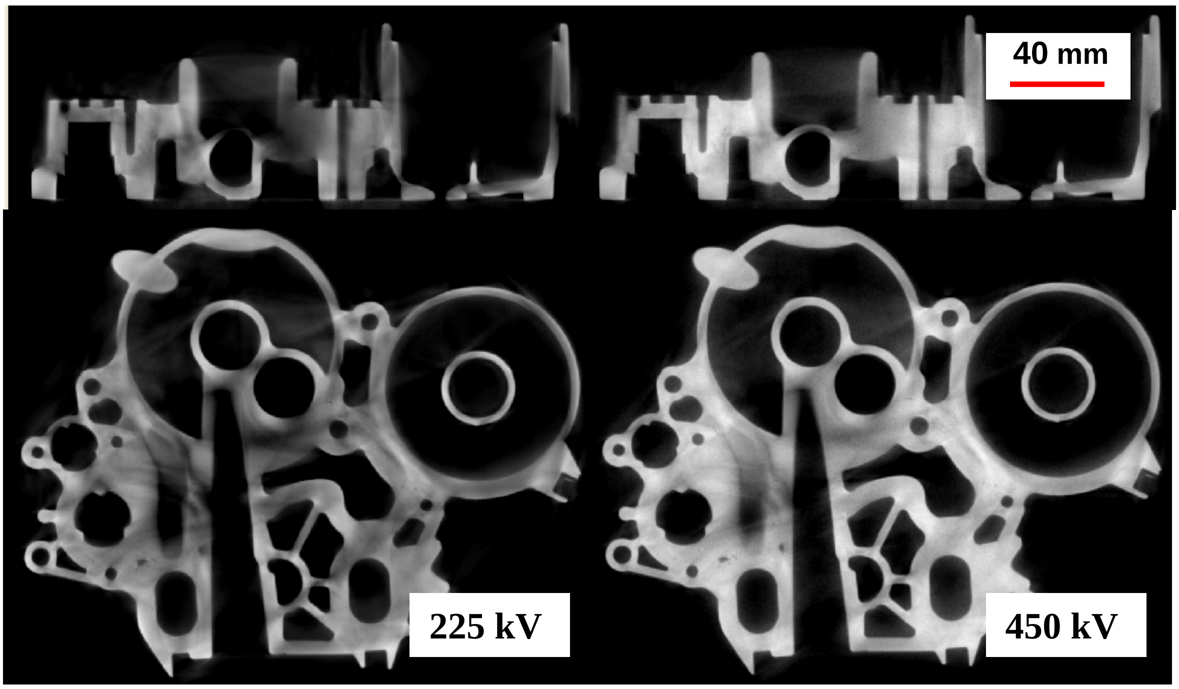

Figure 3: CT-cross sectional pictures of an Al-die casted part from automotive industry (work piece #2). The part was scanned with a 225 kV-micro focus tube (left pictures) and a 450 kV tube (right pictures)

The CT-results of the work pieces #1 and #2 show both, that measurements with the micro-focus tube usually are better suited for non-destructive testing and defect characterisation and detection, especially if one is interested in fine structures and small flaws. However, the CT-measurements with the high-energy tube usually are better suited for dimensional measurements and for getting the geometry of the investigated work pieces, because there are less artefacts and the surface of the work piece can be better segmented.

Work piece #3 is an industrial plug consisting of metallic pins and a polymeric material as the electrically insulating housing. CT-results measured with the 225 kV tube and the 450 kV tube are shown in Fig. 4. In the CT-results measured with the 225 kV-tube dramatic artefacts due to the metallic pins are recognisable. These artefacts are so strong, that the polymeric material in the surrounding of the metallic pins can not be characterised and analysed by CT. This is due to the very different attenuation coefficients of copper and the polymer which exceed the dynamic range of the detector. As can be seen on the right picture of Fig.4, the CT-results with the 450 kV-tube are much better and the artefacts are much less. One can see the metal and the polymer within one picture but the polymer is still not correctly displayed since there are missing areas of the housing. Of course, the edges are much less clear within the CT-results of the 450 kV-tube because the X-ray spot has a diameter of about 2.2 mm.
By using selected local threshold methods[6] one can get the geometry of the metallic pins and the polymeric housing from the 450 kV-CT. The geometrical results are not satisfactory, if the same algorithms are applied to the CT-results measured with the 225 kV-tube. The artefacts are too strong.

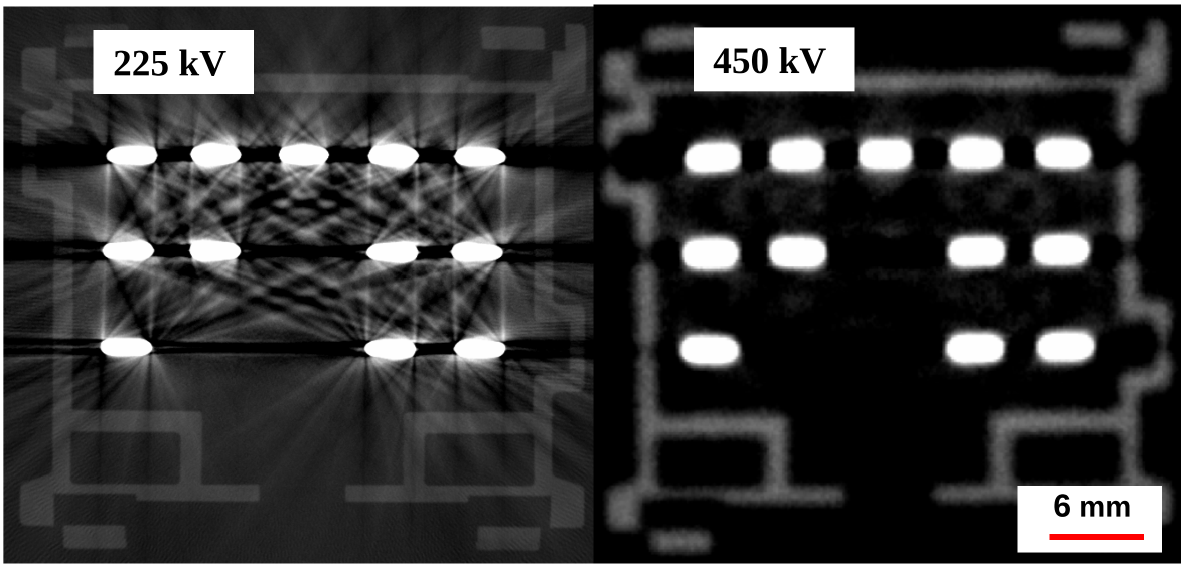

Figure 4: CT-cross sectional pictures of a commercial plug (work piece #3) consisting of metallic pins and a polymeric housing scanned with a 225 kV-tube (left side, tube voltage used 200 kV) and a 450 kV tube (right side, voltage used 300 kV).

2.2 Comparison of 3D-CT and ROI-CT measurements

Figure 5a shows an optical picture of the electronical board of a commercial mobile phone. There are different elements recognisable like integrated circuits, a micro-processor, BGA-housings and the like. Figure 5b shows a cross-sectional picture of a conventional 3D-CT measurement with a resolution of 62 µm and Figure 5c shows a ROI-CT-cross section of a detail of the mobile phone with a resolution of 14 µm. This corresponds to a ratio of 1:6000 (resolution: object size), which is a factor of 6 higher than the corresponding ratio of the 3D-CT measurement. At some regions of the board electronical elements are glued. This glue including rather big air pores can be seen in both CT-results. However, due to the much higher resolution for the ROI-CT-measurement the air-pores can be seen much more in detail in Fig. 5c.

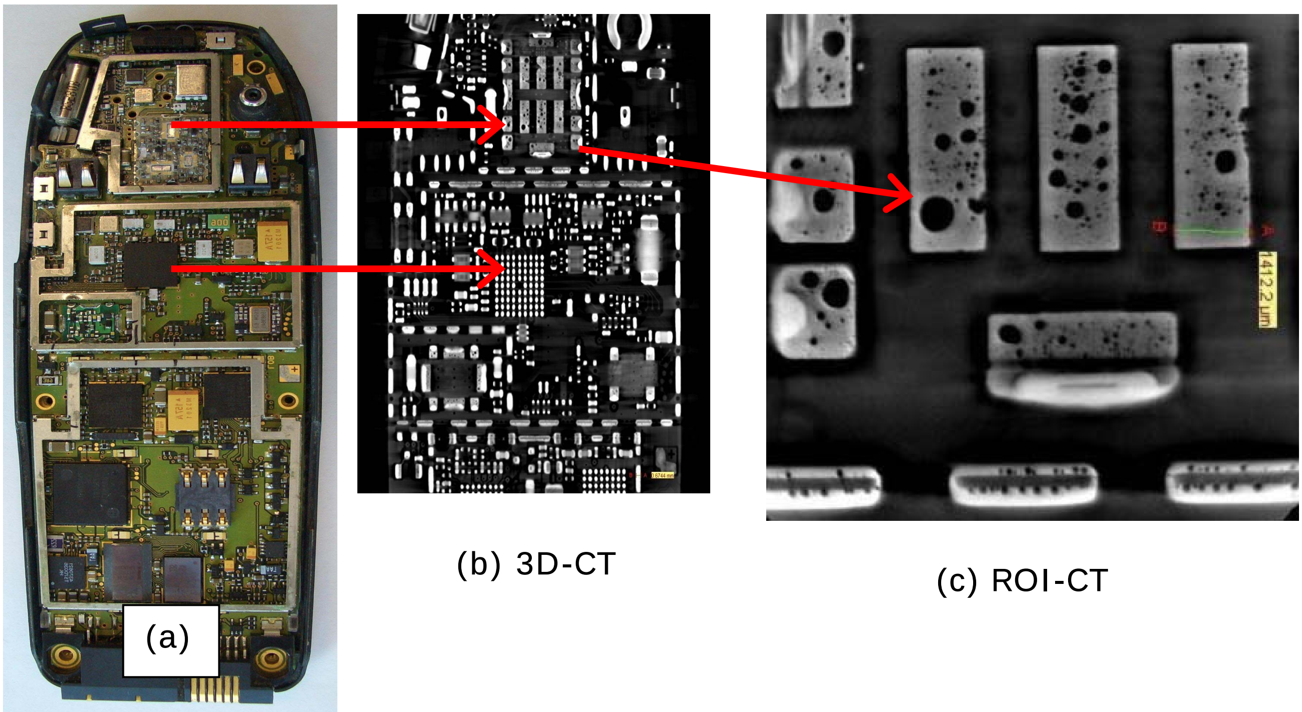

Figure 5. Optical picture of the electronics of a mobile phone work piece #4 (a), 3D-CT-cross section of the electronics of this mobile phone, resolution 62 µm (b) and ROI-CT-cross section of the electronics of this mobile phone showing a glue with many pores, resolution 14 µm, 1:6000 (c).

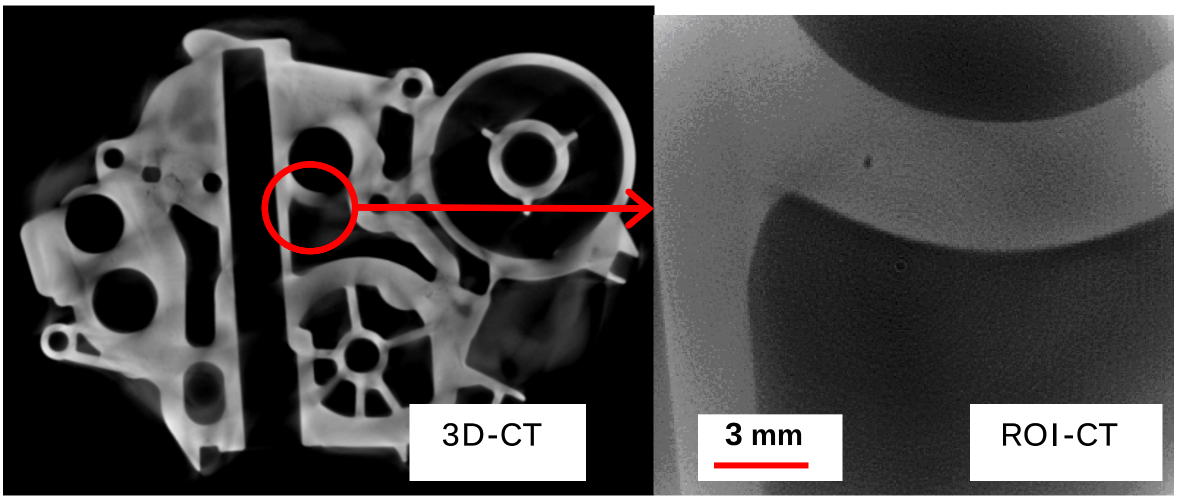

Figure 6: 3D-CT-cross sectional pictures of the Al-diecasted part work piece #2 (left side) and ROI-CT of a selected region of the same part.

Fig. 6 shows 3D-CT- and ROI-CT-results from work piece #2, which is a complex Al-diecasted part from automotive industry. On the left picture of Fig. 6 a cross-sectional CT-picture measured with the 3D-CT mode can be seen, whereas on the right picture results of a selected region of the part measured with the ROI-CT-mode can be seen. The cross-sectional ROI-CT-picture shows the geometry and structure of a region of the part, which is more or less in the centre of the part. The resolution and quality of this result is rather high. The ROI-CT-results of the Al-diecasted part clearly demonstrate, that although the part is not flat and has a rather complex geometry the ROI-CT-results have a high quality. In addition, by ROI-CT a much higher resolution is possible. The ratio between resolution and object size is about 1:6500 for this example.

3. Summary and conclusions

The combination of different X-ray sources and CT-measurement modes within one CT-system leads to significant advantages for the user and to improvements of CT-results, if the CT-device is used in an optimum way. Each source and each measurement mode has its advantages and must be adapted to the task and work-piece to be investigated:

- Using the 225 kV-micro focus source leads to higher resolutions and thus, more details can be recognized.
- Using the 450 kV source usually leads to lower CT-artefacts and to better results concerning dimensional measurements, if you are not so interested in fine geometries.
- If a part consists of metallic and polymeric components the CT-results with the high energy tube are usually better and can be better evaluated than the results measured with a 225 kV-tube
- The ROI-CT measurement mode is very useful for flat parts but also for parts with a complex geometry in three dimensions. It is possible to get resolutions up to 1:10000 (=ratio resolution to object size) of selected regions of the object.

All in all, the combination of different tubes and different CT-measurement modes leads many possibilities and to better results, if the right method and right measurement parameters, which are adapted to the specimen and to the task, are used.

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