Improvement of Polymer Segmentation by X-ray Phase Contrast Computed Tomography

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Introduction

The global escalation in plastic waste, driven by the increasing demand for polymer materials, necessitates the development of effective recycling techniques. Current methods for polymer recycling often rely on sensor-based sorting techniques that analyze surface characteristics such as color, shape, brightness, and fluorescence. However, these methods typically only analyze the surface of the materials, leading to potential inaccuracies, e.g., with coated materials. X-ray inspection techniques can provide a three-dimensional representation of a waste stream which can significantly increase the probability of detection of contaminants that negatively impact the quality of the recycled polymer. Nevertheless, conventional X-ray methods struggle to provide sufficient contrast between different types of polymers, limiting their effectiveness in material separation.

This study explores X-ray phase contrast (PC) imaging as a promising alternative to the standard X-ray attenuation contrast (AC) for the segmentation of polymer materials. Unlike AC imaging, PC imaging utilizes the refraction of X-rays by a material, offering high sensitivity for the characterization of low-density and low atomic number materials such as polymers.

Materials & Methods

A phantom specimen, consisting of four polymers - PMMA, POM, PTFE, and PP - along with H2O as a reference material was prepared. Phase contrast measurements of the phantom were conducted using a SkyScan 1294 desktop system equipped with a Talbot-Lau Grating Interferometer for extracting X-ray phase contrast information.

The computed tomography scan involved capturing 1300 projection images over a 360° rotation of the specimen at 40 kV acceleration voltage, 1200 µA tube current, and 0.5 mm Al pre-filtering applied. With an integration time of 500 ms per projection and averaging over four images, a total scan time of 4.5 hours was achieved.

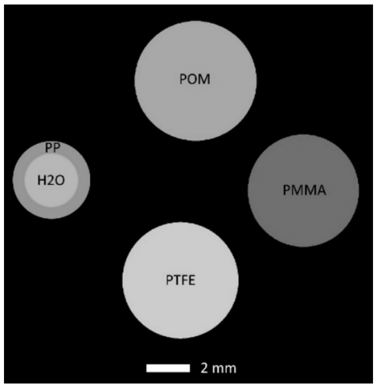

Fig.1: Photograph of the material phantom (top) and schematic cross-section with materials indicated (right).

Results & Discussion

From the AC histogram data shown in Fig.2 (top left) it is obvious that the contrast between PTFE and other polymers is rather high. However, the discrimination between PP, PMMA, and POM poses more difficulties as histogram peaks are partially or completely overlapping. Furthermore, contrast between PP and background (air) is low which complicates its segmentation especially if artifacts, e.g., caused by beam hardening, are present in the image data. The PC histogram in Fig. 2 (bottom left) in comparison shows a better separation of individual material peaks. Consequently, evaluation of the image data revealed, that PC imaging can provide contrast-to-noise ratios more than twice as high in the polymer materials compared to conventional AC imaging, allowing for an easier separation of, e.g., POM and PMMA.

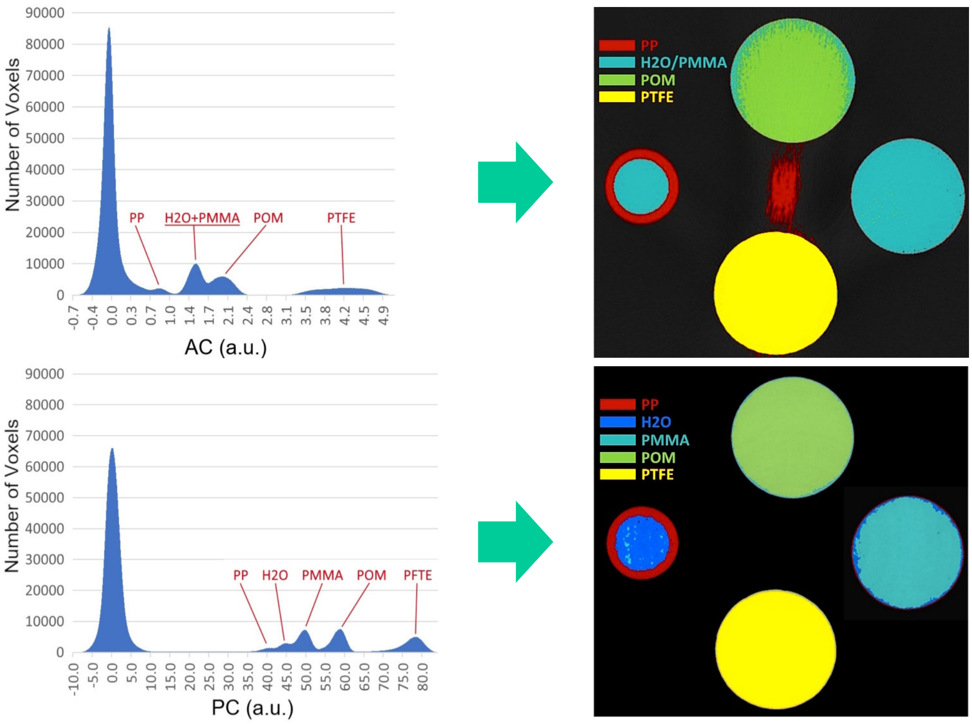

Fig.2: Histograms of standard attenuation contrast (top left) and phase contrast CT data (bottom left). Resulting CT slice images of AC (top right) and PC (bottom right) are shown with color-coded material segmentations.

The color-coded segmentation of computed tomography slice images are shown in Fig. 2 for AC (top right) and PC (bottom right). In AC a differentiation between H2O and PMMA is impossible as well as the low contrast between POM and PMMA partially leads to a wrong segmentation of POM as PMMA. The high contrast in PC data in comparison enables differentiation between PMMA and H2O as well as improved segmentation between POM and PMMA.

Furthermore, beam hardening effects cause an artificial increase in grey values in the AC visible in the background (air) in the image center. This causes the central region in AC to reach a similar grey value as the PP specimen, leading to an erroneous segmentation of air as PP. The phase contrast modality on the other hand is comparably robust to beam hardening effects.

Conclusions

The study presented underscores the potential of PC imaging to improve the segmentation of polymer materials, by providing enhanced differentiation and contrast-to-noise ratios, paving the way for higher-quality recycled polymer products.

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