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Review Article

A Review of Micro Computed Tomography-Based Advanced Material Classification

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ABSTRACT

Materials' mechanical and physical properties and behaviour are substantially determined by their microstructure. As a result, in material design and engineering, visualising the inner structure and morphological properties of materials is critical. The incapacity of two-dimensional (2D) imaging technologies to offer spatial information about the researched structure is an inherent constraint. Three-dimensional (3D) imaging, on the other hand, can reveal inhomogeneity volume, form, spatial and size distribution, and connection. 2D radiographs, for example, can establish the presence of cracks, discontinuities, pores, or structural flaws, but 3D pictures can also assist us in locating and identifying their source. The wavelength of the applied radiation defines the scale of the features being explored in the majority of 3D imaging techniques. When utilising visible light, the theoretical resolution limit is around 200 nm, however with electrons, even individual atoms can be studied.

Keywords: Homogeneity; Ultramicrotomy; Tomography; ferromagnetic

INTRODUCTION

Confocal optical microscopy, which allows for the examination of 3D structures at a finite depth and for transparent materials only, is the entry point into the world of 3D imaging. Using the resonance signal of hydrogen atoms, magnetic resonance imaging produces completely resolved 3D images in a non-invasive and non-destructive manner. Its maximum resolution is a few tens of micrometres, making it ideal for soft tissues [1]. Its significant drawbacks include the inability to analyse ferromagnetic materials and the requirement that the sample be transparent to radiofrequency radiation. The wavelength of the applied radiation defines the scale of the features being explored in the majority of 3D imaging techniques. When utilising visible light, the theoretical resolution limit is around 200 nm, however with electrons, even individual atoms can be studied. Confocal optical microscopy, which allows for the examination of 3D structures at a finite depth and for transparent materials only, is the entry point into the world of 3D imaging. Using the resonance signal of hydrogen atoms, magnetic resonance imaging produces completely resolved 3D images in a non-invasive and non-destructive manner. Its maximum resolution is a few tens of micrometres, making it ideal for soft tissues. Its significant drawbacks include the inability to analyse ferromagnetic materials and the requirement that the sample be transparent to radiofrequency radiation. Scanning electron microscopy (SEM) has a higher resolution (nanometer scale), however it can only be used in two dimensions. The sample must be sectioned, for example, with a focussed ion beam, in order to explore 3D structure with SEM [2].

3D Imaging Techniques

This destructive process takes a long time to complete and can only image a tiny area. Serial block-face scanning electron microscopy with ultramicrotomy enables for automated imaging of a larger volume, but technique is not ideal for sensitive, brittle, or moist materials, and slicing can cause substantial artefacts. The term "electron tomography" refers to 3D imaging using a transmission electron microscope. A 3D model of the sample can be created by reconstructing transmission images of the sample from at least a hundred distinct angles. This is a highly high-resolution technology; however it is only useful for certain applications. For extremely tiny samples 3D photo acoustic tomography is a millimeter-resolution non-invasive, non-destructive imaging technology in which the contrast is based on the absorption of laser light. X-ray imaging can be employed in a variety of ways. Traditional X-ray absorption imaging is the most popular method, in which an X-ray beam passes through the material and the transmitted radiation is recorded to provide a simple attenuation contrast image. Fluorescence X-ray tomography, dual energy X-ray tomography, and phase-contrast X-ray tomography are some of the additional options [3]. In the case of low-density materials, phase contrast is required since attenuation contrast is insufficient due to slight changes in material attenuation coefficients.

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Micro-CT

This technique necessitates a monochromatic beam and sample-to-camera distances that can be adjusted. The X-ray diffraction method can also be used to create a 3D map of the composition of samples. CT is a non-destructive 3D imaging technology that uses the varied X-ray attenuation of different materials. Its non-destructive nature allows for temporal examination (some refer to it as four-dimensional (4D) imaging, with time as the fourth dimension), and the inspected samples stay unaltered, can be further investigated (even in situ), or used. It requires almost no sample preparation, making it ideal for materials that would lose their shape if manually sectioned. During the measurement, the samples are not damaged. In rare circumstances, contrast enhancement with contrast agents is required, however this normally does no harm to the sample. CT imaging can be used to investigate multiple scales, from millimetre resolution with clinical or industrial devices to submicron resolution with nano-CT. MicroCT is recognised as a crucial tool for assessing the structure and quality of bones. It has been used to research metabolic bone illnesses like osteoporosis, to assess disease preclinical models, and to assess the effectiveness of anabolic and anti-resorptive therapies like bisphosphonates. Use of contrast agents to identify and measure bone microdamage is a newly developed method for microCT-based evaluation of bone fragility brought on by loading, ageing, or osteoporotic illness. For instance, the use of barium sulphate (BaSO4) enables the measurement of microdamage from fatigue in the trabecular tissue of cattle in three dimensions (Figure 1). MicroCT makes it possible to rebuild microstructural properties in three dimensions at high resolution, from trabecular architecture to cortical porosity [4, 5]. Trabecular bone from the femoral necks of two people, one 51 years old and the other 84. Diaphyseal femoral cortical bones of a male, 18, and a female, 73, are shown on the left (right). The microstructural characteristics of both cortical and trabecular bone are influenced by age, gender, disease, and other factors; they can be quantitatively assessed by microCT.

In Situ Investigations

Micro-CT is appropriate for temporal investigations because of its non-destructive nature (time-lapse imaging or 4D micro-CT). For instance, it is possible to explore the impact of corrosive environments or various weather patterns on structural materials, or to keep track of changes throughout the course of an electronic device's lifetime. A sample is subjected to external impacts and then quantified by micro-CT in a procedure known as postmortem tomography.

Repeated measurements are performed on either various sample pieces or a single item that is continuously measured. Ex situ tomography refers to a procedure in which the sample must be removed from the CT device in order to make adjustments, whereas in situ micro-CT refers to a way in which the investigation can be conducted using specifically built equipment without the sample being removed. This makes it easier to pinpoint the precise changes in the structure and even enables one-to-one tracking of the changes taking place in a single pore or in a specific area of the sample. Particularly in the design and development of new materials, in situ micro-CT measurements offer novel opportunities. In situ investigations might be either continuous or stopped. When in situ tomography is stopped, the sample is first exposed to an impact, is "frozen" into this state for the duration of the measurement, and then is once more exposed to changes. For instance, a measurement is made after the sample is crushed with a specific amount of force, and then another CT measurement is made after the force is raised.

Repeated a number of times compression, tensile, indentation, and bending tests are all examples of mechanical tests. This method makes it simple to evaluate changes in shape, size, and porosity as well as the beginning and spread of cracks as a result of mechanical impact. The capacity to provide information about the precise alterations in the structure is one of the key benefits of in situ micro-CT [6]. Due to the lack of additional characterization by other techniques the necessary sample size is decreased. Additionally, it is also feasible to track the precise effects that a particular external force has on structural details and assess whether or not the sample deforms uniformly. To ascertain shrinkage, thermal expansion, or freezing characteristics, investigations can also be utilised in conjunction with a progressive thermal profile. Processes are monitored in close to real time with continuous in situ tomography. This implies a quick picture acquisition process because even little changes in the structure during measurement might cause significant artefacts to appear during reconstruction, lowering the quality of the resulting image. Fortunately, software post-processing provides a way to correct for motion abnormalities and enhance the quality of the reconstructed images, making it viable to study dynamic processes. Because of the tremendous photon flux, synchrotron X-ray sources are especially well suited for continuous in situ tomography, which cuts micro-CT picture capture durations to seconds [7].

This makes it possible to investigate electrochemical cells, batteries, fuel cells, and other devices in operation. Assessment of the capacity of gas storage or oil recovery from rocks is made possible by in situ flow micro-CT devices. CT imaging has historically been used for medical purposes, but as the technology has grown and improved, other uses have become apparent. Examples of potential applications for micro-CT include medicine, food chemistry, dentistry, geoscience, life sciences, petroleum geology, scaffolds, building materials, nanotechnology, additive manufacturing, and

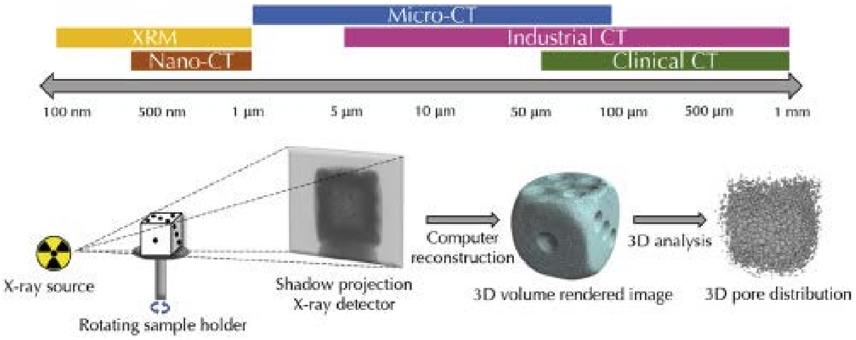

Figure 1: Micro Computed Tomography-Based Advanced Material.

tissue engineering. The basic information obtained from micro-CT is the difference in X-ray attenuation, and the absorption map (2D or 3D), which can be improved through post processing, is the direct quantitative outcome. It is possible to examine the 3D internal structure of samples and confirm the presence of pores, fissures, and structural flaws. Micro-CT is a qualitative diagnostic technique in this regard [8]. Porosity, pore size distribution, connectivity of pores, form, size, and orientation are examples of quantitative data that can be obtained. It's crucial to keep in mind that 3D reconstructions are entirely based on X-ray attenuation contrast while enjoying the visual excitement they provide. Only subsequently is application field-specific meaning given to the differences, and depending on what the photos really depict, wildly divergent interpretations of the same observation are possible. For instance, while identically sized pores in a metallic automobile part can expose serious production problems, pores in bricks are typical and necessary for heat insulation and freeze tolerance. Real material science in micro-CT thus starts with the critical interpretation of the information obtained.

Bio Materials

The word "biomaterial" is incredibly all-encompassing. Any substance intended to interact with a biological system can be referred to as such (often as part of a medical treatment). 'Bioinspired' materials are produced when materials science looks to nature for ideas to develop new types of materials and enhance the quality and application of current ones; 'Biomimetic' materials are produced when inspiration descends into outright theft. Micro-CT research can provide important details about each class. Micro-CT, for instance, is a particularly effective method for examining bone growth and regeneration around implants. Evaluated the rabbit femur's solid implant's bone development and porous implant's bone penetration. Additionally, inferior screw stability in an implant could be discovered via X-ray imaging. a substance. In an effort to aid in the creation of bone-like ceramics, certain characteristics of porous bioceramic scaffolds were compared with the bone tissue by micro-CT.

A metric was developed for the comparison of scaffolds to the bone. Recently, a review of micro-CT research and bioscaffold design was published. Dentistry (where it can aid with dental fillings, crowns, and implants) and artificial organ design (helping cardiovascular engineering and bioinspired design) are two more significant examples of micro-CT applications at the intersection of the real world and materials science. Materials that mimic biological phenomena are created for scientific research [9]. It is crucial to understand their 3D structure in order to accurately duplicate the advantageous traits of distinct biological systems.

CONCLUSION

Provides a good illustration of how to make the biomimicry aspects of micro-CT are thoroughly reviewed in the most recent work of du Plessis and Broeckhoven. There are numerous functional biomimetics application examples in micro-CT. In order to design artificial insect-sized wings for tiny air vehicles, the morphological description of a beetle wing was beneficial. The microstructure of the wings, their circulatory network, the flight muscles, and the wing joints were all mapped out with the use of X-ray imaging. Micro-CT analysis, reverse engineering, and 3D printing of an ancient armadillo-like animal species were used to produce bioinspired prosthetic body armour. Biomimetic aerospace composite joints with superior mechanical properties were made using information gathered from the micro-CT investigation of tree joints. The investigation revealed that there is a difference in porosity between the sections experiencing various.

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