Tomography and radiography using hard X-rays and neutrons: shedding light on materials properties and engineering devices

Guillermo Requena and Alexander Rack

Institute of Materials Research, German Aerospace Center (DLR), Cologne, Germany
ESRF – The European Synchrotron, Grenoble, France

Guillermo Requena

Alexander Rack

The internal structure of engineering materials is one of the main characteristics that determine their performance under service conditions. Moreover, understanding its formation during processing as well as its evolution under the effect of external loads is crucial to design new materials, optimize existing ones and develop theoretical models. In this context, cutting-edge techniques such as synchrotron and neutron imaging have become well established tools that allow materials scientists and engineers to study non-destructively the bulk of materials and components. The use of synchrotron and neutron sources can provide decisive advantages with respect to laboratory-based imaging techniques that include higher temporal and spatial resolution (synchrotron) as well as improved detectability of features. Moreover, next generation synchrotron storage rings as well as the construction of modern neutron sources continuously push the limits of imaging in terms of resolution along with the size of samples and components that can be investigated (ex situ, in situ or in operando).

The present special issue comprises selected contributions from the symposium "Tomographic and Radiographic Imaging with Synchrotron X-rays and Neutrons: Exploiting Contrast and Time" organized in the frame of the conference Materials Science and Engineering (MSE) held from September 25th to 27th of 2018 in Darmstadt, Germany. The aim of the symposium was to provide an exchange platform between researchers involved in the rapidly developing experimental techniques and users applying them in the field of materials science and engineering. The symposium is a direct continuation of the symposia organised during the European Congress and Exhibition on Advanced Materials and Processes in Montpellier, France (EUROMAT2011) as well as in Sevilla, Spain (EUROMAT2013). Due to its ongoing success the symposium will be continued during the MSE conference in September 2020. The eleven papers that form the present issue reflect that imaging at synchrotron and neutron sources has reached a degree of maturity that permits new insights for fundamental science as well as for applied research close to industrial developments.

The application of bulk imaging for the study of engineering lightweight metallic materials is a field that has been growing steadily over the last decade and its relevance is shown in four contributions [1–4]. Tolnai et al. [1] utilize synchrotron imaging and high energy synchrotron diffraction to follow in situ the microstructure formation of Zn-modified Mg–Nd alloys during solidification. The combination of these two synchrotron techniques allowed the researchers to correlate the sequence of formation of phases and their morphological evolution as a function of temperature. The work by Le-Quang et al. [2] shows the power of high-speed synchrotron radiography to study kinetic phenomena. Here, re-solidification dynamics of an Al–Mg alloy locally melted by a fibre laser in different welding regimes is clearly revealed by imaging at an acquisition rate of around 30000 frames per second. The capability of synchrotron tomography to detect microstructural features that cannot be resolved by laboratory-based techniques is shown in the contribution by Zabler et al. [3], where the microstructure of cast Al–Si alloys is analysed considering relevant geometric descriptors. In this work, it was possible to reveal the eutectic and primary Si phases usually found in this family of alloys from the Al-matrix by means of phase contrast. The in-situ study of damage accumulation in metals under the effect of mechanical loads is one the fields in which synchrotron tomography has produced groundbreaking insights. The work by Alfaro et al. [4] presents a 3D study of the evolution of damage in a fibre-metal laminate formed by successive layers of friction-stir-welded high strength aluminium sheets and glass fibre reinforced plies. This type of material is used in the aeronautic industry to fabricate fuselage structures that can exhibit simultaneously light weight and high damage tolerance. Applying in-situ tomography during tensile deformation, the authors were able to reveal the sequence of damage formation mechanisms and how their interaction leads to final failure in these heterogeneous materials.

Two further contributions dealing with engineering metals are the papers by Grosse et al. [5] and Forien et al. [6]. The unique capability of neutron radiation to image hydrogen was utilized in [5] to determine its 3D distribution in zirconium alloys. These materials are used for cladding tubes in nuclear light water reactors. On the other hand, Forien et al. [6] correlated surface roughness and internal porosity with processing parameters of a 316L steel alloy produced by powder-bed-based additive manufacturing. The use of synchrotron tomography helped the authors to identify non-destructively the dependence of porosity and roughness on laser power and scan strategy. A further study dealing with materials for additive manufacturing is the contribution by Scholz et al. [7], in which a mechanochemically synthesized metal-organic framework (MOF) in combination with an acrylonitrile-butadiene styrene (ABS) polymer was used to form a composite filament for 3D printing. Here, absorption edge tomography using synchrotron radiation was used to evaluate the 3D distribution of the MOF material in the filament and in a printed sample at a resolution of a few micrometres.

The relevance of synchrotron imaging for fundamental studies is also well represented in this special issue. Shevchenko et al. [8] applied in-situ synchrotron radiography to follow the evolution of dendrites in a Ga–In alloy during solidification. The investigations revealed a transition from a four-fold symmetry to a hyperbranched dendritic morphology owing to side arm-splitting. The image processing carried out will help to obtain data for validation of numerical simulations. Ohser et al. [9] used time-resolved synchrotron tomography to follow three-dimensionally the movement of particles in solid–liquid flows through porous structures. These investigations are, for example, a prerequisite for the development of new technologies for industrial cell chromatography. The authors were able to estimate several flow characteristics from the 3D data such as the particle deposition rate at the surface of the pore space and the fraction of particles moving close to the surface. The contribution by Reimann et al. [10] deals with the 3D characterization by synchrotron tomography of sphere packing structures in slender prismatic containers. This study is relevant to investigate topological features that are known to determine effective properties in granular media. Finally, the work by Sauer et al. [11] reports on the tomographic analysis of a biological material, namely the microstructure and texture of pike fish. By combining absorption and phase contrast tomography with other laboratory-based imaging techniques the authors were able to reveal the principle design layout of the bone of this predator over several length scales.

We are sure that the readers will enjoy this special issue since its contributions address timely issues in the fields of materials characterization using synchrotron and neutron sources.

The guest editors would like to thank all authors for their contributions as well as participants of the symposium whose enthusiam made this special issue possible. A special thank you to the anonymous reviewers for the extra work. We hope to see you all again for the next MSE Symposium in September 2020 in Darmstadt, Germany.

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