3D Internal Strain Mapping by Tracking Microstructural Features in Tomographic Volumes of Structural Materials

H. Toda[1], T. Ohgaki[1], M. Kobayashi[1], T. Akahori[1], M. Niinomi[1], T. Kobayashi[1], K. Uesugi[2], K. Makii[3] and Y. Aruga[3]

1 Department of Production Systems Engineering, Toyohashi University of Technology, 1-1, Hibarigaoka, Tempaku, Toyohashi, AICHI 441-8580, Japan
2 Japan Synchrotron Radiation Research Institute, 1-1-1, Kouto, Mikazuki-cho, Sayo-gun, HYOGO 679-5198 Japan
3 Kobe Steel, Ltd., 1-5-5, Takatsukadai, Nishi-ku, Kobe, HYOGO 651-2271, Japan

Synchrotron X-ray microtomography has been utilized for the 3D characterisation of microstructures in several aluminium alloys. Tomographs, consisting of isotropic voxels with a maximum of 0.474 µm edge, were collected mainly at the X-ray imaging beamlines BL20B2 and BL47XU of the SPring-8. A combination of the high-resolution deflection contrast imaging technique and several state-of–the-art application techniques have enabled the quantitative image analyses of internal microstructure, such as micro-pore, intermetallic compound particles and grain boundary as well as the assessment of their effects on deformation and fracture behaviours of the aluminium alloys. The application techniques include liquid metal wetting which enhances nanoscopic microstructural features in term of the absorption contrast, microstructural tracking which enables large scale strain mapping, in-situ observation technique using a material test rig specially designed by the present authors and local area observation for samples larger than available fields of view. 3D finite-element meshes were also generated from the tomographic volumes to monitor local stress and strain distributions, then being used to verify the image analyses.

In terms of the microstructural tracking, in order to evaluate microstructural effects quantitatively, the tomographic dataset was thresholded and labelled utilizing a grey value for each 3D feature of interest. Volume, surface area and centre of gravity of each feature were automatically measured at sub-voxel accuracy using software developed by the present authors. Centre of gravity of each microstructural feature was then utilized as a displacement gauge marker to calculate three-dimensional mechanical parameters of the underlying aluminium, such as strain, stress and crack driving force. Variations during loading in the centroid spacings of the pairs of neighbouring microstructural features may then be separated into three directions by orthogonal decomposition.

The tracking technique has provided a highly effective way of assessing microstructure/property relationships in the structural materials, together with supplementary ways of verifying and interpreting them by visualising and quantifying various mechanical behaviours. The proposed technique has been clearly advantageous compared to the very limited procedures for such measurements available in the current literature, where detailed internal information can only be accessible for limited types of material, such as transparent materials.