Assessment of microstructures and properties of metallic materials using synchrotron radiation and high-resolution microscopy

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Structural materials are used in a wide range of infrastructure, including buildings, bridges, aircraft, high-speed trains and automobiles. Examples include metals, cement, glass, plastics and wood, but in our laboratory, we are particularly interested in studying steel, aluminum alloys and nickel alloys. These structural materials are used in high-speed trains, aircraft, rockets, etc., and in recent years there has been a demand for them to be lighter and stronger. In order to improve the performance of structural materials, it is extremely important to understand not only the initial state of the material, but also how deformation, fracture and transformation proceeds within the material. To analyze the time-dependent behavior of materials, we perform 3D/4D image-based analysis using synchrotron radiation. Synchrotron radiation is extremely powerful and can visualize the interior of metallic materials (3D), and by combining it with in-situ testing, it is possible to directly observe the time-dependent behavior of material fracture, deformation and transformation (4D: 3D+time). The left image of figure 1 shows the propagation of a crack in an aluminum alloy, and the right image of figure 1 shows the transformation and disappearance of a single crystal grain in a steel material. These images were taken using synchrotron radiation and then reconstructed in 3D.

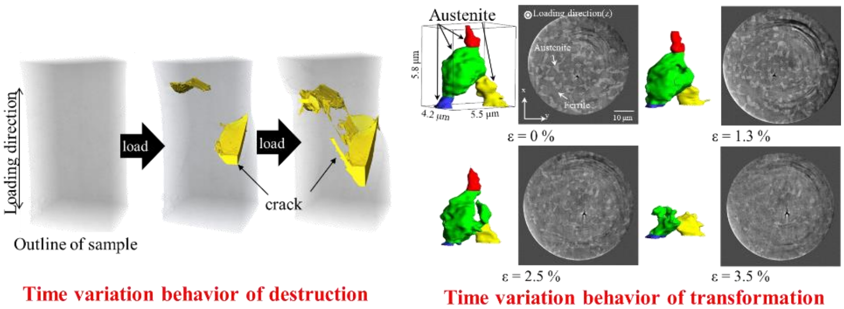

Figure 1 Information obtained through in-situ observation using synchrotron radiation

We acquire different time development behavior as images and analyze these images with different methods. For example, there is the shape and crystal orientation distribution of crystal grains in 3D (top left of figure 2), the change in dislocation density of individual crystal grains (bottom left of figure 2), the strain distribution in 3D inside the material (top right of figure 2), and the identification of the point of fracture initiation (the weakest point of the material) by moving backwards in time (bottom right of figure 2). Because synchrotron radiation experiments can provide a variety of information from a single specimen and a single test, the above 3D/4D analysis can be performed simultaneously. By performing 3D/4D analysis, it is possible to clarify unknown phenomena and make new discoveries that differ from conventional methods. Recently, we have also been conducting 3D observations using a transmission electron microscope, which can observe small structures in metallic materials more clearly than synchrotron radiation. Our aim is to use this knowledge to further improve the functionality of structural materials.

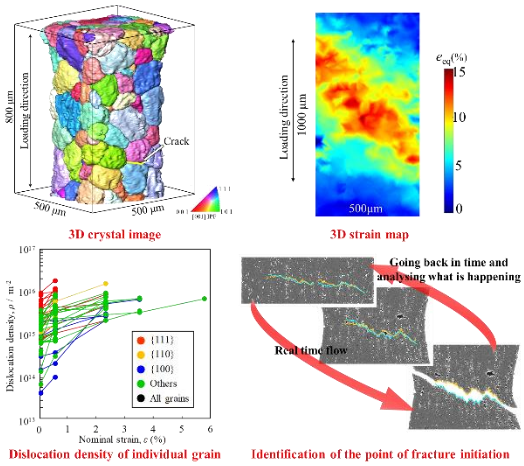

Figure 2 Analysis technology using synchrotron radiation