Atomic-resolution electron microscopy for aluminum alloys as high-performance industry materials

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Developments of high-strength aluminum alloys have always faced a difficult problem: owing to their small size, the early-stage strengthening precipitates are difficult to characterize in terms of composition, structure and evolution. Here we employ atomic-resolution transmission electron microscopy (TEM) imaging and first-principles energy calculations to address these problems. Recent years, we have investigated tens of typical high strength aluminum alloys, such as 2xxx (AlCu, AlCuMg and AlCuLiMg), 6xxx (AlMgSi and AlMgSiCu) and 7xxx (AlZnMg and AlZnMgCu) alloys, with different compositions and with varying thermal processes for understanding their property-structure-process correlations. Using aberration-corrected high-resolution TEM (HRTEM) and aberration-corrected scanning TEM (STEM), much of our attention has been paid to revisit the strengthening precipitates in these important alloys and to clarify the controversies left in the past about their precipitation behaviors. Our study demonstrates the followings:

(1) Atomic-resolution imaging in STEM can provide straightforward structure models at the atomic-scale, whereas atomic-resolution imaging in HRTEM with rapid quantitative image simulation analysis can provide the refined structures with high precision beyond the resolution limitation of the microscope. The combination of the two techniques can be more powerful in solving difficult structure problems in materials science.

(2) Most of the early-stage precipitates in aluminum alloys are highly dynamic in both composition and structure. Typically, having their characteristic genetic skeletons to guide their evolution, these dynamic precipitates initiate, mature and grow with thermal aging following characteristic evolution paths. The fine precipitation scenarios revealed in our studies are rather different from previous understandings in the textbooks and literatures published thus far.

Keywords: Electron microscopy; Aluminum alloys; Precipitates; Phase transformation