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Structure-Property Relationships in Aluminum-Copper alloys using Transmission X-Ray Microscopy (TXM) and Micromechanical Testing

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abstract

Aluminum alloys are ubiquitously used in almost all structural applications due to their high strength-to-weight ratio. Their superior mechanical performance can be attributed to complex dispersions of nanoscale intermetallic particles that precipitate out from the alloy's solid solution and offer resistance to deformation. Although they have been extensively investigated in the last century, the traditional approaches employed in the past haven't rendered an authoritative microstructural understanding in such materials. The effect of the precipitates' inherent complex morphology and their three-dimensional (3D) spatial distribution on evolution and deformation behavior have often been precluded. In this work, for the first time, synchrotron-based hard X-ray nano-tomography has been implemented in Al-Cu alloys to measure growth kinetics of different nanoscale phases in 3D and reveal mechanistic insights behind some of the observed novel phase transformation reactions occurring at high temperatures. The experimental results were reconciled with coarsening models from the LSW theory to an unprecedented extent, thereby establishing a new paradigm for thermodynamic analysis of precipitate assemblies. By using a unique correlative approach, a non-destructive means of estimating precipitation-strengthening in such alloys has been introduced. Limitations of using existing mechanical strengthening models in such alloys have been discussed and a means to quantify individual contributions from different strengthening mechanisms has been established. The current rapid pace of technological progress necessitates the demand for more resilient and high-performance alloys. To achieve this, a thorough understanding of the relationships between material properties and its structure is indispensable. To establish this correlation and achieve desired properties from structural alloys, microstructural response to mechanical stimuli needs to be understood in three-dimensions (3D). To that effect, in situ tests were conducted at the synchrotron (Advanced Photon Source) using Transmission X-Ray Microscopy as well as in a scanning electron microscope (SEM) to study real-time damage evolution in such alloys. Findings of precipitate size-dependent transition in deformation behavior from these tests have inspired a novel resilient aluminum alloy design.

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