The Advanced Photon Source

Toward a Strong, Lightweight, and Ductile Aluminum Alloy

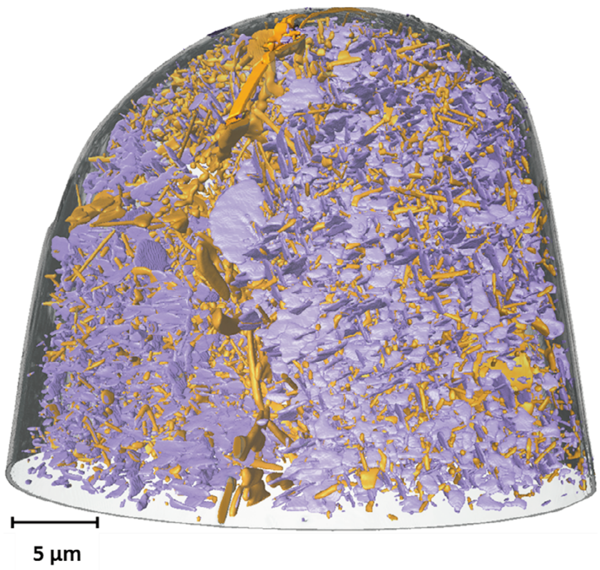

Fig. 1. This transmission x-ray microscope image shows the interior nanostructure of the aluminum copper alloy. The blue areas are aluminum, while the orange shows the needle- and plate-like AL_2Cu nanoparticles that precipitate out of the mix and are responsible for the alloy's strength.

Inexpensive, abundant, and useful—pure aluminum metal is soft and ductile and perfect for end uses such as soda cans and aluminum foil. But add just a little bit of copper, magnesium, or zinc, and aluminum transforms into a super-strong yet lightweight material, stiff and resilient enough to be used in aircraft and automobile frames. Although scientists discovered how to alloy aluminum with other metals 60 years ago, it is still not entirely understood how these small additions cause such dramatic changes in aluminum properties. Now, researchers have used the unique capabilities of the APS to detail for the first time how these metals change the nanoscale structure of aluminum, and to explore how we might control the metallurgy to design even better aluminum alloys with even more desirable properties.

Metallurgists make aluminum alloys by dissolving a small amount of one or more metals—say 1% of copper by weight—into a larger body of aluminum. Once the addition is completely dissolved, the mixture is quenched, that is, cooled quickly so that it stays evenly mixed. Then the mix is slowly reheated just enough that tiny particles of Al_2Cu precipitate out.

These particles are shaped like tiny needles or plates. Just a few tens of nanometers long, they give aluminum alloys their strength and stiffness. Material scientists knew the particles did this, but until now they didn't know exactly how.

A team of researchers from Arizona State University used the APS to find out. They took a sample of aluminum copper alloy and heated it slowly to allow the copper to precipitate into nanoparticles of Al_2Cu. The researchers, with colleagues from the APS, then milled pillars, using a focused ion beam, down to about 50 µm at the tip, and imaged these at beamline 32-ID-C at the APS. The researchers used transmission x-ray microscopy to perform absorption full-field hard x-ray nano-computed tomography (Fig. 1).

Once they had imaged the starting structure of the alloy, the team carefully applied pressure to the wire with a diamond tip until the wire indented.

When they examined the deformation, the researchers found something intriguing: the larger nanoparticles, thicker than ~80 nm, tended to buckle and kink when stressed. This buckling gave the alloy ductility as it allowed energy to dissipate. Meanwhile, the smaller nanoparticles of Al_2Cu were what gave the material strength by serving as obstacles for slip in the material. Without these obstacles, stressing the aluminum caused the metal to separate into regions that slide against each other, eventually shearing apart. But the small, needle-like nanoparticles blocked those movements and prevented the shearing.

Typically, materials that are strong are also brittle, while ductile materials tend to be soft. It was thought that ductility and strength were mutually exclusive, but the results of this study suggest that aluminum alloys might be able to have both strength and ductility—if the distribution of small and large nanoparticles can be tuned just right. With clever metallurgy, we might be able to have aluminum alloys that are both super strong and ductile, the researchers suggest. — Kim Krieger

See: C. Shashank Kaira[1], Tyler J. Stannard[1], Vincent De Andrade[2], Francesco De Carlo[2], and Nikhilesh Chawla[1*], "Exploring novel deformation mechanisms in aluminum-copper alloys using in situ 4D nanomechanical testing," Acta Mater. **176**, 242 (2019). DOI: 10.1016/j.actamat.2019.07.016
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