

Multi-scale Imaging of Al-7at.%Cu Eutectics using Micro- and Nano-scale X-ray Computed Tomography

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Multi-scale X-ray computed tomography has the ability in the laboratory to answer a variety of questions related to the structure of materials, as well as the resultant differentiation of materials during solidification. Laboratory based 'micro-scale' systems (i.e., imaging with fields of view from 1 to 10's of mm) can produce 3D, non-destructive images with ~1- μm resolution. This scale is useful for meso-scale structure and metallic primary solidification dendritic structures and can be used to examine structural morphology and changes in morphology as a result processing both quantitatively and non-destructively and in three dimensions [1-3]. 'Nano-scale' CT has the ability to measure ~100 μm field of view down to ~10's of μm field of view, with resolution of ~50 nm. These systems can be used to measure micro-scale features and solidification eutectics.

Aluminum-copper eutectics are ideal systems for the study of solidification due to their high X-ray contrast and well differentiated structures; an added bonus is that the resultant microstructure has features on two length scales. A typical 'micro-scale' CT is shown in Figure 1, highlighting the separation of the Al and Cu-containing regions. The primary dendritic structure, with ligaments 20-100 μm in thickness, lends itself very well to 'micro-scale' CT. Within the Cu-containing regions, eutectic structures with ~2 μm thick lamella are present and are ideal for imaging with 'nano-scale' CT. Three 100 μm thick foils of an Al-7at.%Cu alloy were melted and cooled in a boron nitride crucible at various cooling rates. The cooling rates were 0.44, 0.67, and 1.33 $^{\circ}\text{C}/\text{s}$, in order to develop distinct microstructures. Micro-scale CT was used to 'pre-screen' samples and locate areas of interest, as well as aid in determining the 'global' structure of the material. Figure 2 shows a series of radiographs of a foil, imaged using micro-CT and stitching a series of radiographs together (Figure 2a). A ~60 μm diameter post was then machined and is shown relative to the original radiograph. Finally, the samples were then radiographed using a nano-scale CT (Figure 2c).

Results indicate that there are differences in the secondary dendritic arm spacing's seen in the radiographs of the three foils at the 'micro-scale'. Reconstructed slices (Figure 3(left)) show the ~1- μm lamella present in the Cu-containing eutectic. Overlaying the images from the two length scales (Figure 3(middle)) and finally measuring the lamella thicknesses (Figure 3 (right)) gives an indication of the effect of cooling rate upon solidification. The thickness of the lamella decreases linearly with an increasing cooling rate[4].

References:

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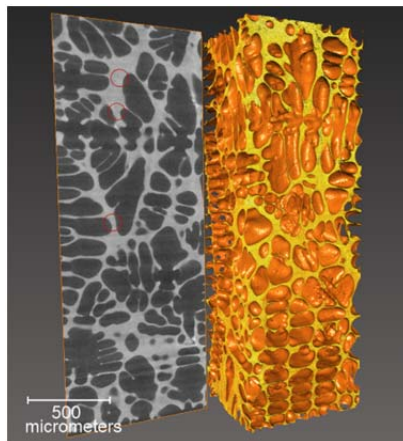


Figure 1: Micro-scale X-ray CT of an Al-7at.%Cu sample. The Cu-containing region is lighter in the reconstructed slice and rendered in 3D on the right. Eutectic structure is beginning to be resolved and a couple of features are seen in this 1.21 μm isotropic voxel sized image (red circles).

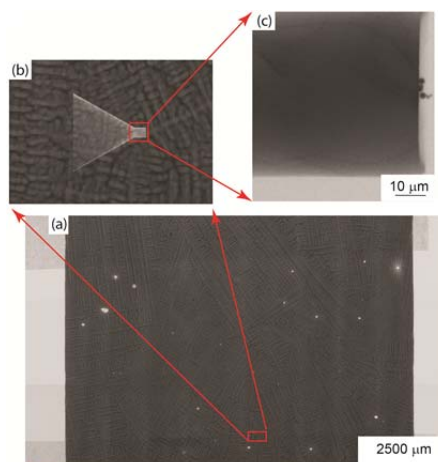


Figure 2: Successively higher resolution radiographs of a thin film of Al-7at.%Cu. (a) has voxel size of 2.48 μm . (b) is an overlay of the radiography with the piece after it has been machined into a 60 μm post. (c) shows the same post radiographed with a 'nano-scale' tomography instrument.

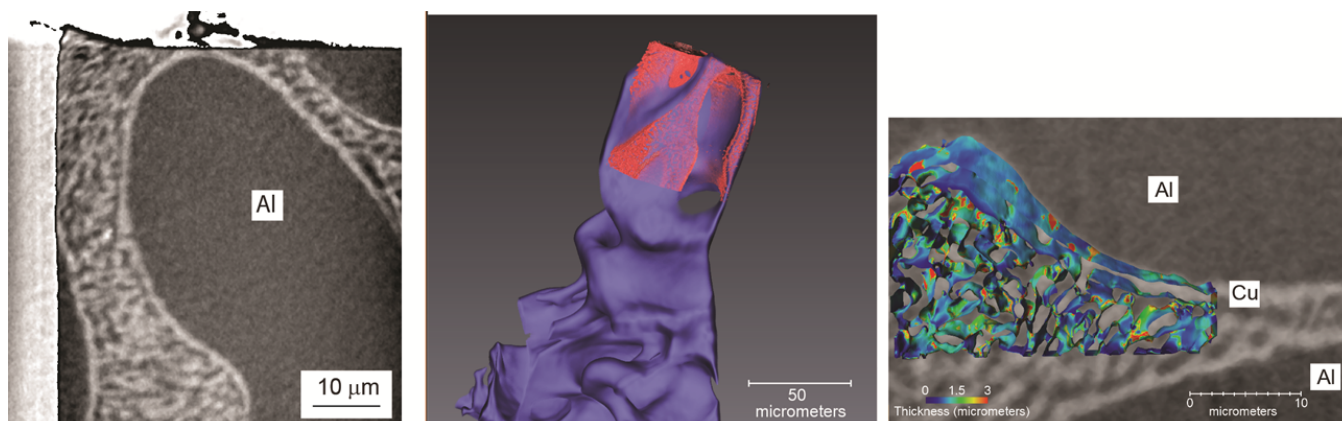


Figure 3: Reconstructed slice (left), overlay of the 'nano-scale' (65- μm voxel) and the 'micro-scale' image of the Al-7at.%Cu eutectic (middle), and a measurement of the eutectic lamella thickness (right).