

Materials in Space: The CSLM-2 Project

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In any mixture that contains particles of different sizes, the large particles tend to grow while the smaller particles shrink. This process is known as coarsening, and is caused by the system's desire to decrease the amount of interfacial area and corresponding free energy. Coarsening is a widespread phenomenon, occurring in nearly all two phase materials, including metals, plastics and ceramics, as well as everyday examples such as the formation of raindrops in clouds and the coalescence of oil drops after shaking a bottle of salad dressing. It is important from an industrial standpoint since most metals used in industry are alloys whose mechanical properties and aging characteristics are controlled by coarsening. Turbine blades in jet engines, for example, must be replaced after a certain number of hours in use because coarsening during high-temperature use causes the blades to become structurally unsound. Precise control of coarsening is also necessary to achieve the correct hardness for dental fillings.

For reasons such as these, it is important to have accurate models of the coarsening process. Coarsening is driven by the change in concentration due to curved interfaces, so that atoms diffuse from regions of high curvature (small particles) to regions of low curvature (large particles). In this way, the system can decrease the amount of surface energy associated with the particles without the total volume of particles changing. However, it is difficult to study just the process of diffusion because there are a number of other factors which influence most coarsening experiments. First, gravity will cause the particles to either float or sink, depending on the relative densities of the two phases (see Figure 1). In the presence of even very small temperature gradients, gravity also induces convection currents which interfere with the movement of atoms due to coarsening.

To avoid issues of sedimentation and convection, Peter Voorhees, now a professor at Northwestern University, conceived the idea of coarsening samples in space, which would produce data that, for the first time, could be compared directly to theory. His association with NASA began in 1986 and has now evolved to the running of his experiments in the micro-gravity environment of the International Space Station. While coarsening can occur in solid-solid and liquid-liquid mixtures, CSLM-2 is the study of Coarsening in Solid-Liquid Mixtures. More specifically, we use lead-tin alloys, coarsening solid tin particles in a lead-tin liquid alloy.

CSLM-2 is a continuation of the original CSLM project that flew on the space shuttle in 1997. Using new furnaces that permit longer coarsening times, the first batch of samples went up to the space station in 2002. Before they were scheduled to return, the Columbia crashed, stranding the samples on the space station for more than two and a half years. When they were finally returned to our lab for analysis in early 2006, we were surprised and delighted to find that the samples were still suitable for analysis despite the extended storage. Based on this success, plans were made to fly a second set of samples.

Twenty new samples were created in our lab by casting four hypereutectic lead-tin ingots and using a combination of machining and cold working to create small

cylindrical samples with a specific microstructure. The samples were sent to our partners at Glenn Research Center in Cleveland where NASA technicians loaded them into five specially designed isothermal furnaces. Now on the space station, the samples will be heated to just above the eutectic temperature so that spherical particles of primary tin are left floating in eutectic liquid. The samples are held at this temperature for a specified time before being quenched with water. After the samples are returned to our lab, they will be analyzed using 2D techniques and 3D reconstruction of the microstructure (see Figure 2) to see how the size distribution of spheres changes with coarsening time and alloy composition. We hope that these studies of the fundamental science of coarsening will help to advance the future of materials design.

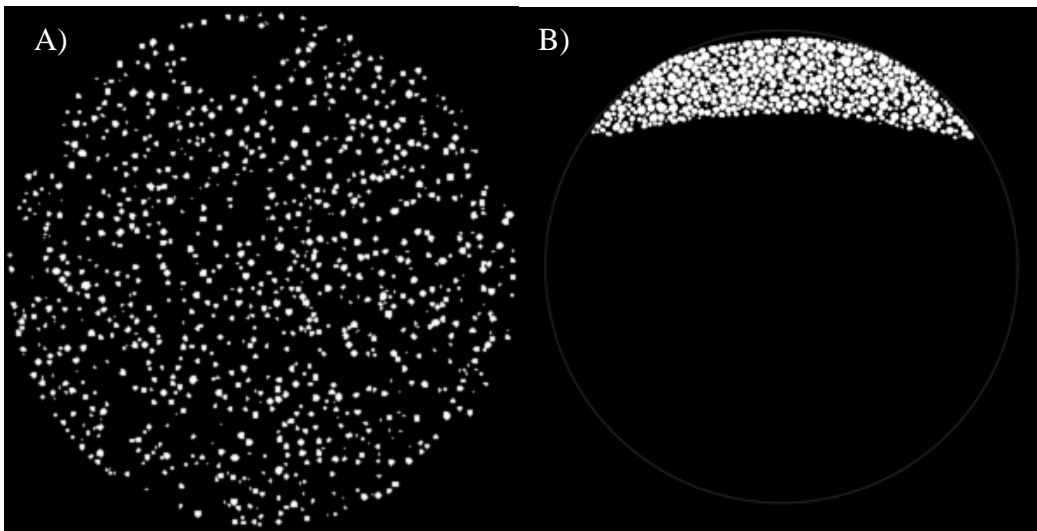


Figure 1: Cross-section of a lead-tin sample coarsened for ten minutes (a) in space and (b) on the ground, showing the effects of sedimentation due to gravity.

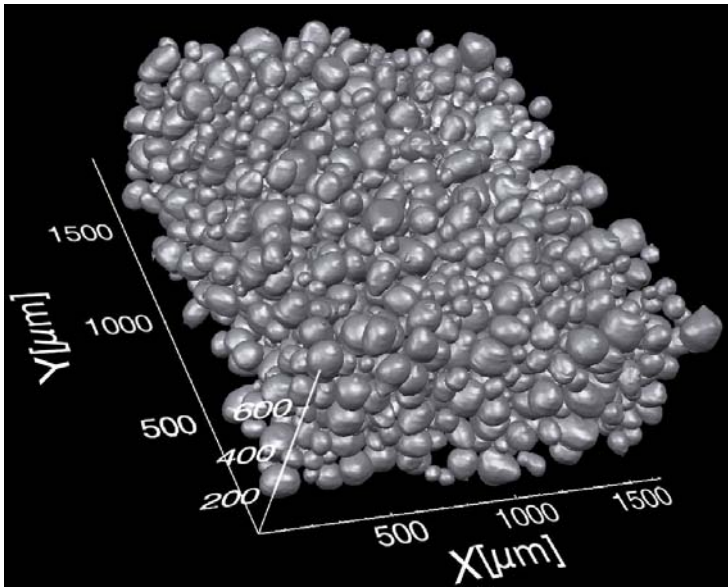


Figure 2: 3D reconstruction of tin particles coarsened in microgravity.