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# Three Dimensional Analysis of High Volume Fraction Coarsened Dendritic Microstructures

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Dendritic microstructures are very often present after the solidification of cast alloys. This makes their study of technological importance, since many properties of the cast materials are related to the dendritic structure. A coarsening or Ostwald ripening process is what determines the dendritic morphology. During the coarsening process, the mushy zone, namely a two-phased region consisting of the dendritic (solid) phase and the matrix (liquid) phase, evolves over time.

The driving force for coarsening is the variation of the mean interfacial curvature $H$ with position. These variations lead to diffusional fluxes of solute from regions of high mean interfacial curvature to regions of low mean interfacial curvature. The mean interfacial curvature is a three-dimensional morphological property though, making it necessary to study the microstructures in three dimensions, in order to quantitatively analyze them and understand coarsening.

Using a recently developed serial sectioning technique [1], the samples were serial-sectioned and a digital picture was taken for each section. The pictures were then converted into binary images and with the appropriate algorithms they were stacked and aligned, allowing for the reconstruction of the microstructure in three dimensions. In order to obtain the dendritic samples, a Pb-Sn ingot was produced by casting the materials. The cast ingot was then swaged and directionally solidified in a Bridgman furnace to produce a uniform dendritic microstructure. Samples were cut from the directionally solidified rod and then coarsened at $185^0$C in a coarsening furnace for various times. The samples consist of a volume fraction of solid (Sn dendrites) of 80%.

The three-dimensional reconstructions of a 3 minute and a 2 day coarsened sample are shown in Fig. 1. The liquid is shown, while the solid phase is transparent. The microstructure has coarsened over time, accompanied by a significant increase of the length scale of the system. Also, the structure starts off as highly complex and interconnected and evolves with time to one that is mainly characterized by liquid walls and liquid cylinders or cylindrical-like shapes.

In order to quantitatively characterize these dendritic microstructures, we measure the mean and Gaussian curvature and then calculate the probability of finding an interface with a certain pair of principal curvatures, $\kappa_1$ and $\kappa_2$. Such a probability function is the interfacial shape distribution (ISD). A map of the various regions and the corresponding interfacial shapes [2], shown here in Fig.2, helps in the interpretation of the ISDs.

The ISDs of the 3 minute coarsened sample and the 2 day coarsened sample are shown in Fig. 2. Each plot is scaled by the corresponding inverse surface area per unit volume ($S_v^{-1}$) that serves as the length scale of our system. Also, it should be noted that the range of probabilities represented by the color bar is independent of coarsening time. As one would expect by looking at the three-dimensional reconstructions, a dramatic difference between the two ISDs is observed, in terms of curvature distribution. The ISD of the 3 minute coarsened sample is characterized by a very broad probability distribution. The peak is primarily situated in the saddle shaped region but also touches the solid-cylinder line, crossing into the convex shape region, thus further indicating the complexity of the microstructure. The ISD of the 2 day coarsened sample is characterized by the formation of a secondary peak, situated on the liquid cylinder line. This peak is associated with the liquid tubes that are present at this structure. The primary peak has shifted towards lower curvatures and is now solely situated in the saddle shaped region, as a result of the liquid walls that dominate this structure. Another interesting observation is that the existence of the secondary peak makes the primary peak shorter, compared to the primary peak of the ISD of the 3 minute coarsened sample.

References

[1] J. Alkemper and P.W. Voorhees, Journal of Microscopy, 201:388-394 (2001).
[2] R. Mendoza, J. Alkemper and P.W. Voorhees, Metallurgical and Materials Transactions A, 27A:481-489 (2003).

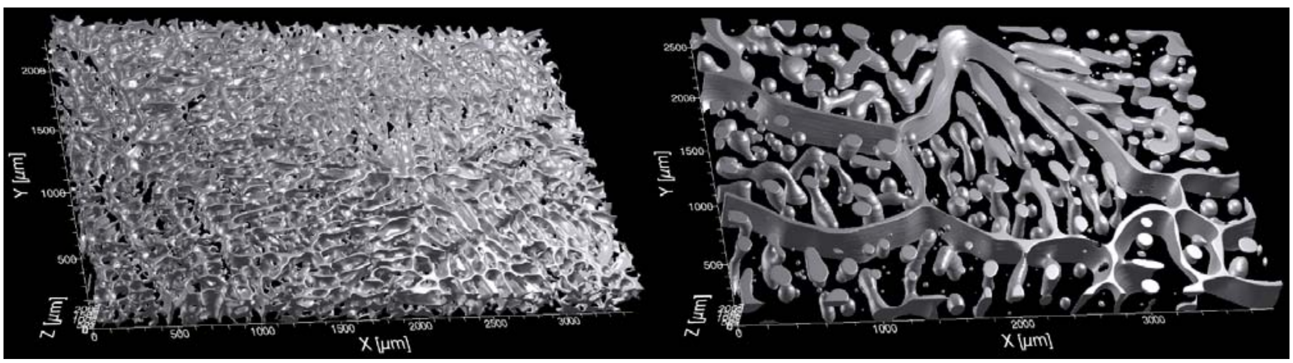

Fig.1. Three dimensional reconstruction of the coarsened samples, with the liquid shown and the solid phase transparent: 3 minutes (left), 2 days (right).

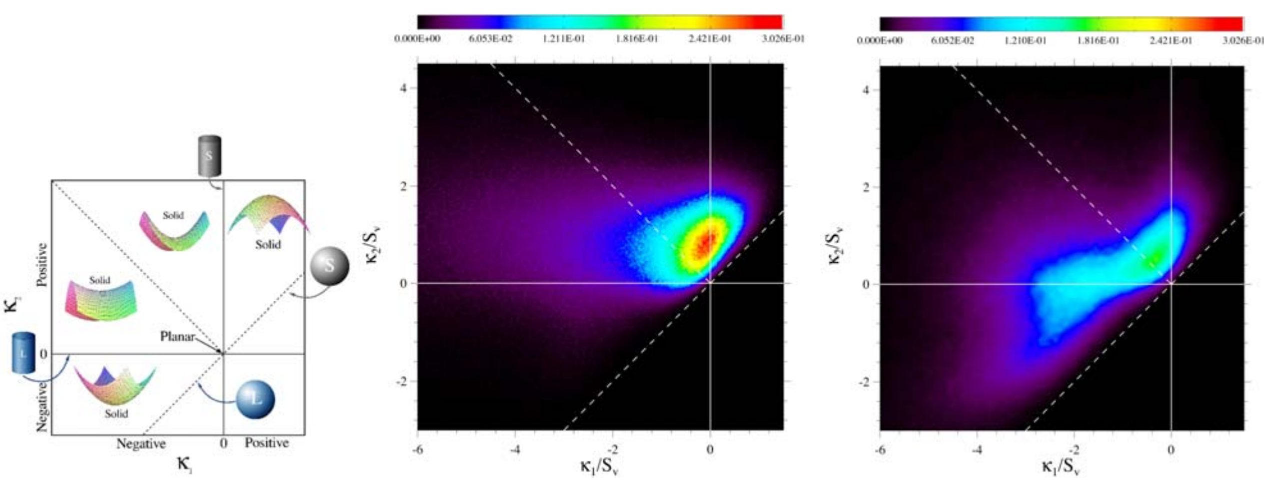

Fig.2. Map of the local interfacial shapes for the interfacial shape distribution contour plots (left). Interfacial shape distributions of the coarsened samples: 3 minutes (middle), 2 days (right).

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