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Dendrite Morphology of Pb-5.8 Sb Alloy: Gradient Freeze DS with Cross-Section Area Change

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Introduction:

Directional solidification (DS) is the process of solidifying a metal alloy from one end to another resulting in aligned primary dendrites which are branched tree like features. Alignment of primary dendrites along [100] direction and their uniformity and distribution along the DS length determines the mechanical property. These are especially important for single crystal turbine blade applications in modern gas turbine engines. Convection during solidification plays an important role in formation of detrimental defects such as misaligned grains, non-uniformity of dendrites and composition inhomogeneity. The purpose of this study was to examine the microstructural evolution during "Gradient Freeze DS process", and effect of cross-section change during DS. Pb-5.8 wt.% Sb alloy was chosen as a model alloy for this study because of its ease of processing and availability of all physical property data to compare with predicted solidification behavior and morphology. This research is a ground-based research in support of a potential Space Station research involving convection free DS in zero "g".

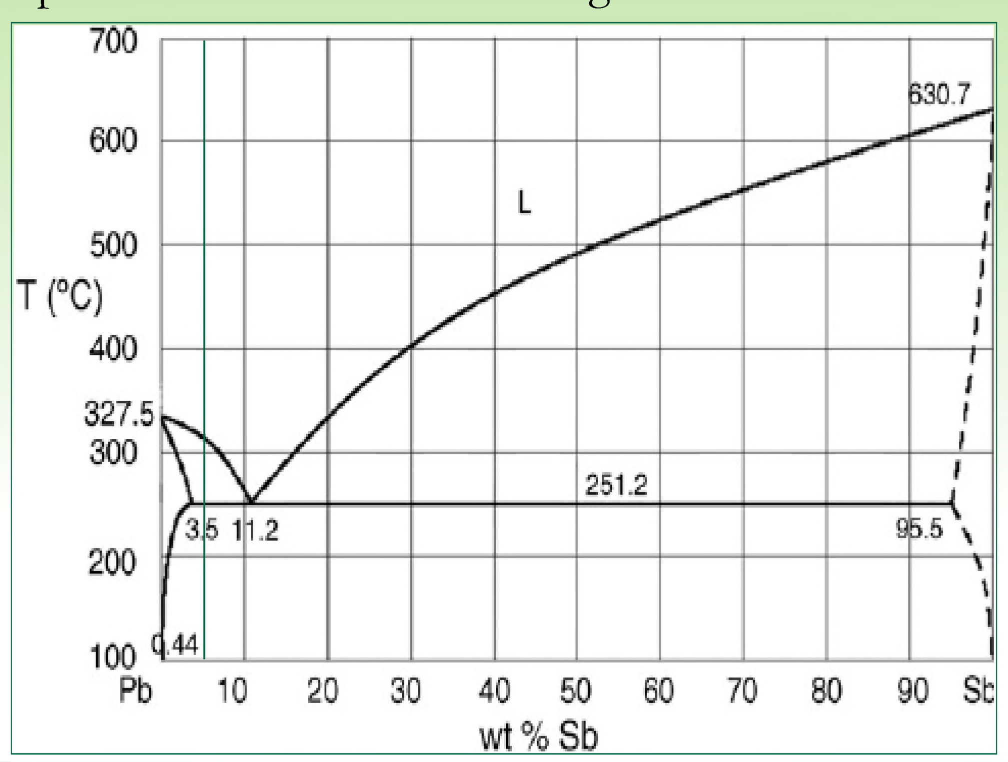

Figure 1: Lead-Antimony Phase Diagram

Equipment-Procedure:

The Gradient Freeze DS set-up especially fabricated for this research consists of a two-zone resistance heated furnace at the top and a water cooled gallium bath at the bottom separated by a hollow insulating disk. The cylindrical quartz crucible containing the alloy is heated from above and solidified by cooling the furnace at controlled cooling rates. The liquid-solid interface thus moves from the bottom towards the top of the sample in a directional manner. In this study two crucibles were used, both involving a sample cross-section decrease during DS. The furnace hot-zone temperature was decreased from 650˚C at 0.5 and 4˚C/min, respectively, for the two samples to examine the role of solidification speed. Temperatures along the DS length were recorded by ten chromel-alumel thermocouples attached to the ampoule wall along its length.

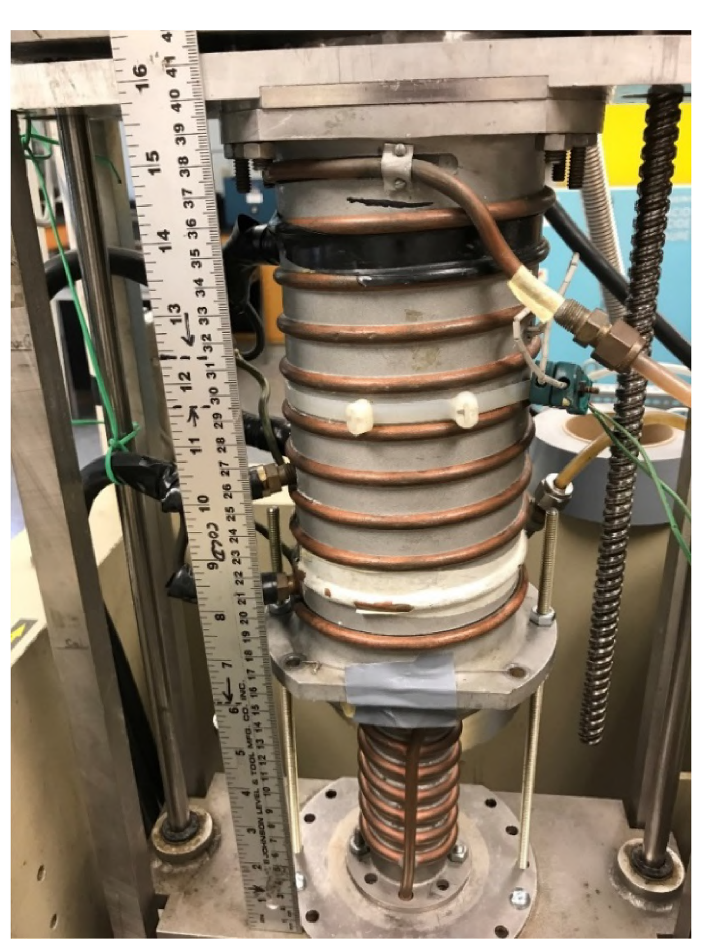

Figure 2: Gradient Freeze directional solidification apparatus used in our experiments

Observations:

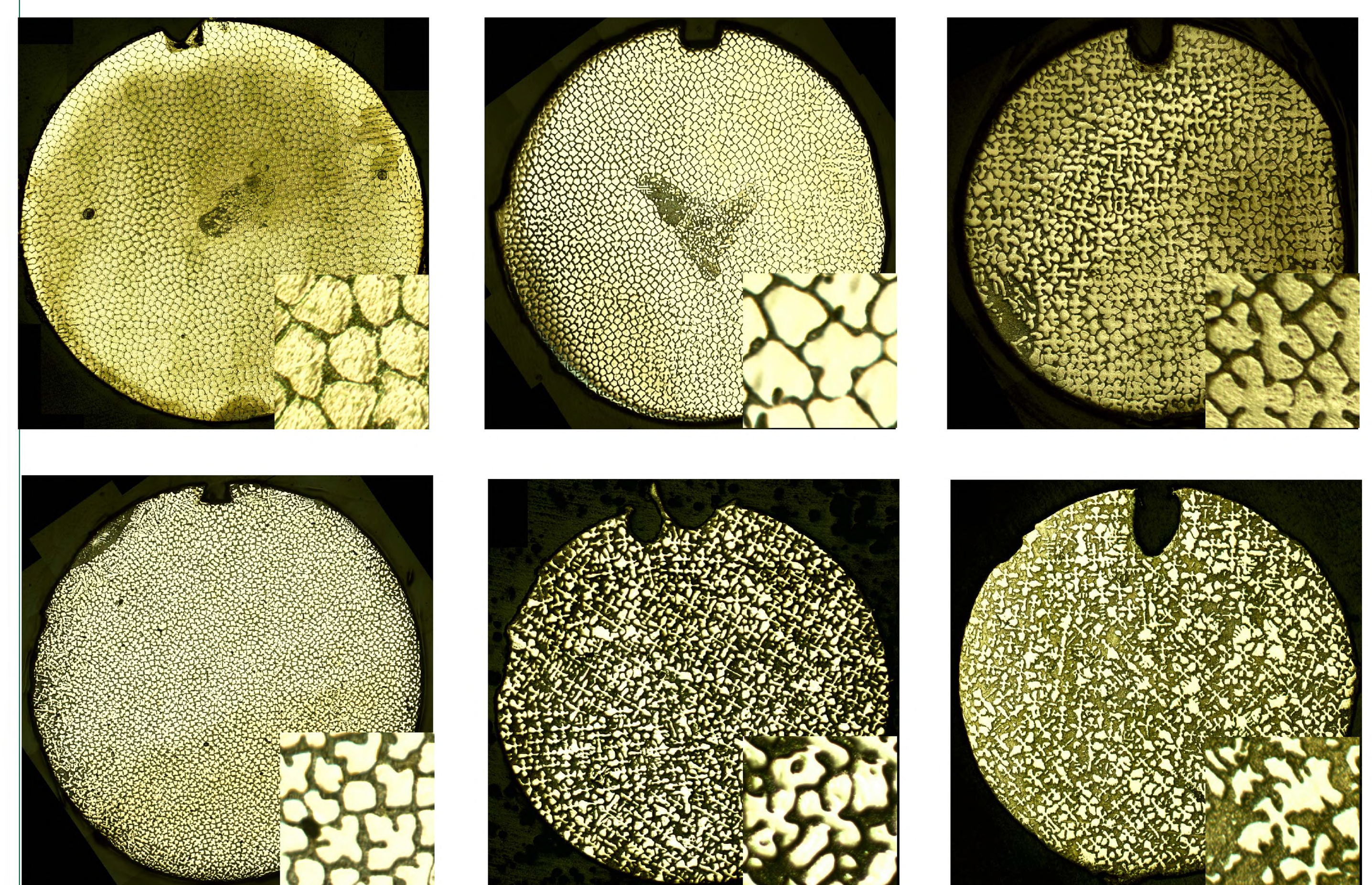

Figure 3: Top row shows (left to right) 3, 5, and 6.5 cm from the start of DS (Slower Cooling rate). Bottom row shows (left to right) 1, 6, and 8.5 cm from the start of DS (Faster Cooling rate). Insets are high magnification views of dendrite morphology

- "Freckles" caused by "severe plume-type" convection seen in the slower cooling rate sample. The faster cooling rate sample does not show these "freckles".
- Dendrite changes from cellular, to onset of side-branching, to well-branched morphology as solidification progresses from cold to the warm end of samples.

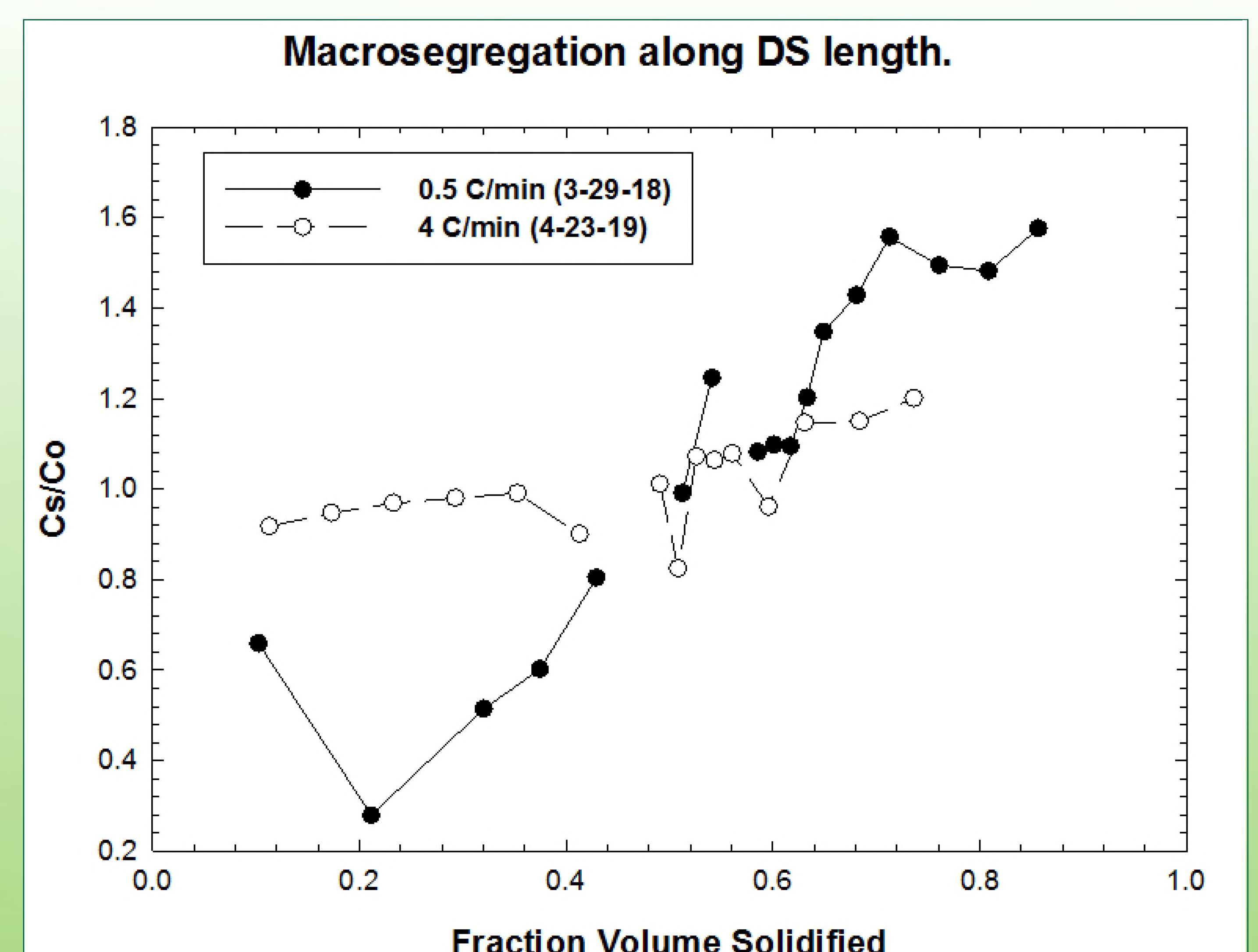

Figure 4: Ratio of local solute concentration (Cs) to the original solute content (Co) is plotted as a function of volume fraction of liquid solidified. Breaks correspond to the distance when cross-section decrease occurred.

- Fraction eutectic in the microstructure increases. This indicates positive Sb segregation along DS length (Figure 4). The macrosegregation is more severe in the slower cooled sample because of "plume" type of thermosolutal convection.
- There is solute buildup just before the section decrease and abrupt decrease after the section change. This is more clearly evident in the faster cooled sample.

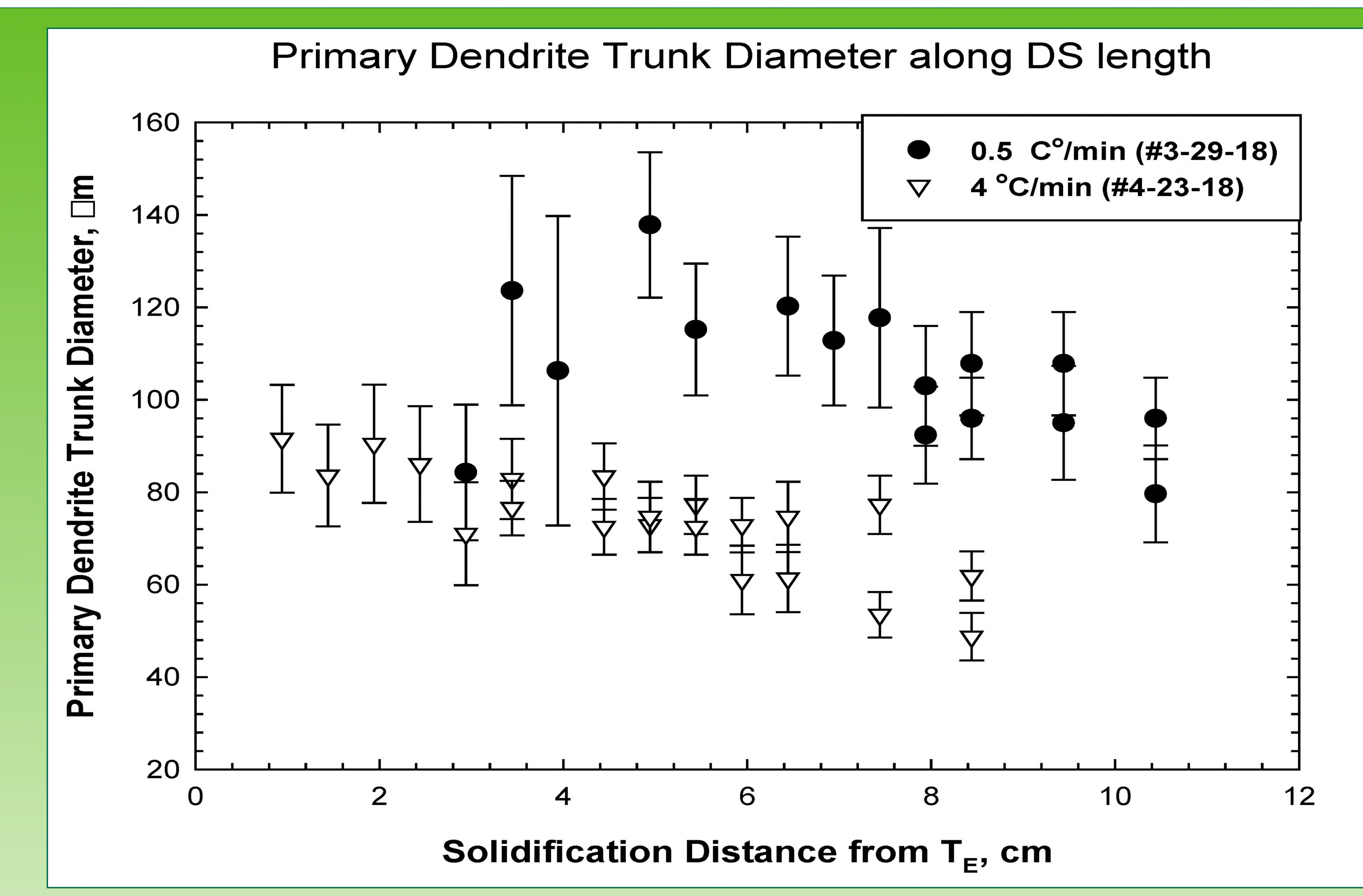

Figure 5: Primary dendrite trunk diameter as a function of solidification distance (cm)

- Primary dendrite trunk diameter decreases with solidification distance.
- Dendrites are coarser (larger trunk diameters) in slower-cooled sample.

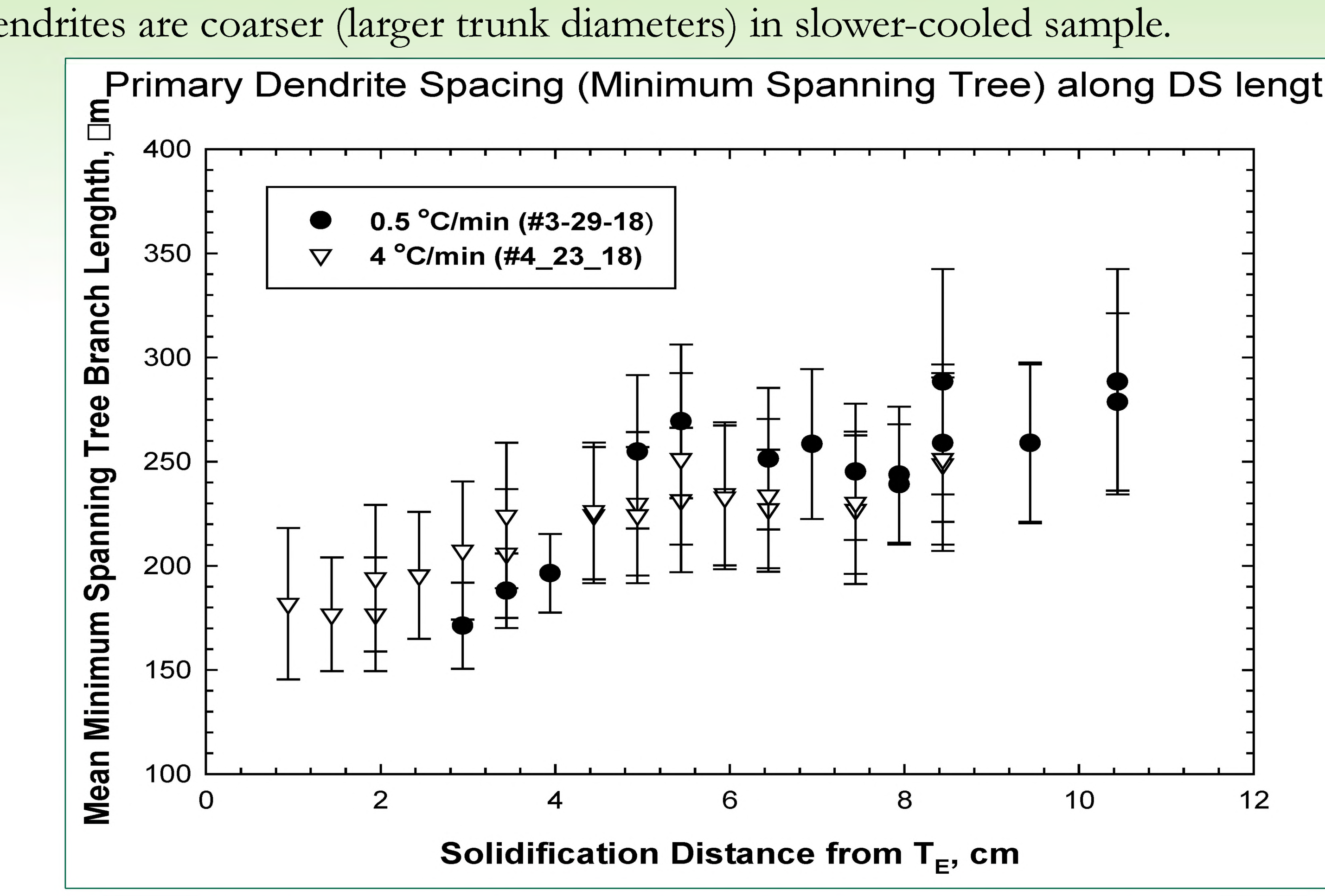

Figure 6: Average nearest neighbor spacing as a function of solidification distance (cm)

- Primary dendrite spacing (mean minimum spanning tree branch length) increases with solidification distance.
- The well-branched dendrites have larger spacing in the slower cooled sample.

Conclusions:

- Dendrite morphology transitions from cellular, to onset of side-branching, to well-branched with increasing solidification distance. Transitions occur earlier in the faster cooled sample.
- "Freckles" caused by "plume-type" convection are seen in the slower cooled sample and not in the faster cooled sample.
- Antimony content increases with solidification distance. The macrosegregation is more severe in the slower cooled sample.
- There is a solute build-up just before the cross-section decrease and a solute depletion just after the section change.

Acknowledgements:

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References:

1. C. Lacdao, Influence Of Cross-Section Change During Directional Solidification On Dendrite Morphology, Macrosegregation And Defect Formation In Pb-6 wt. Sb Alloy, Cleveland State University, 2017.