Evaluation of Primary Dendrite Arm Spacings from Aluminum-7wt% Silicon alloys Directionally Solidified aboard the International Space Station – Comparison with Theory

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MICAST
A NASA and European Space Agency (ESA) Collaboration:

*Microstructure Formation in Castings of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions*

- A systematic analysis of the effect of convection on the microstructural evolution in the directional solidification (DS) of engineering alloys.

- Experiments are carried out under well defined processing conditions.

- Sample analysis conducted using advanced diagnostics and theoretical modeling.
Previous Investigation

Al-26.5 wt. % Cu: Primary dendrite arm spacing increases in microgravity

30 K cm\(^{-1}\), 4.2 μm s\(^{-1}\)

25 K cm\(^{-1}\), 4.2 μm s\(^{-1}\)

30 K cm\(^{-1}\), 4.2 μm s\(^{-1}\)

Terrestrial: Solutally unstable

Primary spacing = 450 ± 20 μm

Terrestrial: Solutally stable

Primary spacing = 340 ± 10 μm

Microgravity

Primary spacing = 1540 ± 10 μm

Microgravity Processing

- Rods of Al-7Si cast at Alcoa Technical Center
- DS-ed at CSU to obtain aligned dendritic structure
  - \(<100>\) parallel to axis
- Precision machined and shipped to ESA-contractor
- Inserted into alumina “crucible-molds”
- Put into Sample-Cartridge-Assembly (SCA)
Expectations:
Solidification Processing in a Microgravity Environment

Advantages: Mitigate Thermo-Solutal Convection

Intent: DS Samples under Diffusion-Controlled Conditions that are Free of Macrosegregation

Purpose: Better Understand the Relationship between Processing and Microstructural Development

Application: Benchmark measurements applicable to modeling efforts, improve ground-based processing
Comparison of ISS and Ground-based Experiments

MICAST6 / 6Ground
• DS growth rate increase (5 μm s\(^{-1}\) to 50 μm s\(^{-1}\))
• Temperature gradient: \(\sim 20\) K/cm

MICAST7 / 7Ground
• DS growth rate decrease (20 μm s\(^{-1}\) to 11 μm s\(^{-1}\))
• Temperature gradient: \(\sim 26\) K/cm

(MICAST12, Constant growth rate is currently being evaluated)
Microstructural Comparison: **Earth** and Microgravity

Terrestrial:
Al – 7wt.% Si
$G = 15 \text{ K cm}^{-1}$

$V = 5 \mu\text{m s}^{-1}$  
$V = 50 \mu\text{m s}^{-1}$
MICAST6:
\( \text{Al} - 7\text{wt.\% Si} \)
\( \text{G} = 20 \text{K cm}^{-1} \)

\( V = 5 \text{µm/s} \)

\( V = 50 \text{µm/s} \)

- Based on diffusion in the liquid around the dendrite tip.
- Calculates PDAS assuming no convection in the liquid.
- Physical constants for Al-7Si are well known.
- Final Equation: \[ \lambda' = 0.15596V' \left(a - 0.75\right) \left(V' - G'\right)^{0.75} \left(G'\right)^{-0.6028} \]
- Calculates the spacing as the tip-to-tip spacing.

MICAST6- Primary Dendrite Arm Spacing
MICAST6G - Primary Dendrite Arm Spacing

![Graph showing Nearest Neighbor Spacing](image)
Separation may result in Marangoni convection in the liquid during DS at 60mm mark.
Marangoni Convection Effect - Continued

118.1 mm from the seed

149.4 mm from the seed
MICAST7G- Primary Dendrite Arm Spacing

\[ \lambda (\mu m) \]

mm from seed

Nearest Neighbor Spacing
Conclusions

• The primary dendrite spacing increased in microgravity.
• The “array stability limit” of the Hunt and Lu model successfully predicted dendrite arm spacing.
  → Based on nearest-neighbor spacing measurements.
• Comparison of the results implies that dendrite arm spacings respond quicker to growth rate changes in μg than on the ground
• Separation was observed between the crucible and alloy in the ISS sample.
  → Presumed Marangoni convection disrupts steady-state dendrite growth.
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