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**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Temperature</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrestrial: Solutally unstable</td>
<td>30 K cm^{-1}, 4.2 μm s^{-1}</td>
<td>25 K cm^{-1}, 4.2 μm s^{-1}</td>
</tr>
<tr>
<td>Primary spacing =</td>
<td>450 ± 20 μm</td>
<td>340 ± 10 μm</td>
</tr>
<tr>
<td>Microgravity</td>
<td>30 K cm^{-1}, 4.2 μm s^{-1}</td>
<td>1540 ± 10 μm</td>
</tr>
</tbody>
</table>

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: \(~20\) K/cm

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

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

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

\( V = 5 \mu \text{m s}^{-1} \)  \( V = 50 \mu \text{m s}^{-1} \)
Microstructural Comparison: Earth and Microgravity

MICAST6:
Al – 7wt.% Si
$G = 20 \text{ K cm}^{-1}$

$V = 5 \mu m/s$

$V = 50 \mu m/s$
Theoretical Model (diffusion-controlled growth), 
J.D. Hunt and S.-Z. Lu, 1996

- 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

![Graph showing data points for different methods and spacing measurements from seed.](image-url)
MICAST6G - Primary Dendrite Arm Spacing

![Graph showing primary dendrite arm spacing](image-url)
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

\[ \lambda(\mu m) \]

\[ mm \text{ from seed} \]
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 $\mu g$ 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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