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 \(\mu m\) s\(^{-1}\)  
25 K cm\(^{-1}\), 4.2 \(\mu m\) s\(^{-1}\)  
30 K cm\(^{-1}\), 4.2 \(\mu m\) s\(^{-1}\)

Terrestrial: Solutally unstable
Primary spacing = 450 ± 20 \(\mu m\)

Terrestrial: Solutally stable
340 ± 10 \(\mu m\)

Microgravity
1540 ± 10 \(\mu m\)

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 \( \mu m \ s^{-1} \) to 50 \( \mu m \ s^{-1} \))
• Temperature gradient: \( \sim 20 \) K/cm

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

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

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

$V = 5 \mu\text{m s}^{-1}$

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

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

$V = 5 \mu\text{m/s}$ 
$V = 50 \mu\text{m/s}$
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: $\lambda' = 0.15596 V' (a - 0.75) (V' - G')^{0.75} (G')^{-0.6028}$
- Calculates the spacing as the tip-to-tip spacing.

MICAST6- Primary Dendrite Arm Spacing

The diagram shows a scatter plot with the x-axis labeled as "mm from seed" and the y-axis labeled as "\( \lambda (\mu m) \)". The plot includes data points for the "Area Method", "Hunt and Lu Model", and "Nearest Neighbor Spacing". The data points are represented by different symbols and colors, indicating the variation in dendrite arm spacing at different distances from the seed.
MICAST6G- Primary Dendrite Arm Spacing
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
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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