PURDUE UNIVERSITY
School of Materials Engineering

Bi-containing SnAgCu Alloys: Material property evaluation for advanced semiconductor devices

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Body sizes of high performance semiconductor devices have been increasing to meet performance and functionality demands. Stress and strain caused by mismatches in CTE between circuit boards and these components are exacerbated by these increases. Solder joint fatigue life can worsen because of these increases in stress and strain. New and potentially more creep resistant solder is needed to improve the long term reliability of the product. In this work we report preliminary mechanical testing results of SAC305 + Bi and also findings from a critical review of literature.

This project was funded by Juniper Networks.

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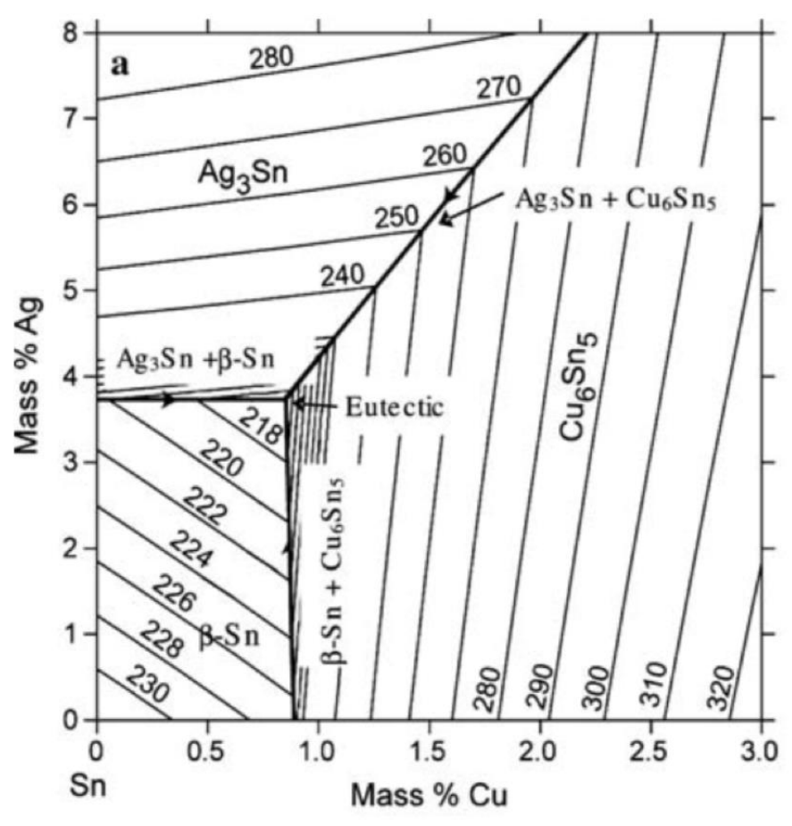
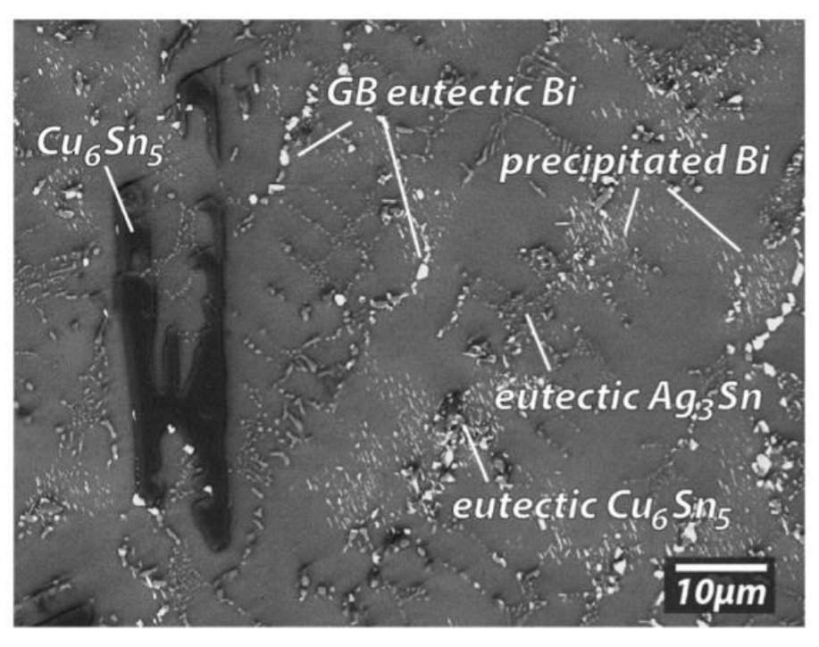
Background

Solidification

- Liquidus projection of SAC phase diagram [1]
- 217°C eutectic temp
- Microconstituents may be predicted from phase diagram



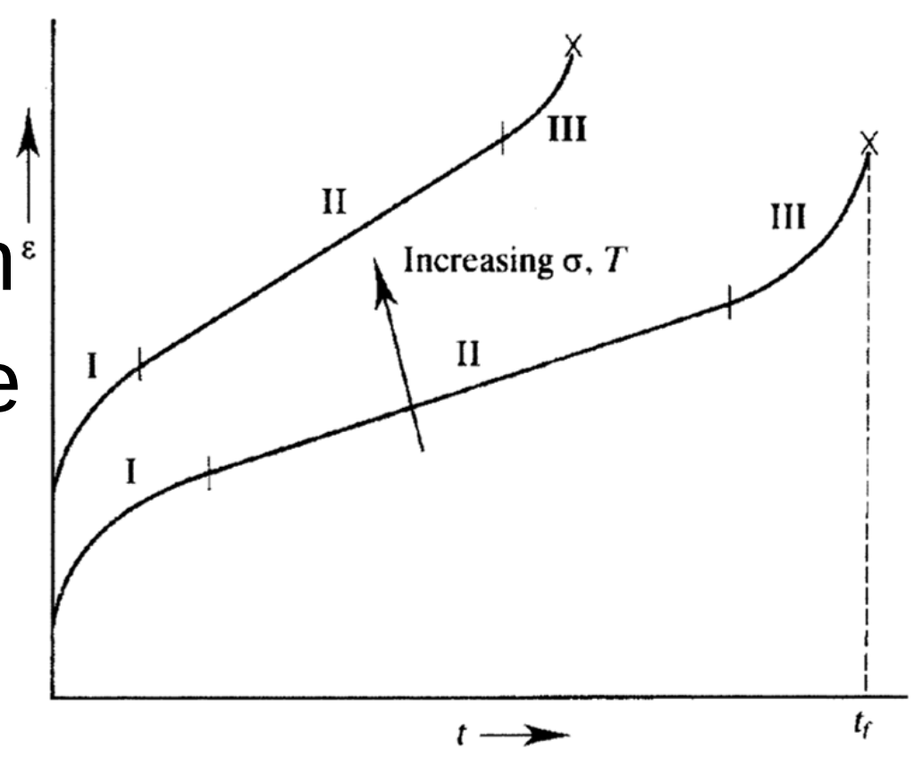
Microstructure



- β-Sn dendrites [2]
- Brittle IMCs form during annealing
  - Cu_6Sn_5
  - Ag_3Sn
- Bi addition strengthens for concentrations up to 2%
  - Reduces IMC formation

Creep in Solder:

- Temperature dependent
- Stress dependent [3]
- Negatively affected by microstructural coarsening (includes IMC growth)
- SAC has higher dislocation activation energy than pure Sn [4]
- Three model equations
  - Hyperbolic sine (a.) [5]
  - Power law (b.) [5]
  - Anand model (c.) [6]



a. $\dot{\gamma} = A\sinh^n(B\tau)\exp\left[\frac{-Q}{RT}\right]$

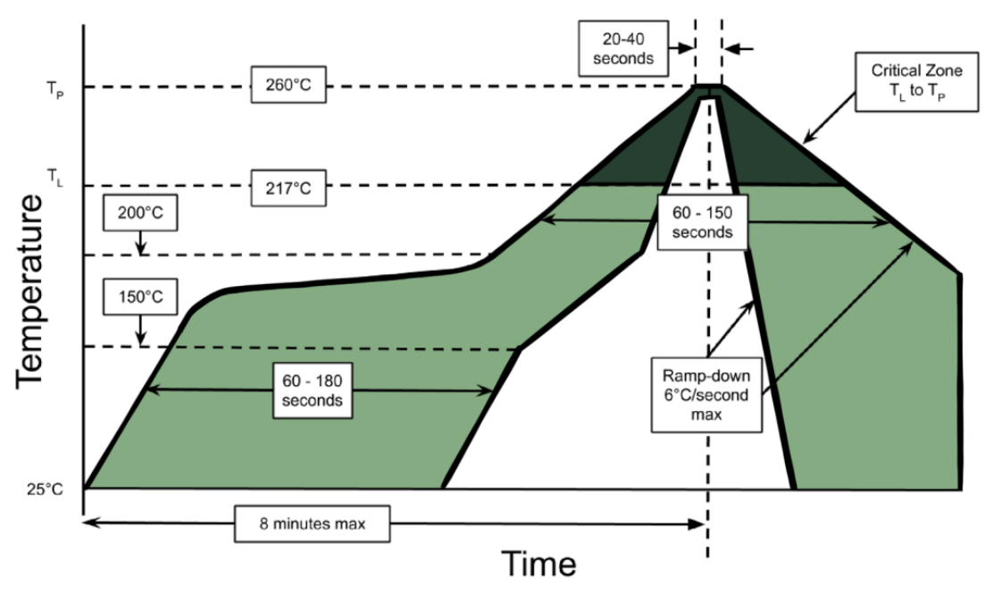
c. $\dot{\epsilon}^p = A\exp\left(\frac{-Q}{k\theta}\right)\left(\frac{\sigma^*}{s}\right)^{\frac{1}{m^*}}$

b. $\dot{\gamma} = A\frac{G}{T}\left(\frac{\tau}{G}\right)^n\exp\left[\frac{-Q}{RT}\right]$

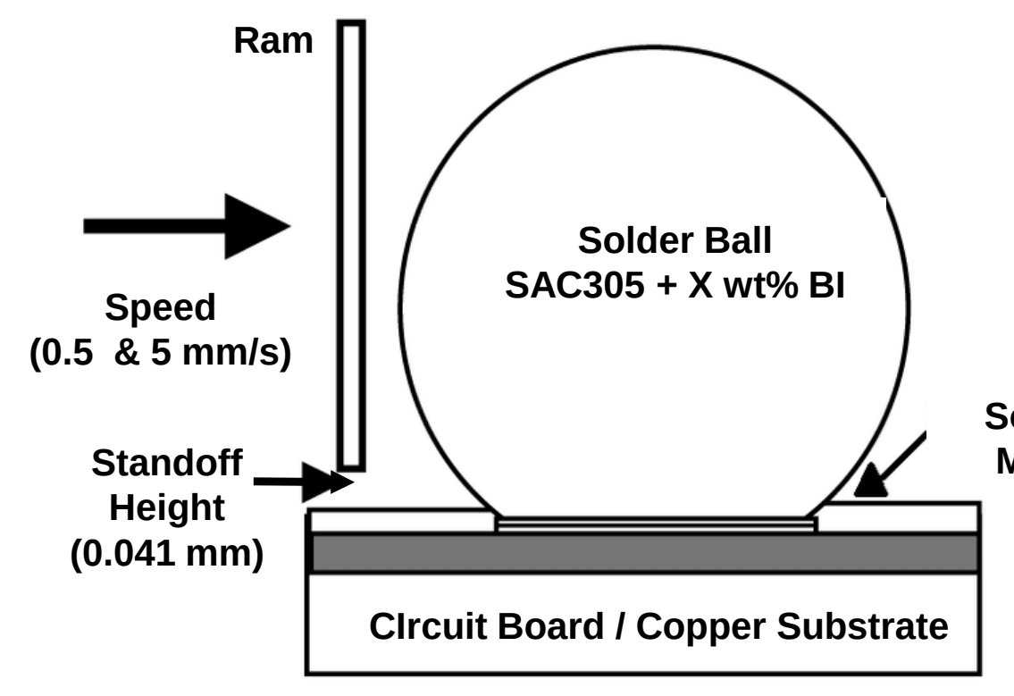
Experimental Procedure

Reflow and PCB Preparation:

- Kester TSF 6522 No-Clean Tacky Flux used
- JEDEC reflow profile standard J-STD-020E



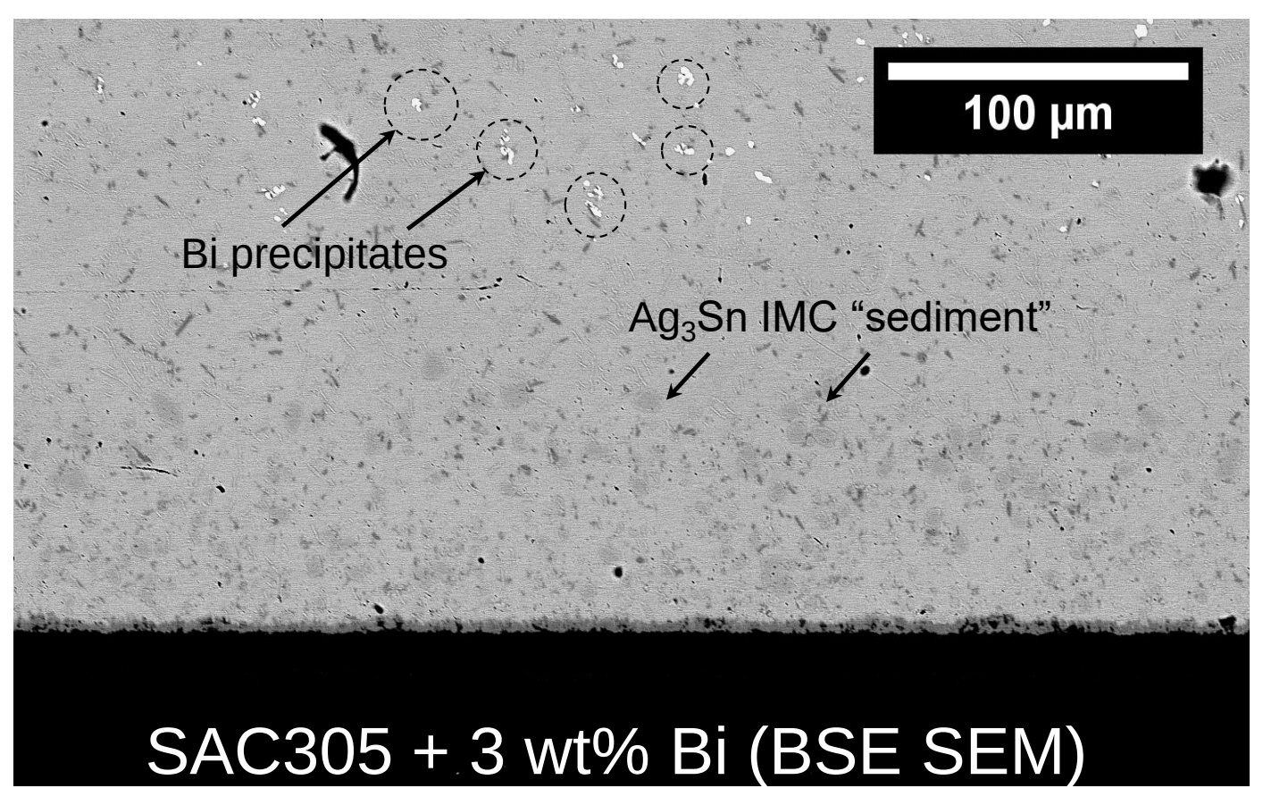
Ball Shear Testing:



- Ball size - 625μm
- Fast shear - 5 mm/s
- Slow shear - 0.5 mm/s
- Load - 25 kg
- Standoff height - 0.041 mm

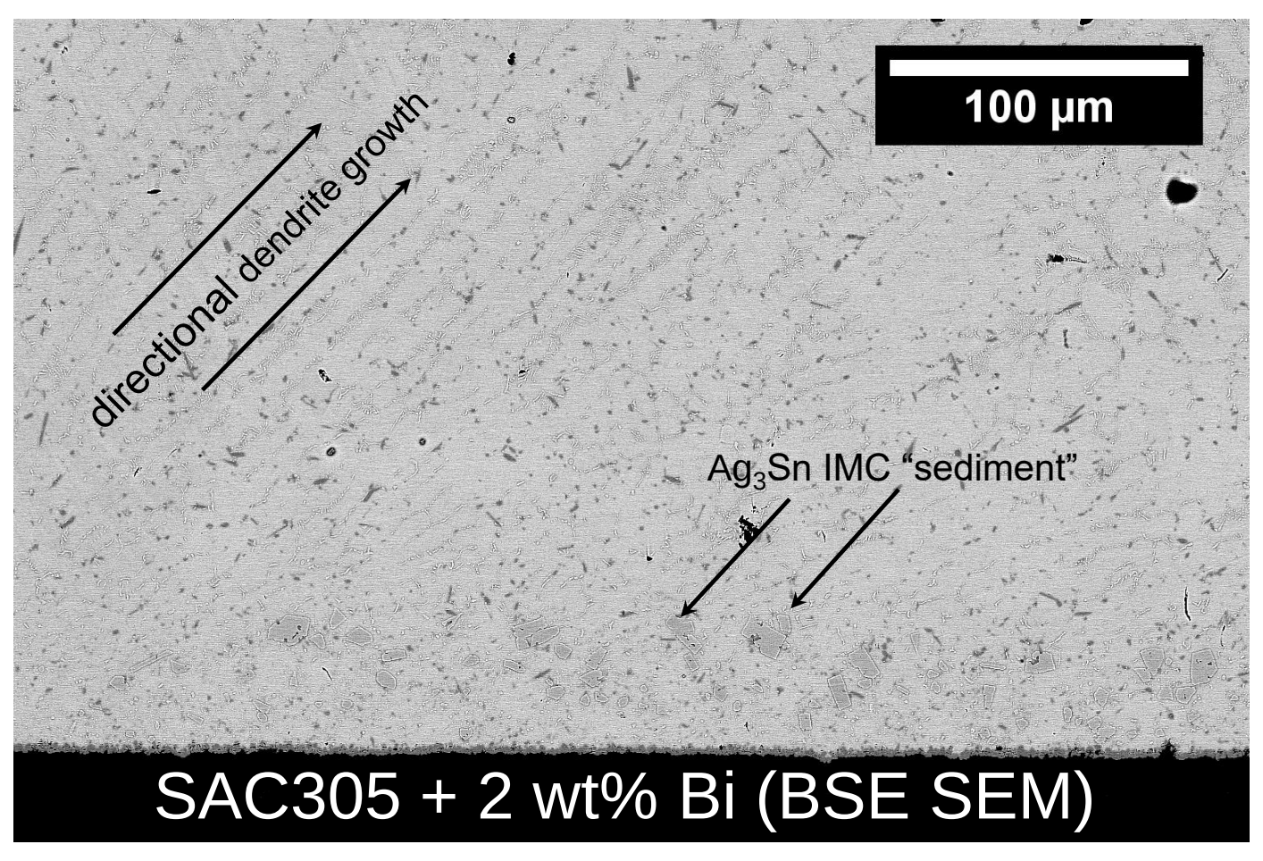
Results

Microstructure



SAC305 + 3 wt% Bi (BSE SEM)

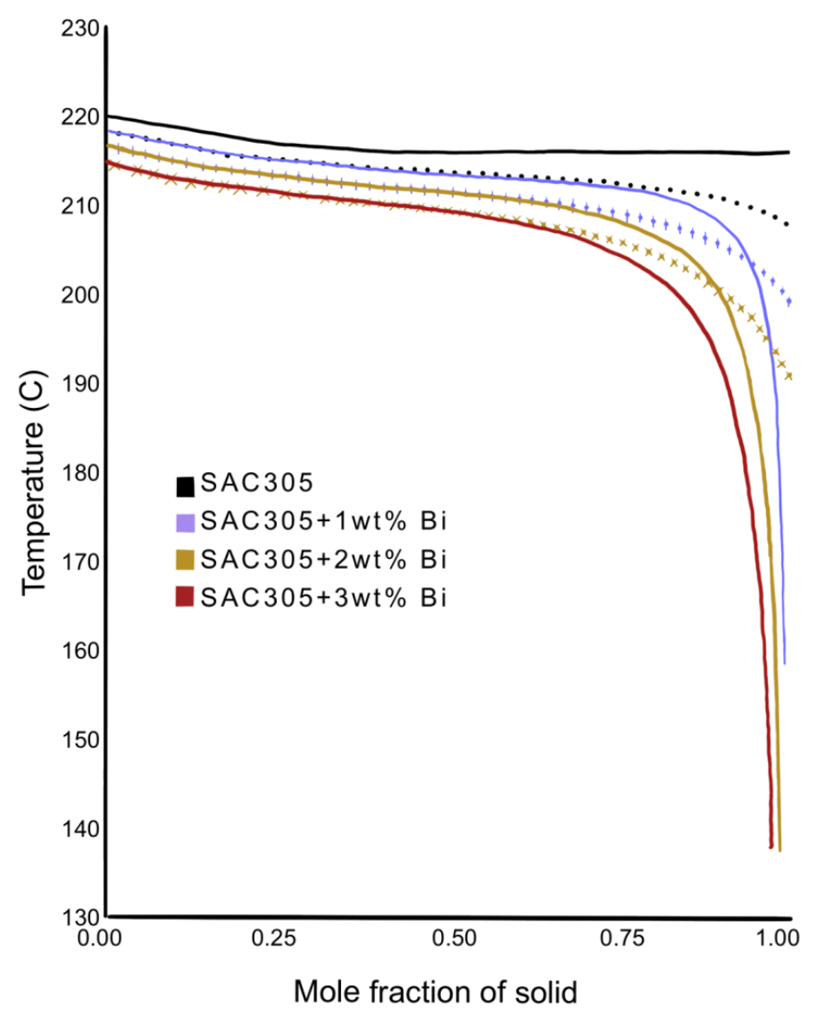
- Bright, Bi precipitates
- IMC sediment - ~0-75 μm above the interface



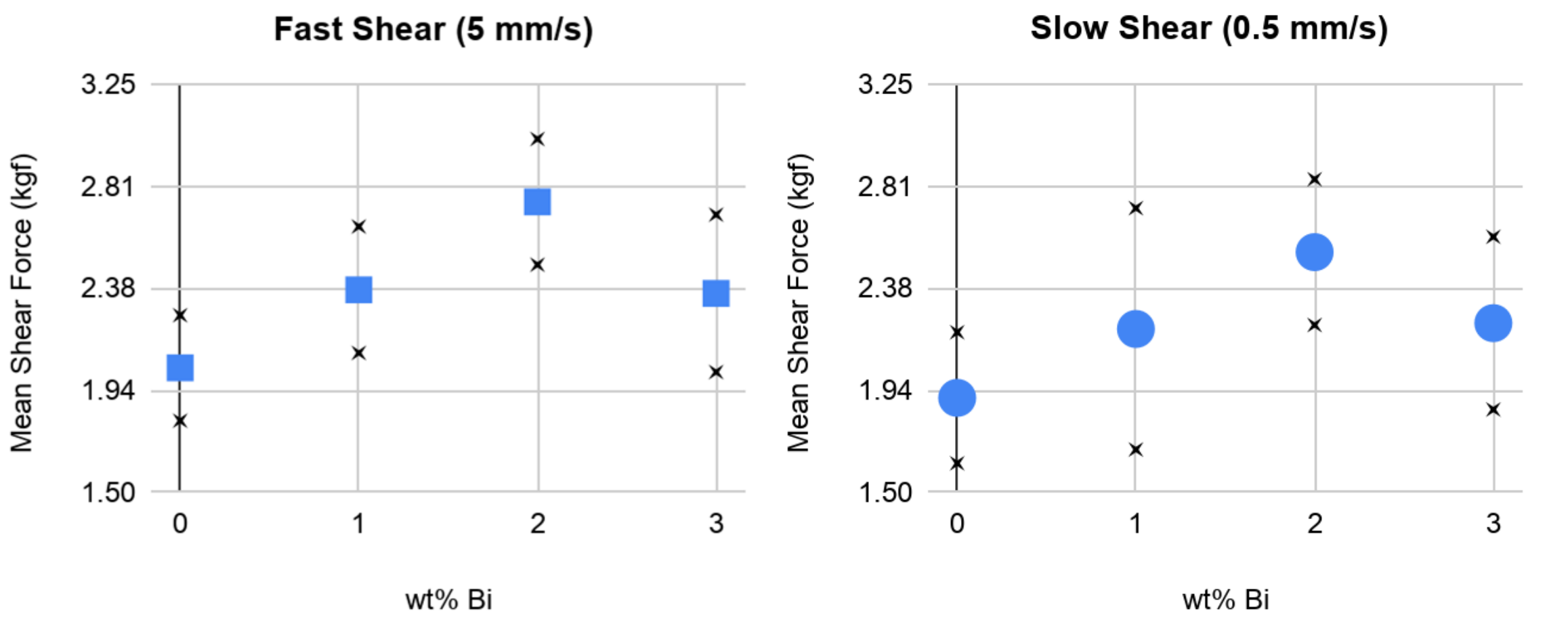
SAC305 + 2 wt% Bi (BSE SEM)

- Directional β-Sn dendrites
- IMC sediment - ~0-50 μm above the interface

- ThermoCalc TCSLD3: Solder Alloy Database v 3.2 [7]
- Scheil (non-equilibrium solidification) paths (solid lines)
  - Can be used to explain microstructures that differ from those predicted from equilibrium phase diagram (dashed lines)

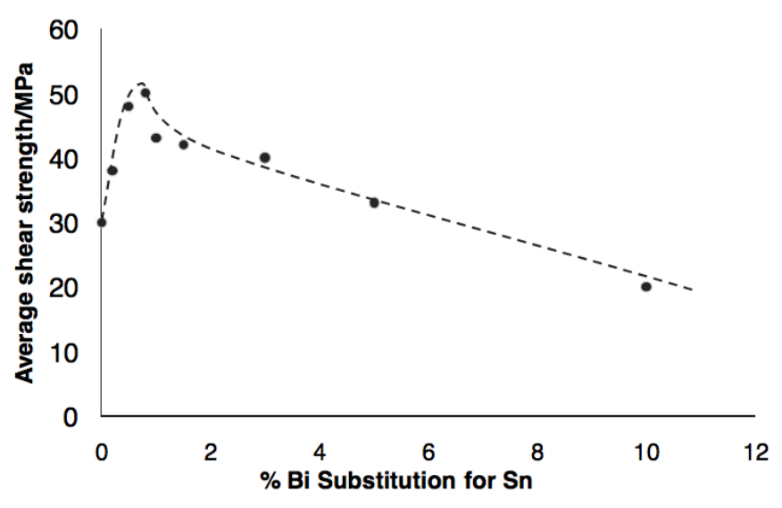


Ball Shear

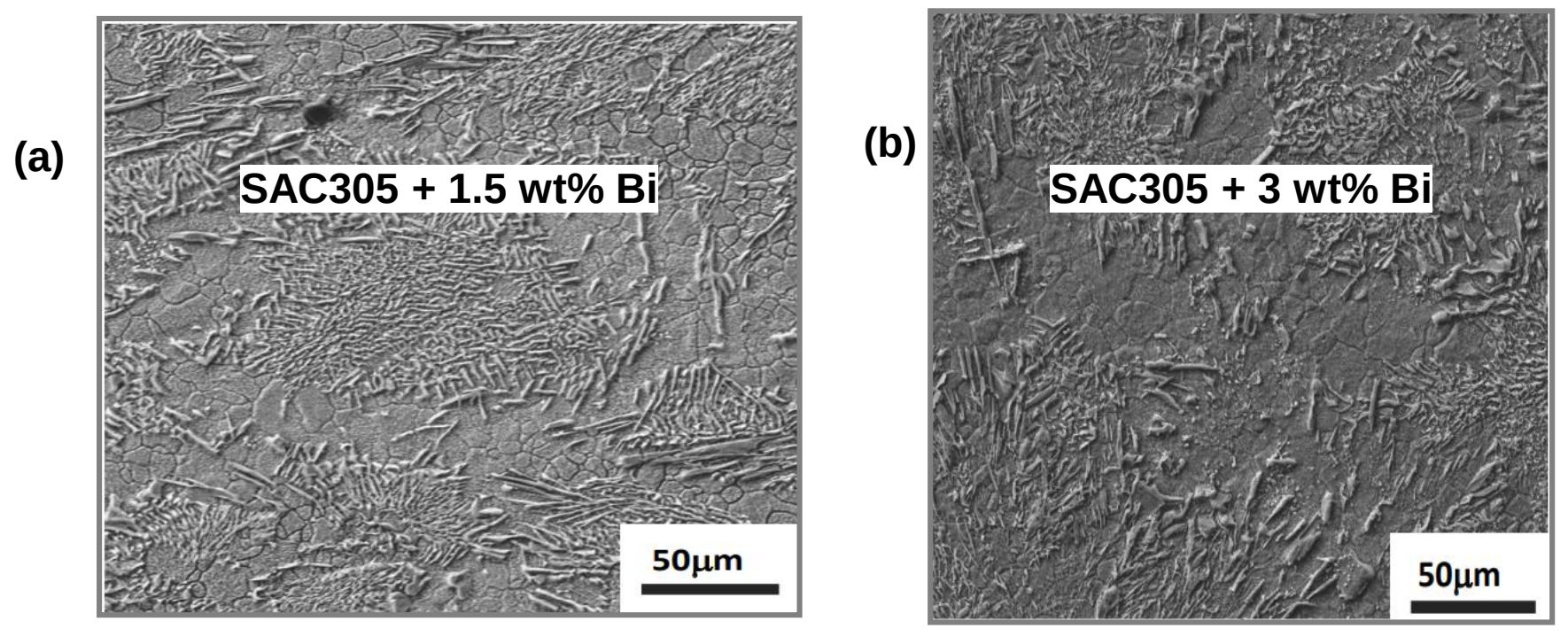


- SAC305 +2 wt% Bi possessed greatest shear strength
  - Fast shear (5 mm/s)
  - Slow shear (0.5 mm/s)
- Linear increase in strength until 2 wt% Bi
  - x = ± 3 × standard deviation

Discussion



- Average shear strength in different Bi %Bi from literature[8]
- Our shear strength data match with the literature

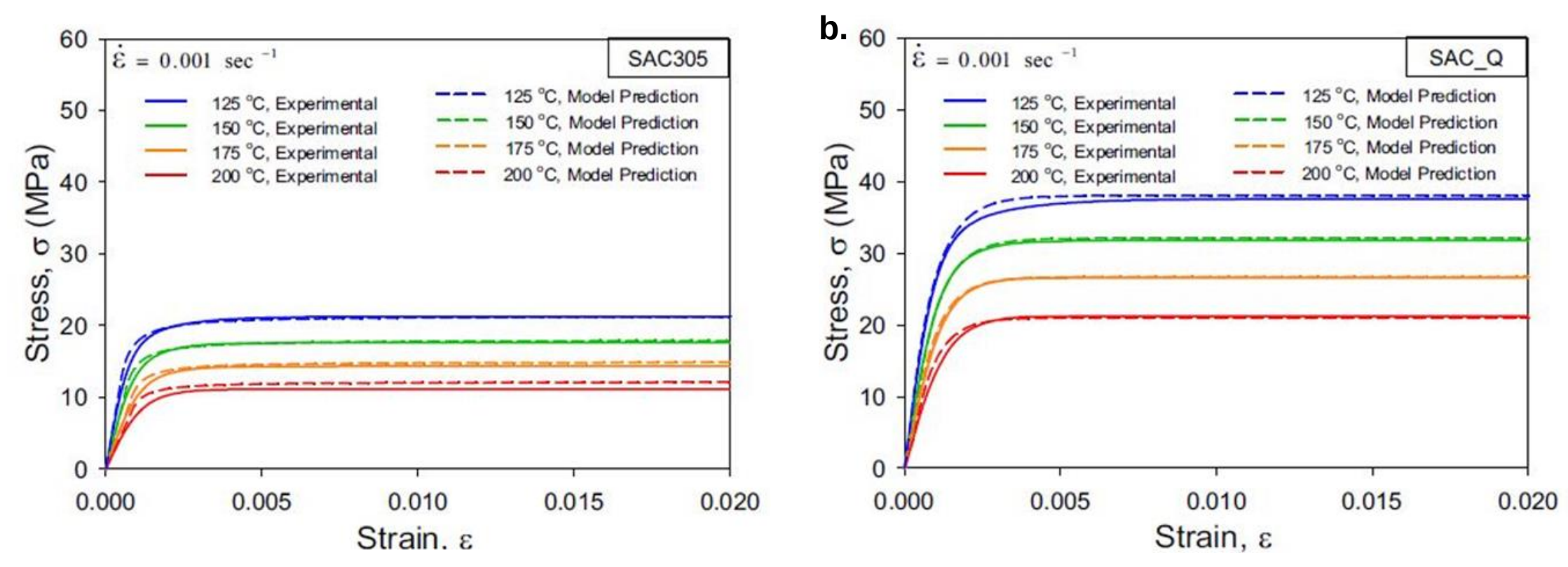


- (a) - Large Ag_3Sn IMC plates with Bi matrix in solid solution of β-Sn at 1.5wt%Bi
- (b) - Finer Ag_3Sn IMC plates, Bi precipitates at 3wt% [8]

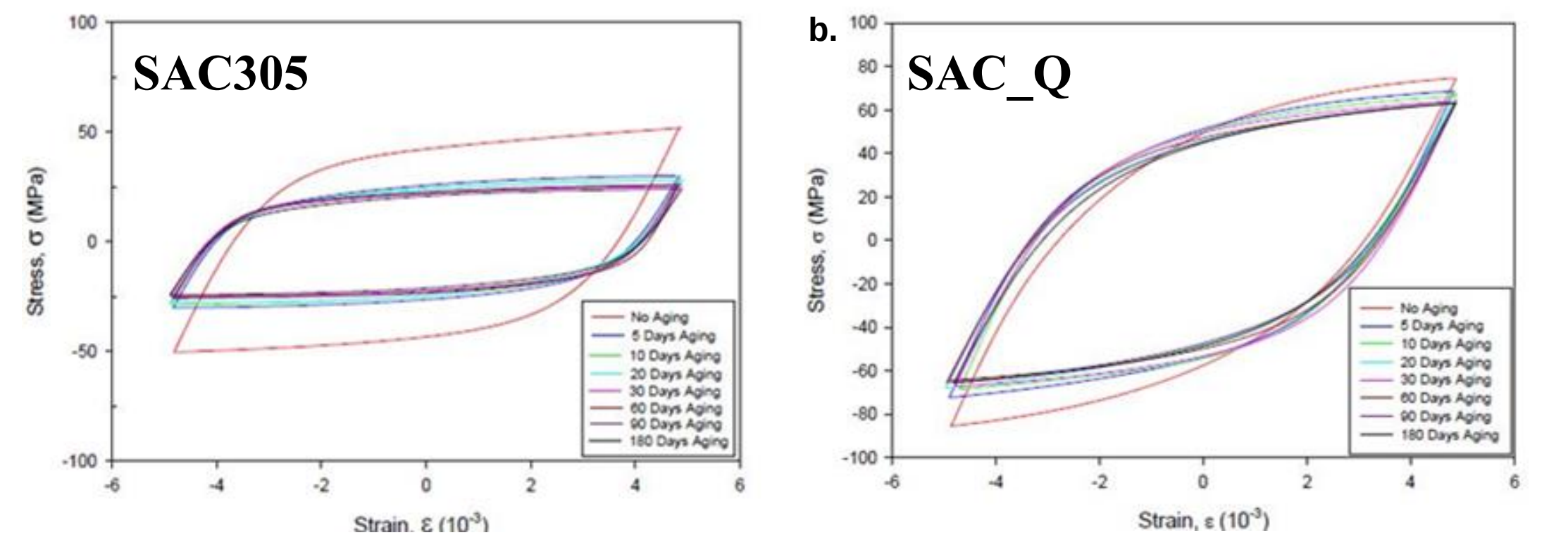
Discussion

Material Properties

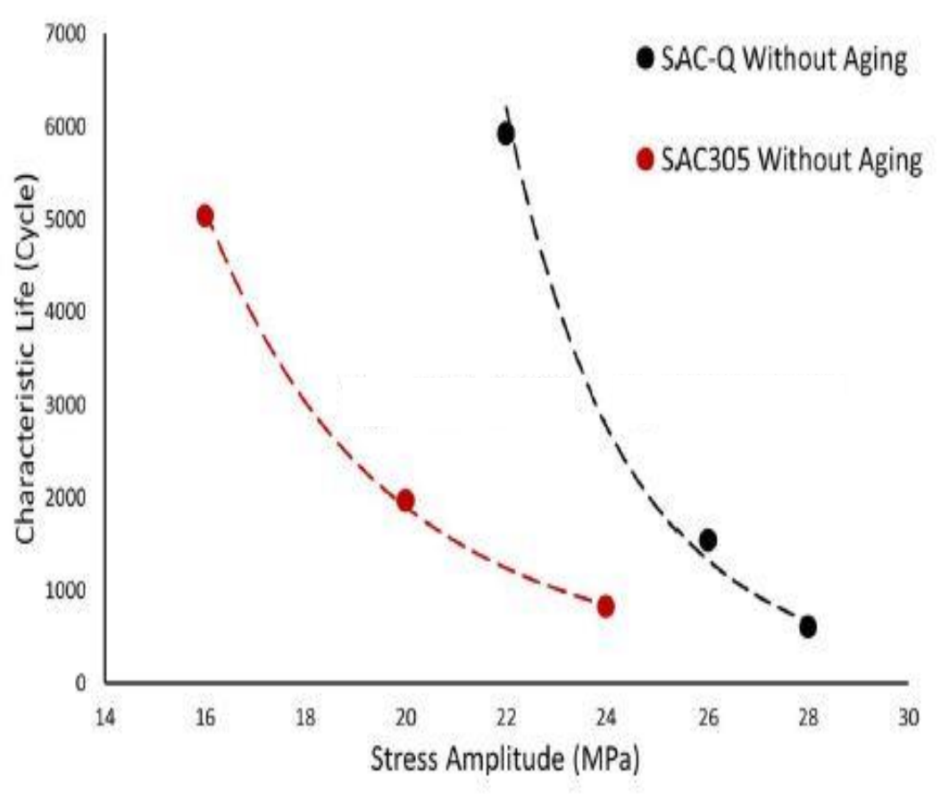
- Stress-strain curves at elevated temperatures for SAC305 (a) and SAC_Q (Sn-3.4Ag-0.5Cu-3.3Bi) (b) showing experimental data and Anand model fit [9]
- Bi-containing alloys have higher yield strength compared to similar alloys with no Bi due to solid-solution strengthening and Bi precipitates.



- Fatigue behavior-aged SAC305(a), SAC_Q(b) [10]
- Bi-containing alloys tolerate higher stresses, longer aging without degrading cyclic fatigue properties



- Fatigue life of SAC305 and SAC_Q [11]
  - Bi addition improves fatigue life due to solid solution and precipitation strengthening



Future Work

- Bulk solder creep/tensile testing
- Comprehensive ball shear / microhardness testing
- Optical/BSE SEM microstructural imaging

Summary

Based on a review of ball shear data and literature, the team recommends the alloy SAC305 + 2%Bi due to its improved mechanical properties over SAC305. The team recommends further testing of microhardness, ball shear performance, and bulk creep properties of this composition both aged and as-reflowed to better characterize the mechanical behavior.

Acknowledgements

The team would like to thank Dr. Peng Su for his project oversight, Dr. John Holaday and his colleagues at NSWC Crane for conducting ball shear testing, and graduate students Yaohui Fan, Hannah Fowler, and Yifan Wu for their assistance.

References