Welding and Weld Repair of Single Crystal Gas Turbine Alloys

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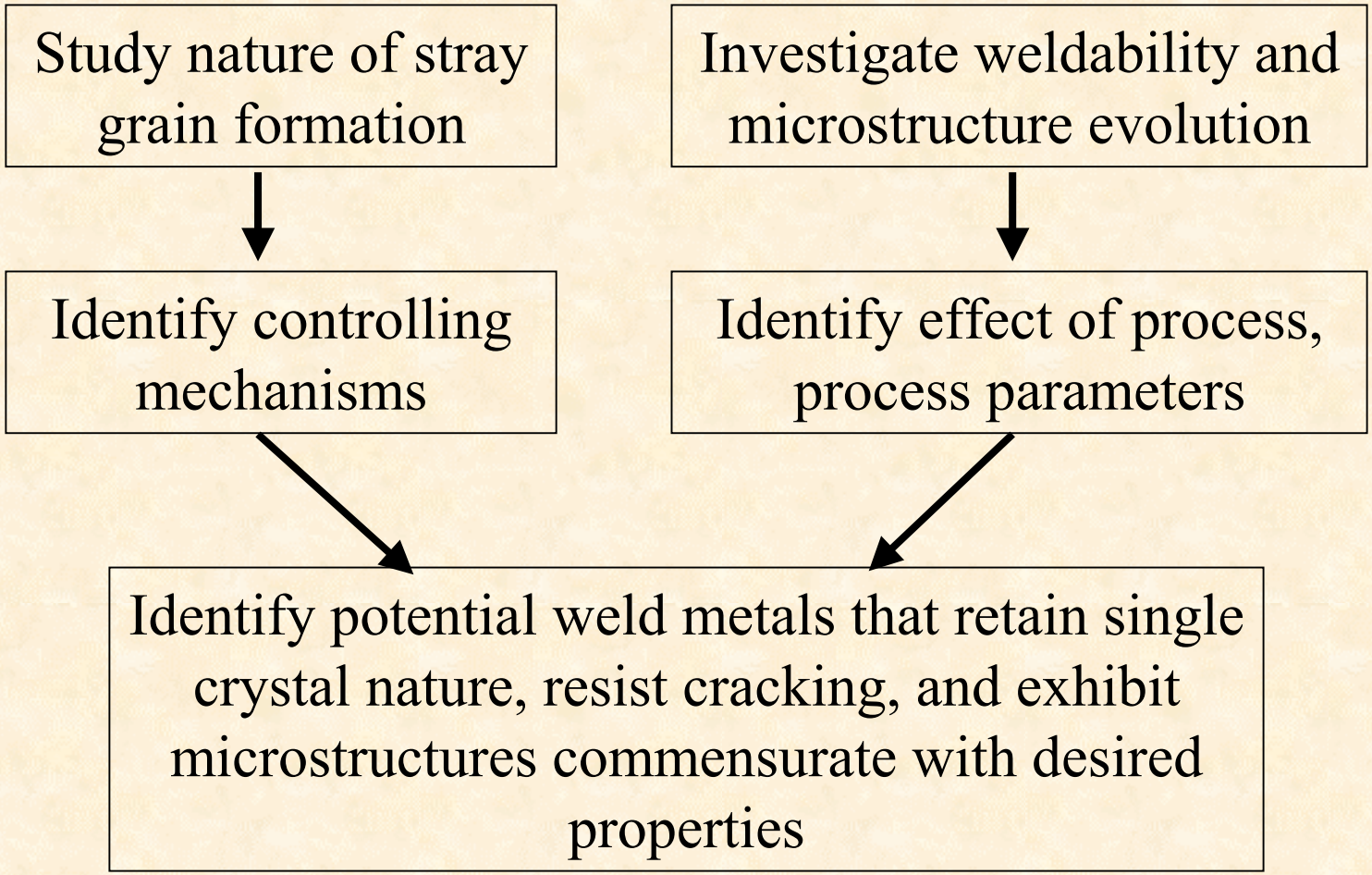
ORNL Has Started a New Project, Sponsored by the DOE-NETL Fossil Energy Program, on Welding and Weld Repair of Nickel Alloys



Coarse Breakdown of Tasks:

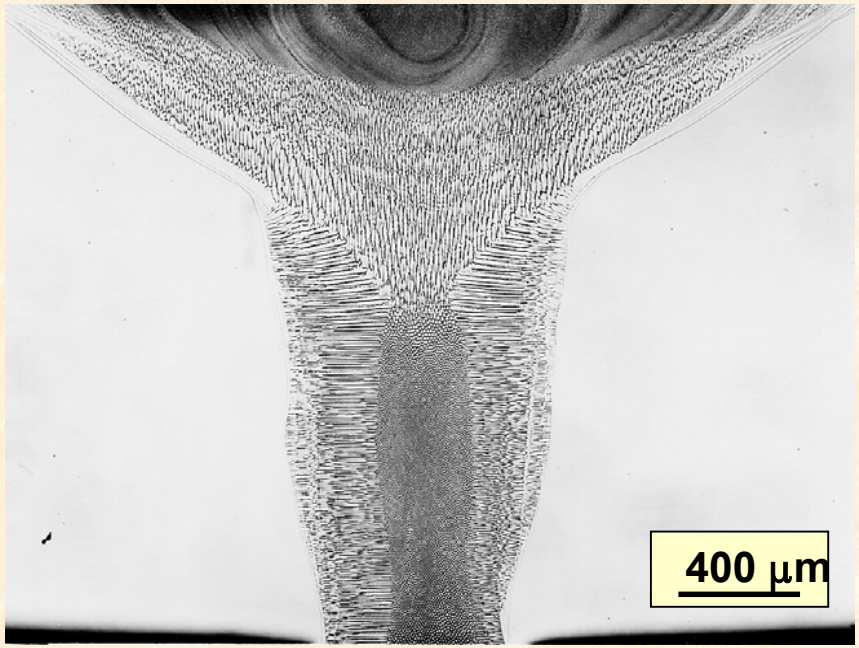
- **Stray grain formation**
  - **Investigate mechanisms for stray grain formation**
  - **Identify and procure model alloys**
  - **Analyze stray grain formation in model alloy welds**
  - **Develop experimental filler metals**
  - **Procure and evaluate experimental filler metals**

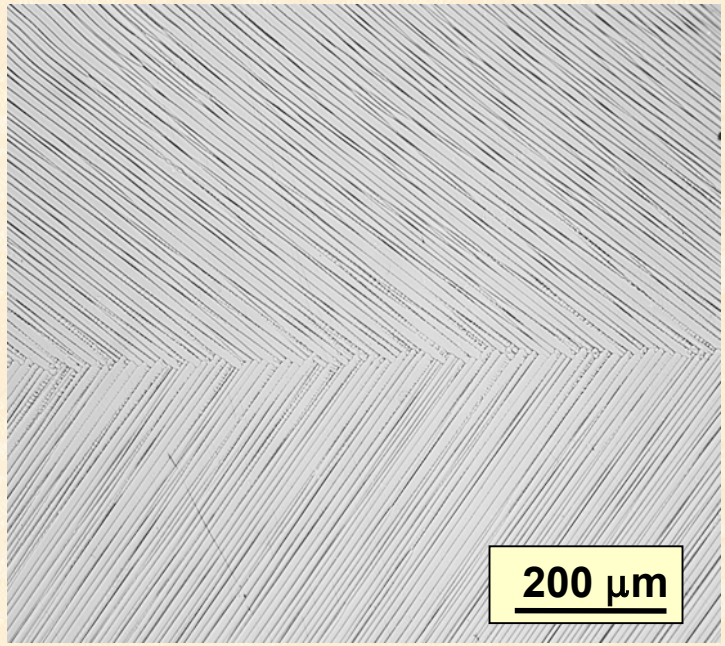
Coarse Breakdown of Tasks:

- **Weldability and microstructure of commercial alloys**
  - **Evaluate cracking susceptibility**
  - **Characterize microstructure versus process conditions**
  - **Model microstructure evolution**
  - **Develop optimum welding procedures**
  - **Evaluate long-term phase stability**

Previous Work at ORNL

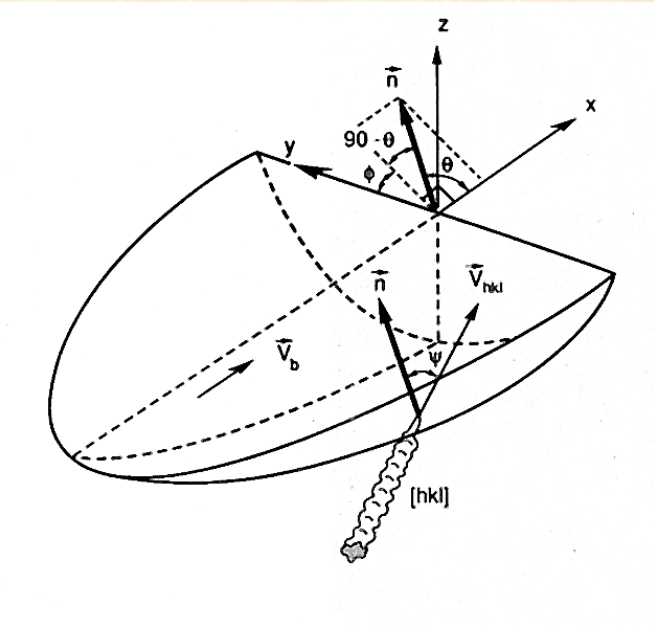
ORNL Has Worked Extensively on Welding of Single Crystals

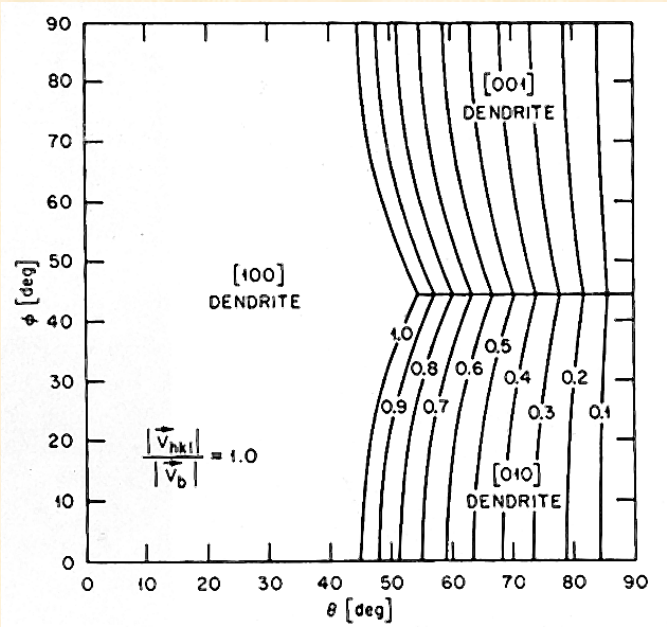




Single crystal nature was maintained in welded Fe-15Cr-15Ni

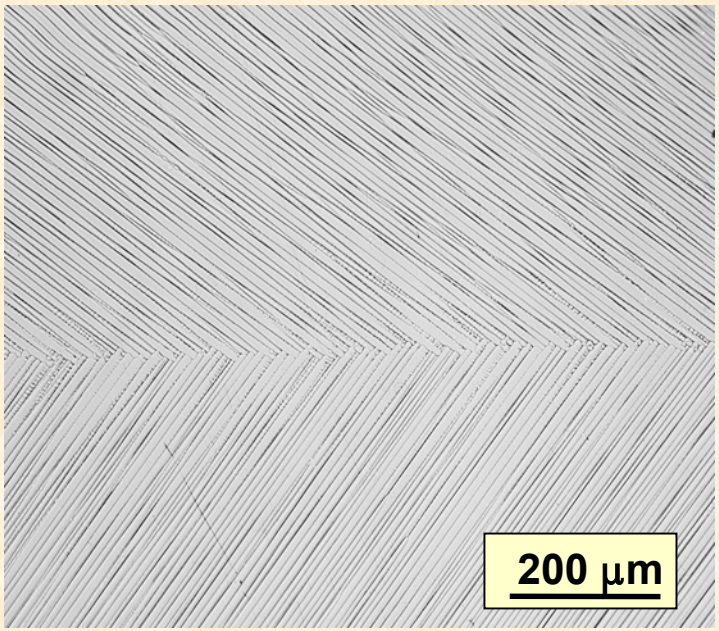
A Geometrical Model Was Developed to Predict the Dendritic Microstructure in Single Crystal Welds



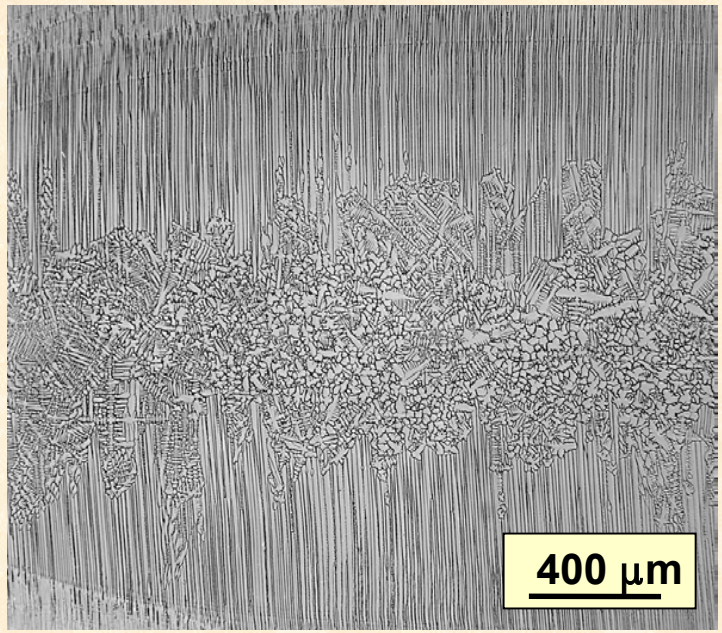


The preferred growth direction can be calculated as a function of the solidification front orientation and weld pool shape.

It Was Found That the Tendency to Form Stray Grains Was Very Sensitive to Composition



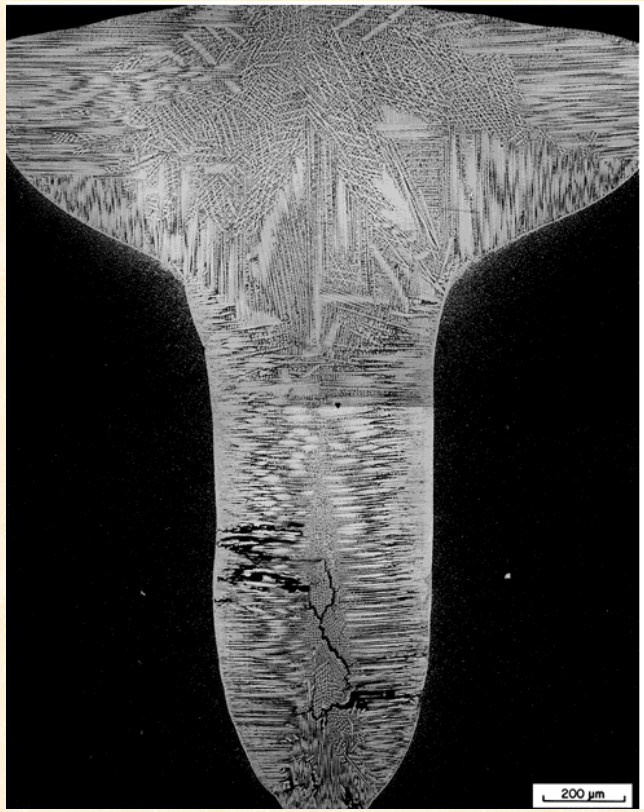
Fe-15Cr-15Ni

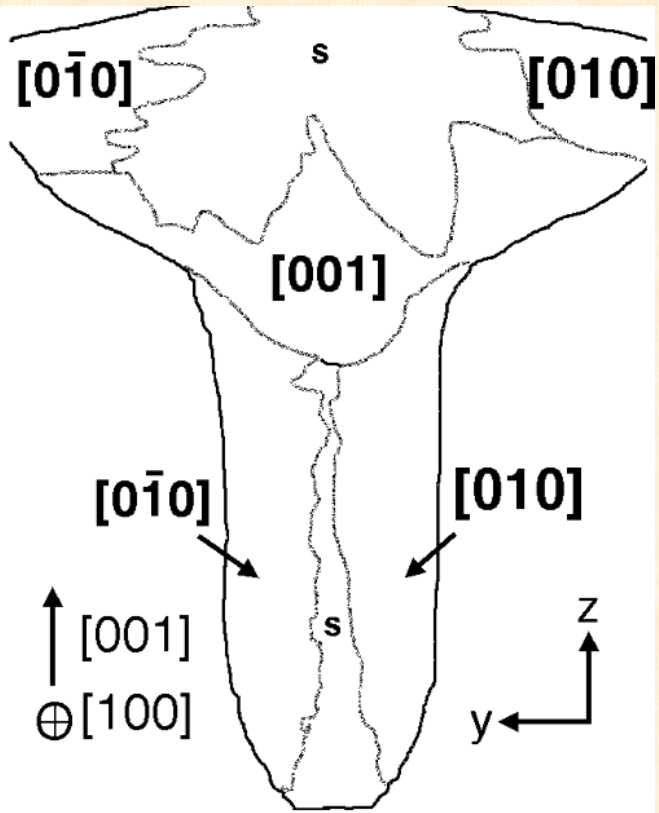


Fe-15Cr-15Ni + S

Stray Grain Formation Is a Serious Problem With Nickel Superalloys

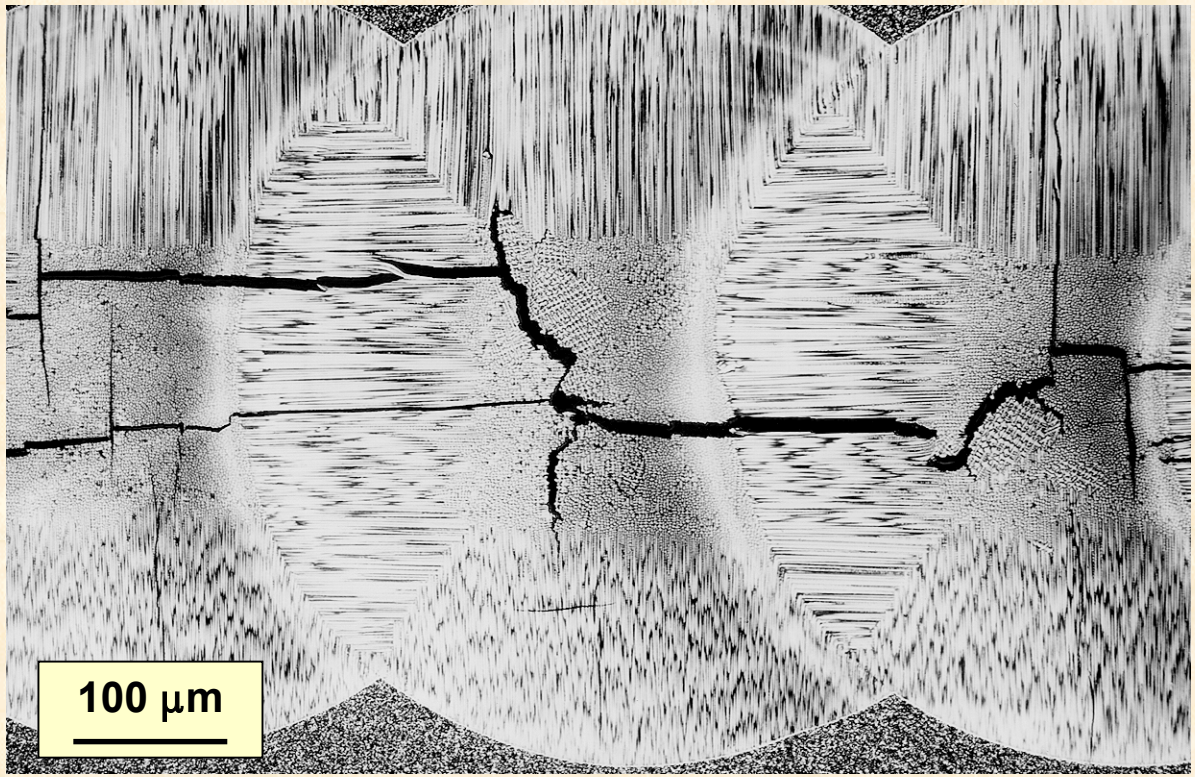
Electron beam welded PWA 1480





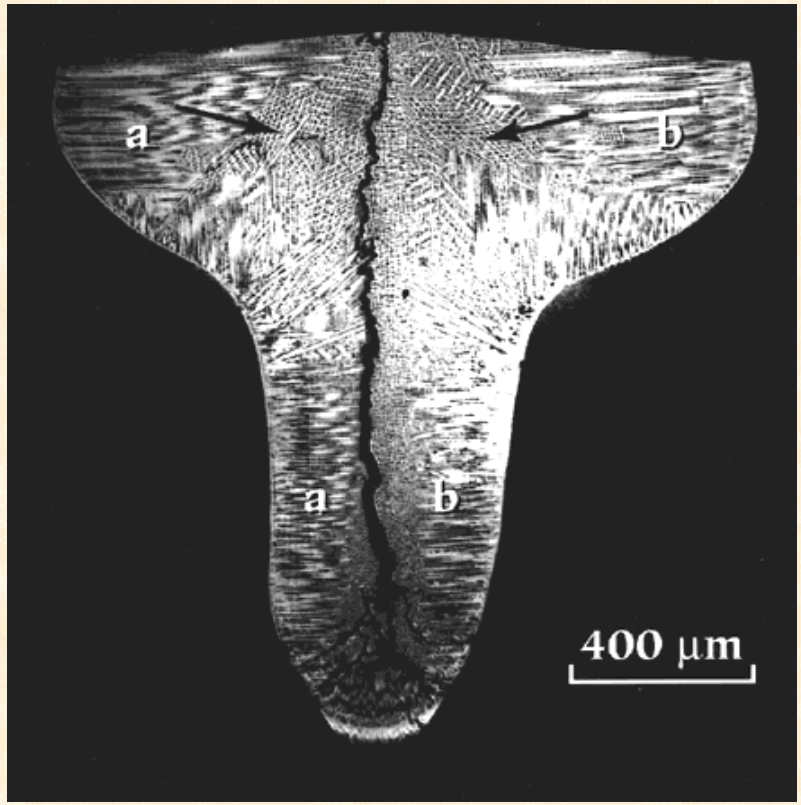
Furthermore, Cracking Is Associated With Stray Grain Formation

Pulsed laser welded PWA 1480

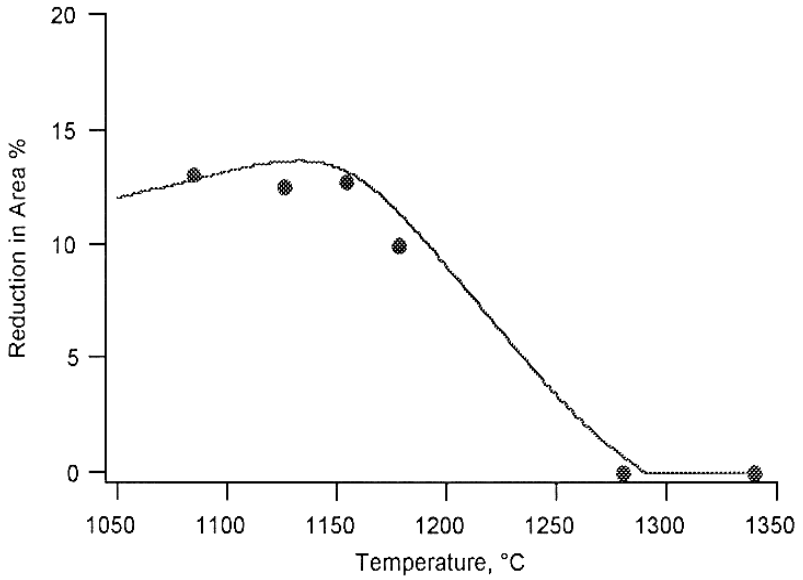


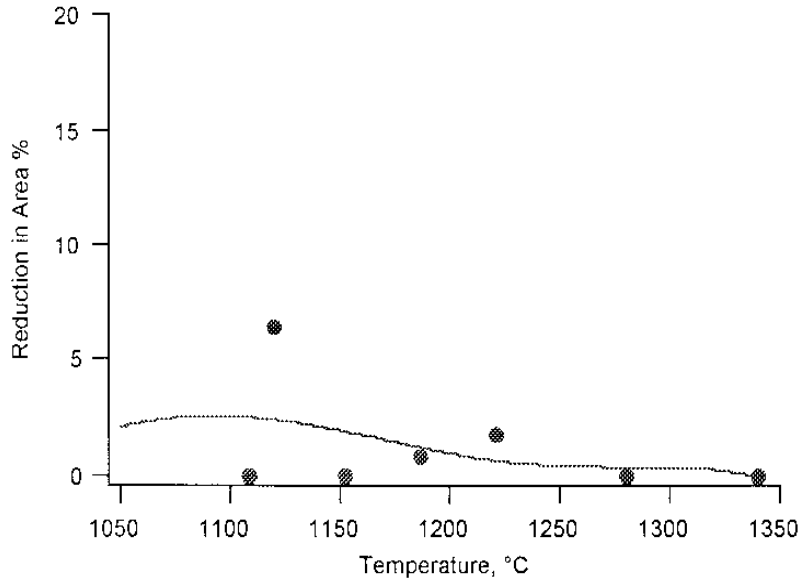
It Is Also Known That Single Crystal Nickel-base Superalloys Are Extremely Susceptible to Hot-Cracking

Electron
beam welded
PWA 1480



Hot Ductility Tests Are a Good Measure of Hot-Cracking Susceptibility

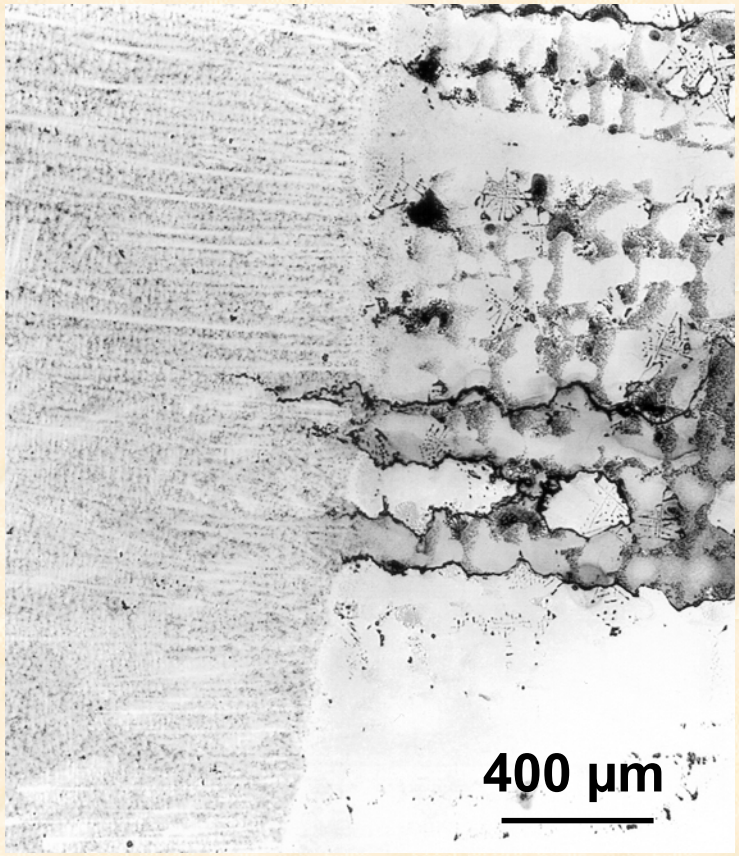




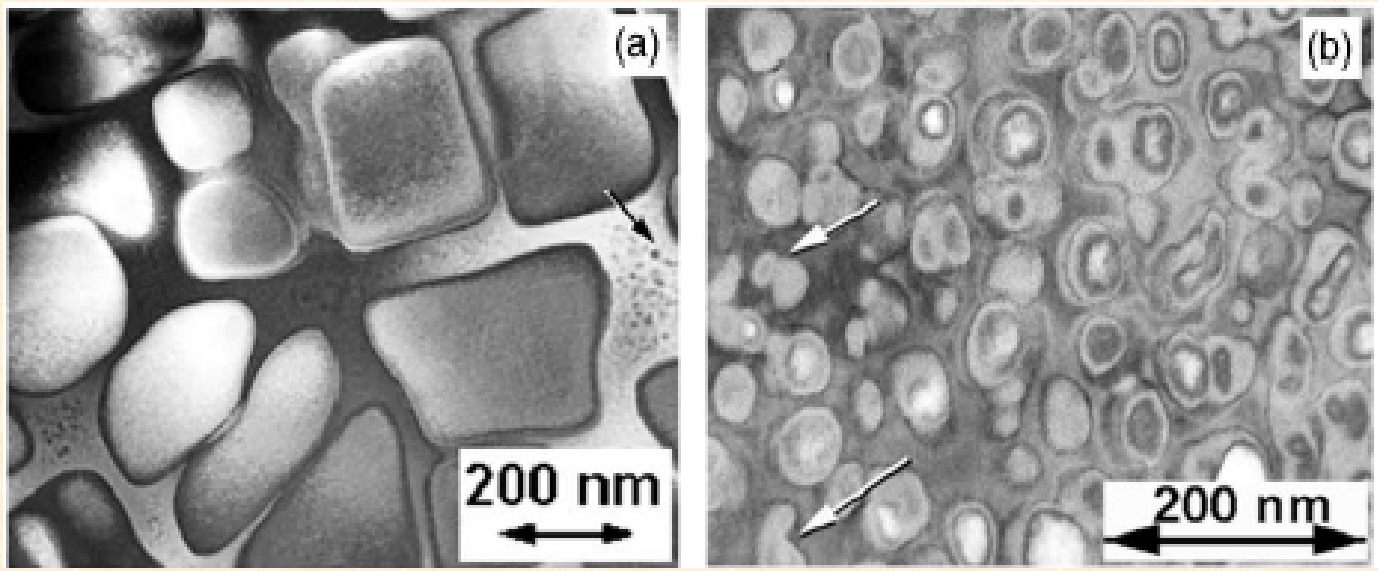
Measured hot ductility in Westinghouse alloy (left) and CMSX4 (right)

Nickel-Base Superalloys Are Also Susceptible to HAZ Cracking

Autogenously welded
homogenized
MarM 002

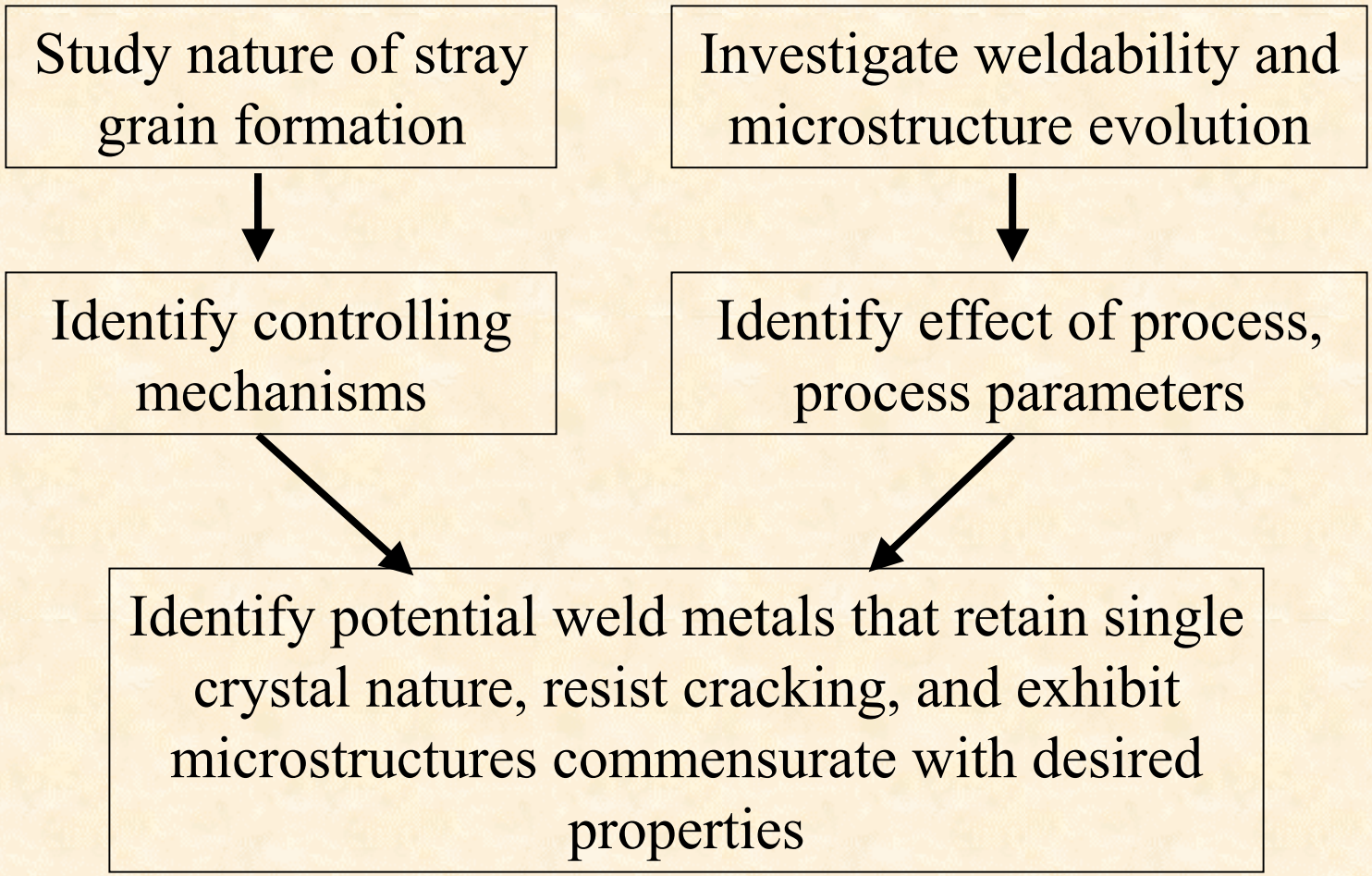


Weld Process Conditions Severely Alter the Weld Microstructure



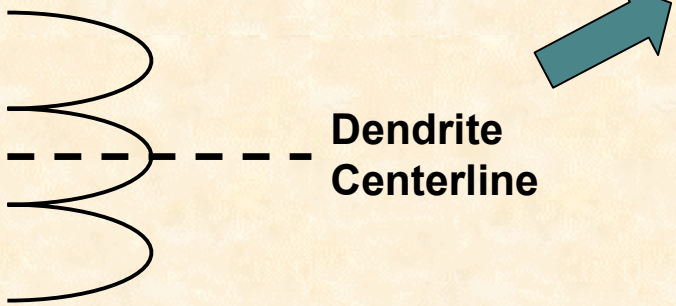
High magnification TEM micrographs of (a) slow-cooled and (b) rapidly cooled CM247

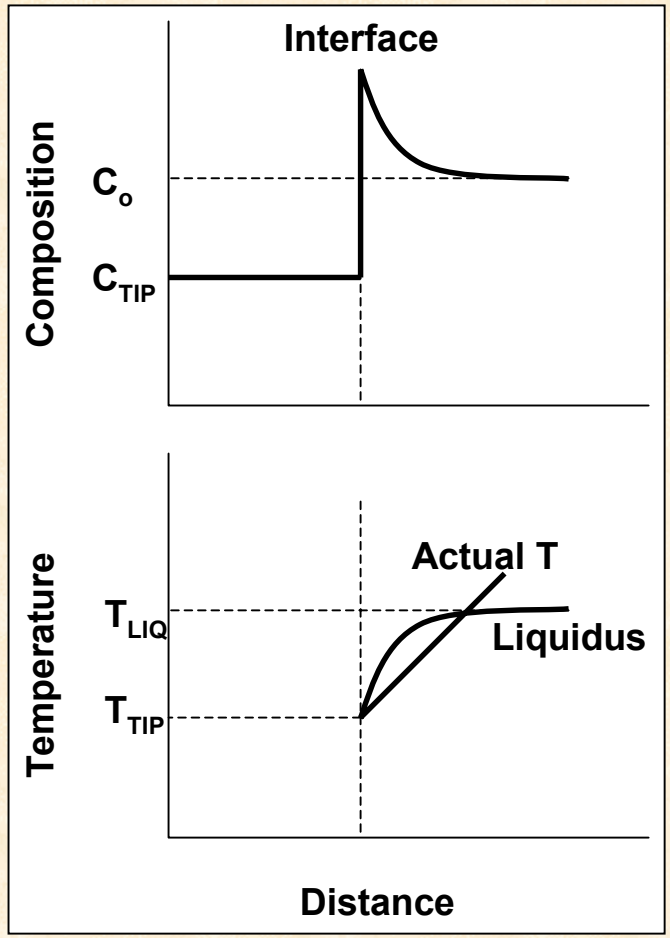
This Project Will Investigate Weldability From Two Perspectives



Constitutional Supercooling (CS) Will Be Evaluated As a Controlling Mechanism for Stray Grain Formation

- More advanced theories exist but
- Simple theory provides criterion to avoid CS
  - $G/R > \Delta T_S / D_L$





Computational Thermodynamics (CT) Will Be Used Extensively to Evaluate the Degree of CS

- A database specific to single crystal nickel-base superalloys has been acquired
- The accuracy of the CT predictions will be evaluated using independent data on liquidus and solidus temperatures
- CT will be used to determine the ΔT_{sol} as a function of composition

Hot-Cracking Will Be Investigated

- Commercial alloys will be used
- Gleeble tests will be carried out to evaluate hot ductility as a function of composition, heat treatment, homogenization condition, etc
- Autogenous welds will be made using different processes (EB, LB) and process conditions (speed, pre-heat)

The Effect of Weld Conditions on Microstructure Development Will Be Evaluated

- Process and process conditions will be evaluated by changing cooling rate
- Influence of initial microstructure will be considered (related to base metal homogenization and in-service phase stability)
- Microstructural characterization will be done using TEM, SEM, and atom probe

An Advisory Group Has Been Organized to Assist In:

- Materials
- Data
- Guidance