Effective Exploration of New 760°C Capability Steels for Coal Energy

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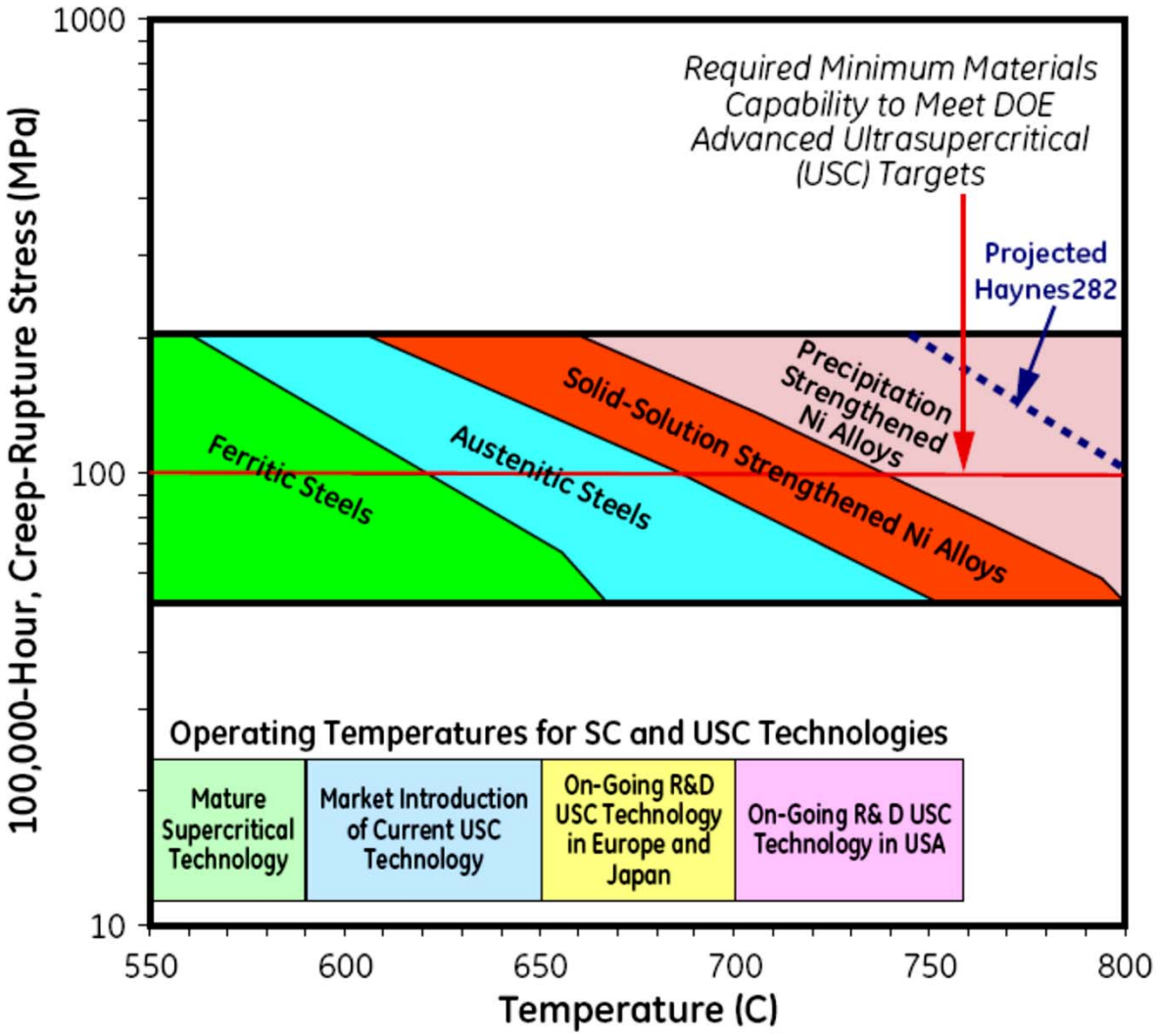
Outline

1. Background and Project Introduction
2. Technical Approach
3. Results
4. Summary
5. Future Work

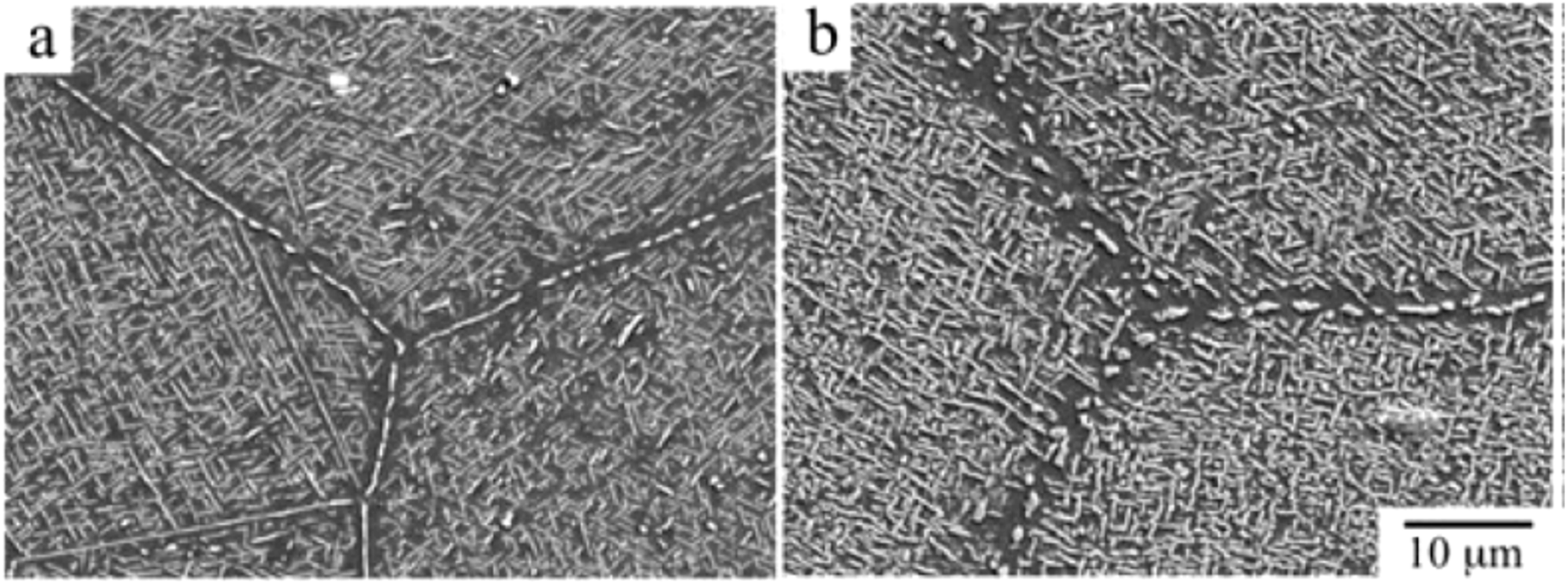
1. Background and Project Introduction



L. Jiang, 2011

- Martensite strengthening no longer workable at 760 °C.
- New strengthening mechanism is sought.

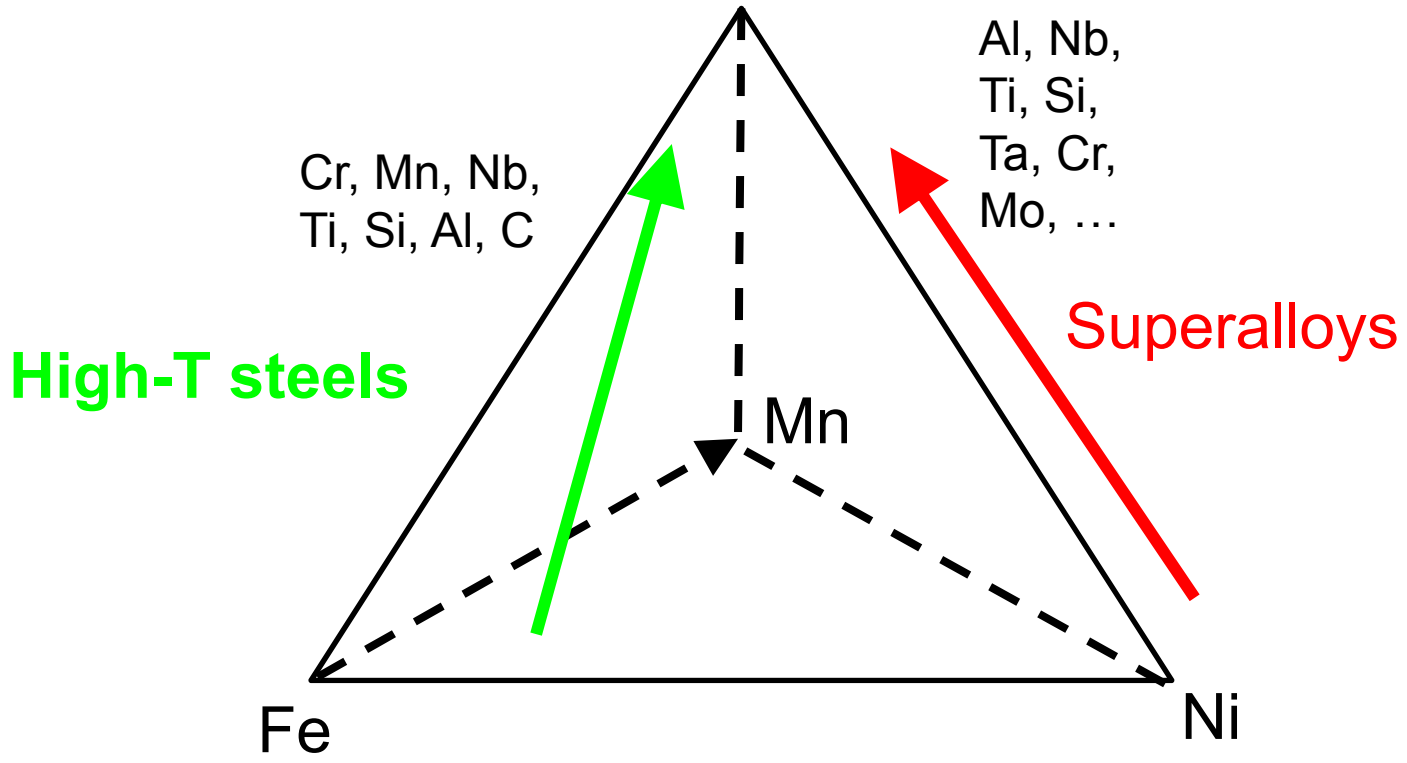
1. Background and Project Introduction



Finely dispersed Laves phase in a Fe-20Cr-30Ni-2Nb (at.%) steel after a creep test at 700°C and 120 MPa: (a) boron-doped steel, and (b) boron-free steel (Takeyama et al.)

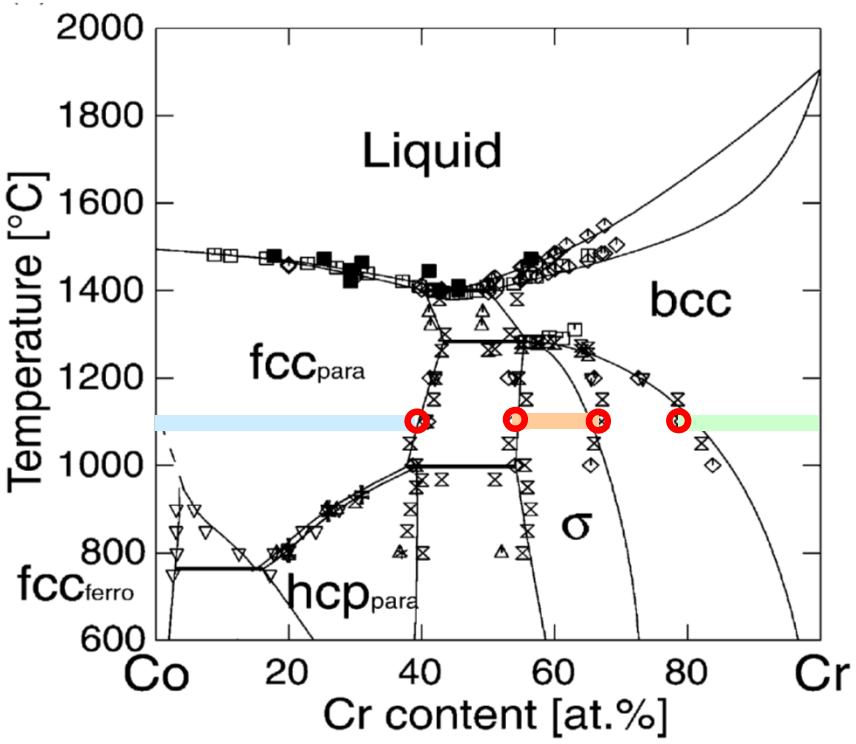
- Laves phase has demonstrated good properties.
- Sluggish precipitation kinetics.
- Grain boundary precipitates key to good creep strength.
- High enough Cr for hot corrosion resistance.

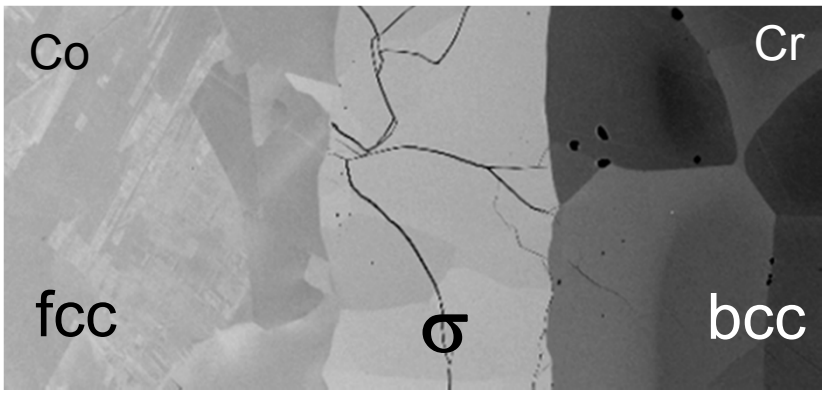
1. Background and Project Introduction



- Identification of new strengthening phases through high-throughput exploration together with computational thermodynamics.
- Cost-effective steels for AUSC clean coal systems.

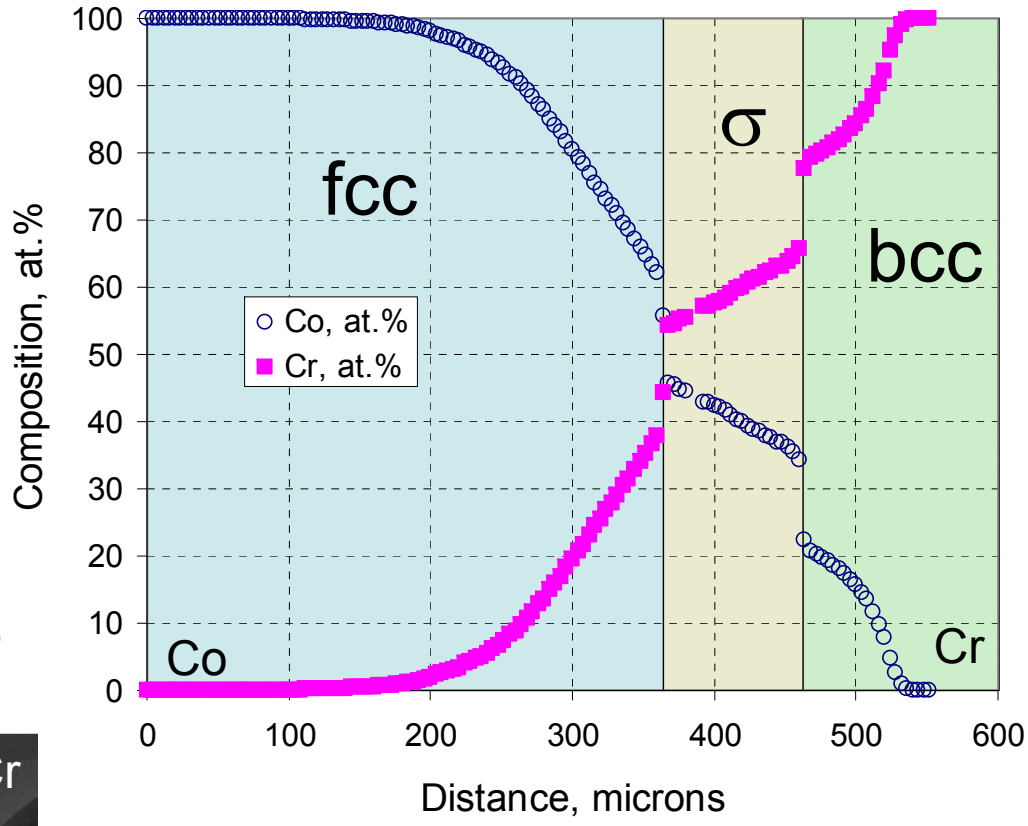
2. Technical Approach





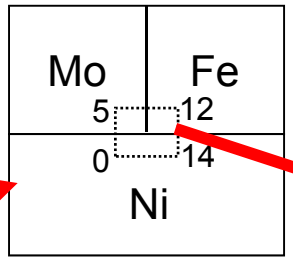
1100°C, 1000h

100 μm

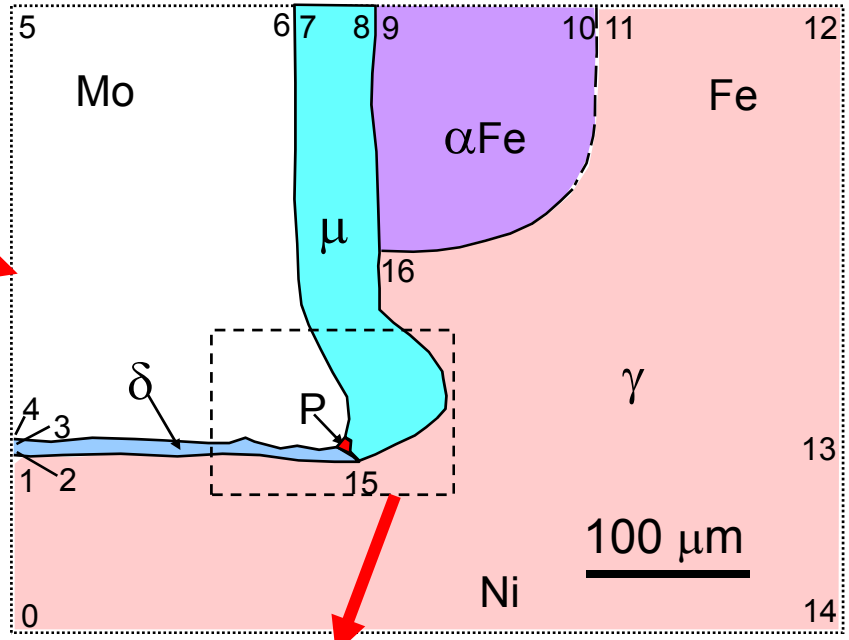


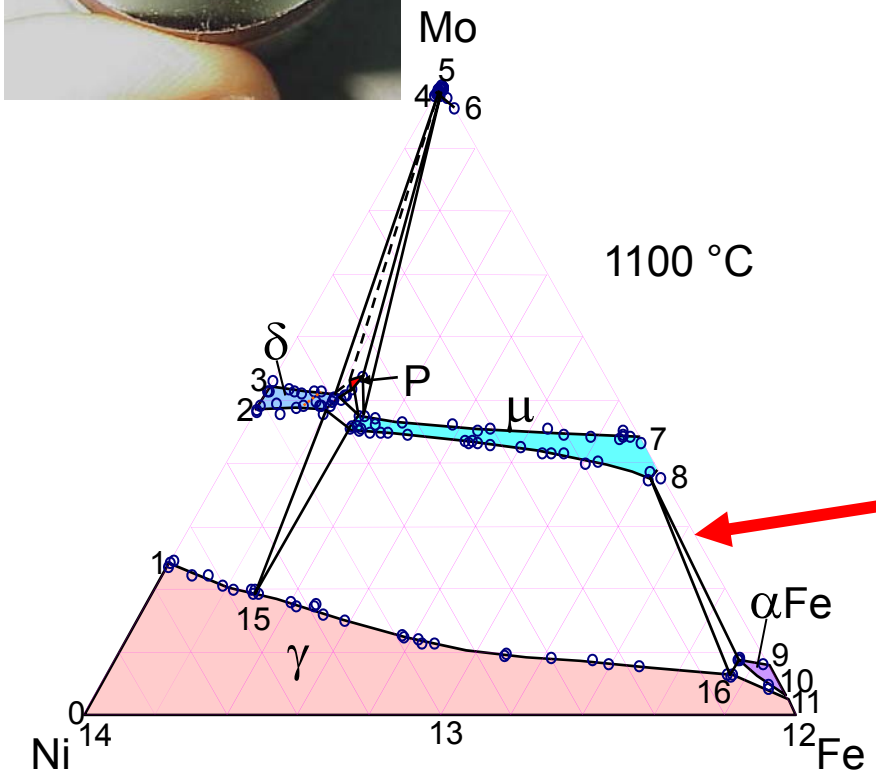
- Local equilibrium at phase interfaces defines the tie-lines
- Interdiffusion creates all single-phase compositions

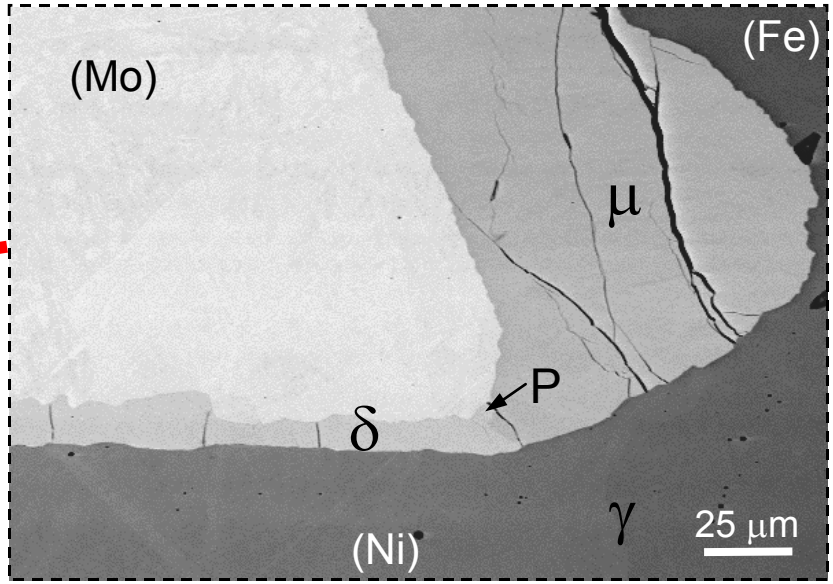
2. Technical Approach



1100°C 1500 hrs



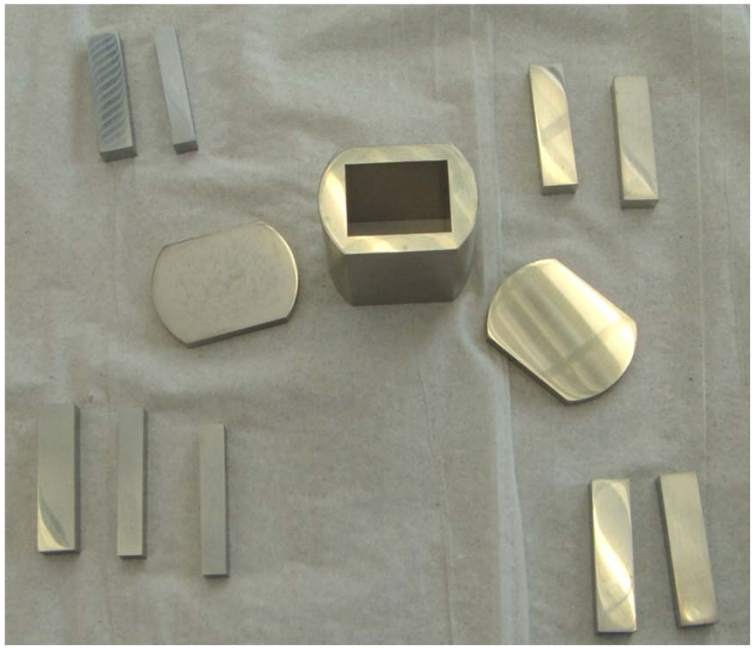


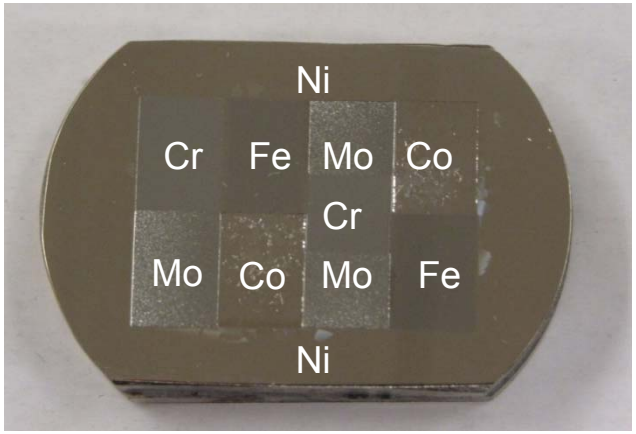


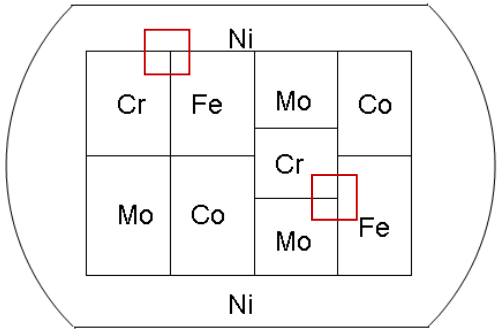
Zhao: J. Mater. Res. 2001;16:1565.

2. Technical Approach

Diffusion-multiple approach





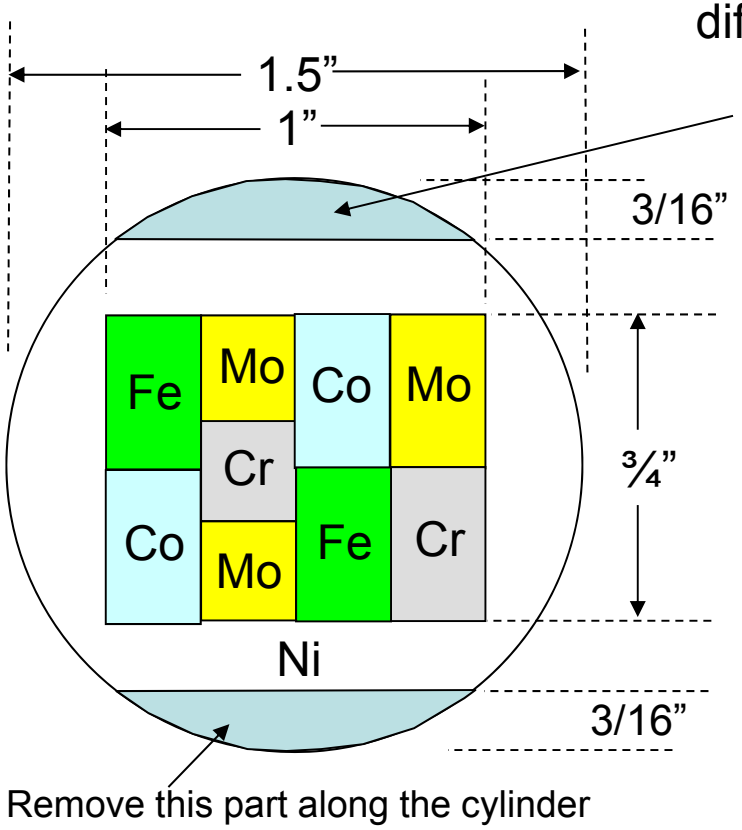


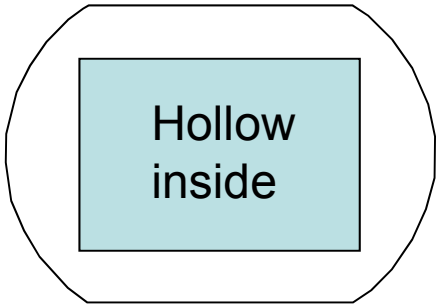
2. Technical Approach

8 Mo bars: 0.25” x 0.25” x 1.5”
8 Fe plates: 3/8” x 0.25” x 1.5”
4 Cr plates: 3/8” x 0.25” x 1.5”

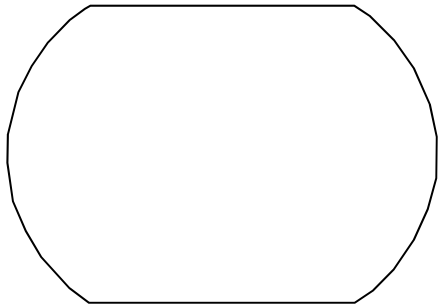
4 Mo plates: 3/8” x 0.25” x 1.5”
8 Co plates: 3/8” x 0.25” x 1.5”
4 Cr bars: 0.25” x 0.25” x 1.5”

All surfaces need to be grinded to 1200 grit finish and ultrasonically cleaned before assembling the diffusion multiples.





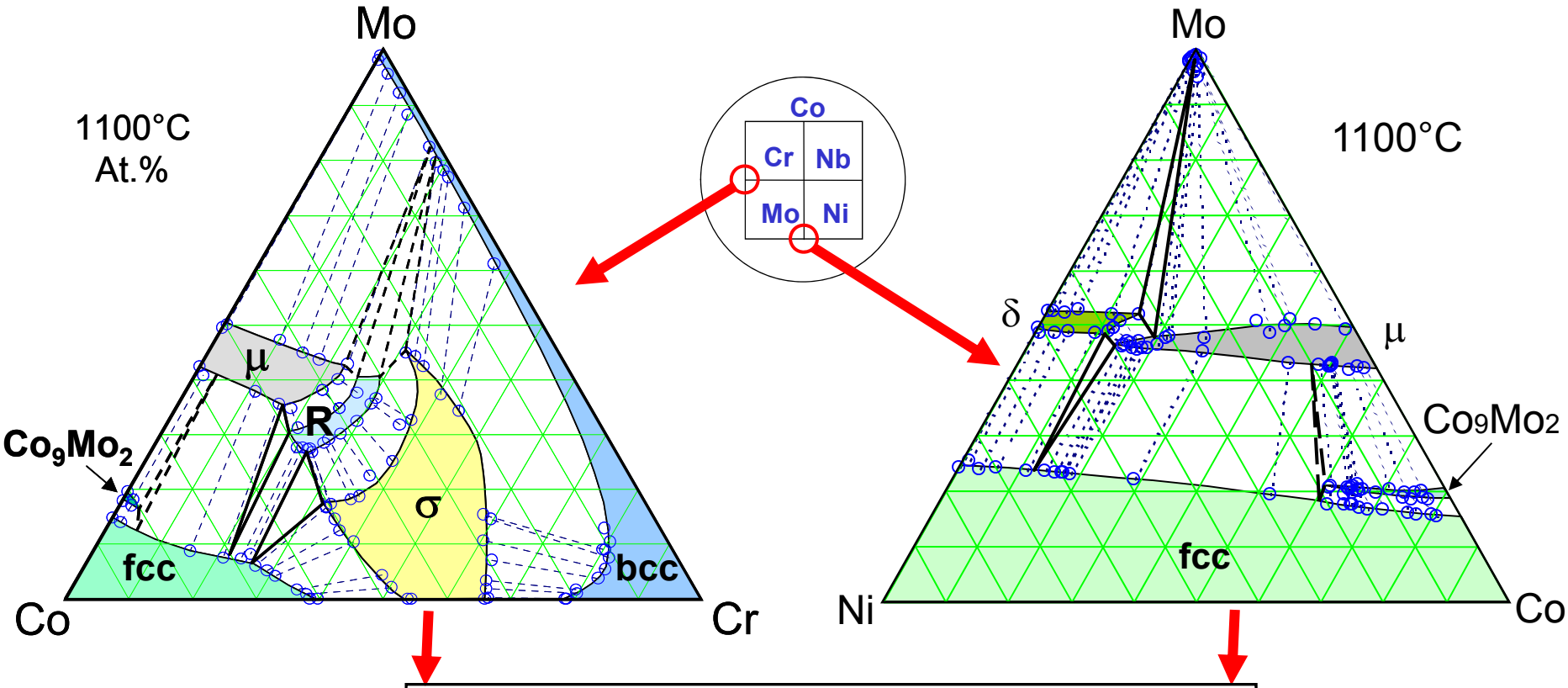
4 pure Ni shells:
1.5” diameter x 1.5” height
With a 1” x 3/4” inside opening



8 pure Ni caps:
1.5” diameter x 3/16” in thickness with 3/16” caps cut off

2. Technical Approach

Sponsored by DARPA AIM Program



CALPHAD Assessments

High-fidelity thermodynamic databases

2. Technical Approach

GTD222 → **GTD262**

4 years from concept to production

- 2X creep strength ↑
- Ta replacement by Nb: cost ↓
- Computational design: validated with only one set of 4 alloys.

Box 5-3
ICME Example: Development of Superalloy GTD262 at GE

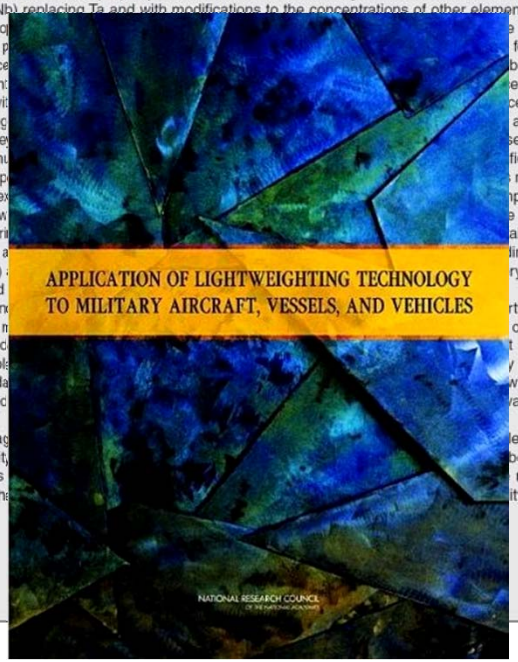
GE was one of the three companies that carried out a DARPA-AIM project, which facilitated the adoption of the AIM/ICME approach inside the company. During the AIM project, extensive testing was performed on the reliability of thermodynamic databases in predicting phase stability in multicomponent superalloys,[1] which resulted in a rigorous assessment of the fidelity level of thermodynamic data for several key phases.

A GE-funded project was initiated in 2002 and executed by both GE Global Research and GE Energy to replace tantalum (Ta), a critical refractory element subjected to high risks of supply and price disruptions, in superalloy GTD222, which was widely used in nozzles and vanes in GE power generation gas turbines. Using the AIM/ICME approach, especially by integrating computational thermodynamic predictions of phase equilibria with GE's materials property models and databases, Jiang and his collaborators designed four alloys with niobium (Nb) replacing Ta and with modifications to the concentrations of other elements to optimize and balance key pro… four Ta-free alloys for mechanical p… four alloys doubled creep-resistance… bearing GTD222. It was subsequent… essfully passed the qualifications wi… cessfully introduced into GE power g… adoption today.

The first ke… es are essential to the design of mu… fidence level for the predictions in sp… not only eliminated several of the ex… positions (GTD262 was designed w… long-term thermal exposure experi… al phases. GTD262 was developed a… ling design property data gathering)… ry likely a record in both speed and…

The secon… rty predictions from physics-based … of properties. GE's proprietary mod… t of GTD262. More widely applicabl… models as well as higher-fidelity da… wider compositional validity) are bac… astly from those of existing alloys.

Early engag… le design goals and manufacturabilit… boratory to produc- tion, which was … rapid development of GTD262 is th… ity of computational alloy design and its associated methodologies, models, and databases. GE teams have since successfully designed and deployed into GE products new superalloys at similar high speed and low cost as a result of using the same AIM/ICME approach, which has now firmly established a vital role in new alloy development at GE.



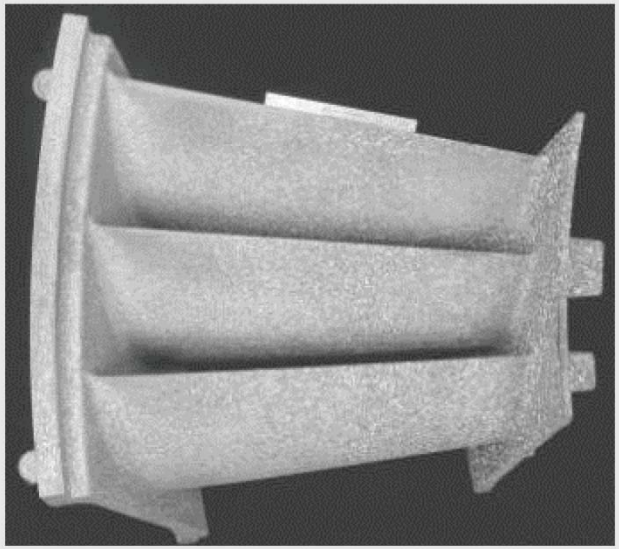


FIGURE 5-3-1 A production trial gas turbine nozzle made up of a new superalloy, GTD262. SOURCE: Courtesy of the General Electric (GE) Company.

[1] J.-C. Zhao and M.F. Henry. 2002. "CALPHAD—Is It Ready for Superalloy Design?" *Advanced Engineering Materials*, Vol. 4, No. 7, pp. 501-508.
[2] L. Jiang, J.-C. Zhao, and G. Feng, 2005, "Nickel-Containing Alloys, Method of Manufacture Thereof," and articles derived therefrom, World Patent Application WO2005056852, filed on September 29, 2004, published on June 23, 2005; U.S. Patent Application 20100135847, filed on October 21, 2009, published on June 3, 2010.

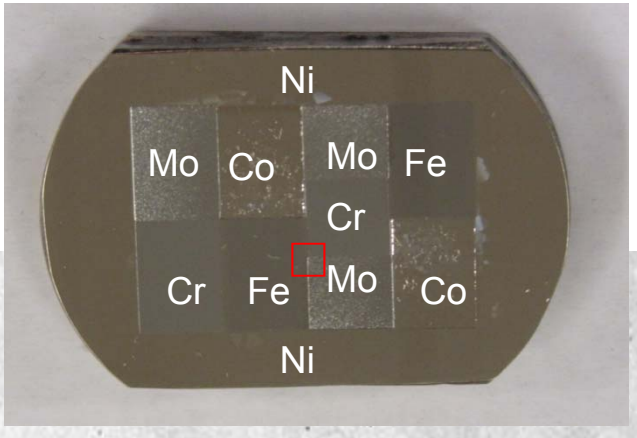
Inventors:
L. Jiang
J.-C. Zhao
G. Feng

Now widely used in GE gas turbines

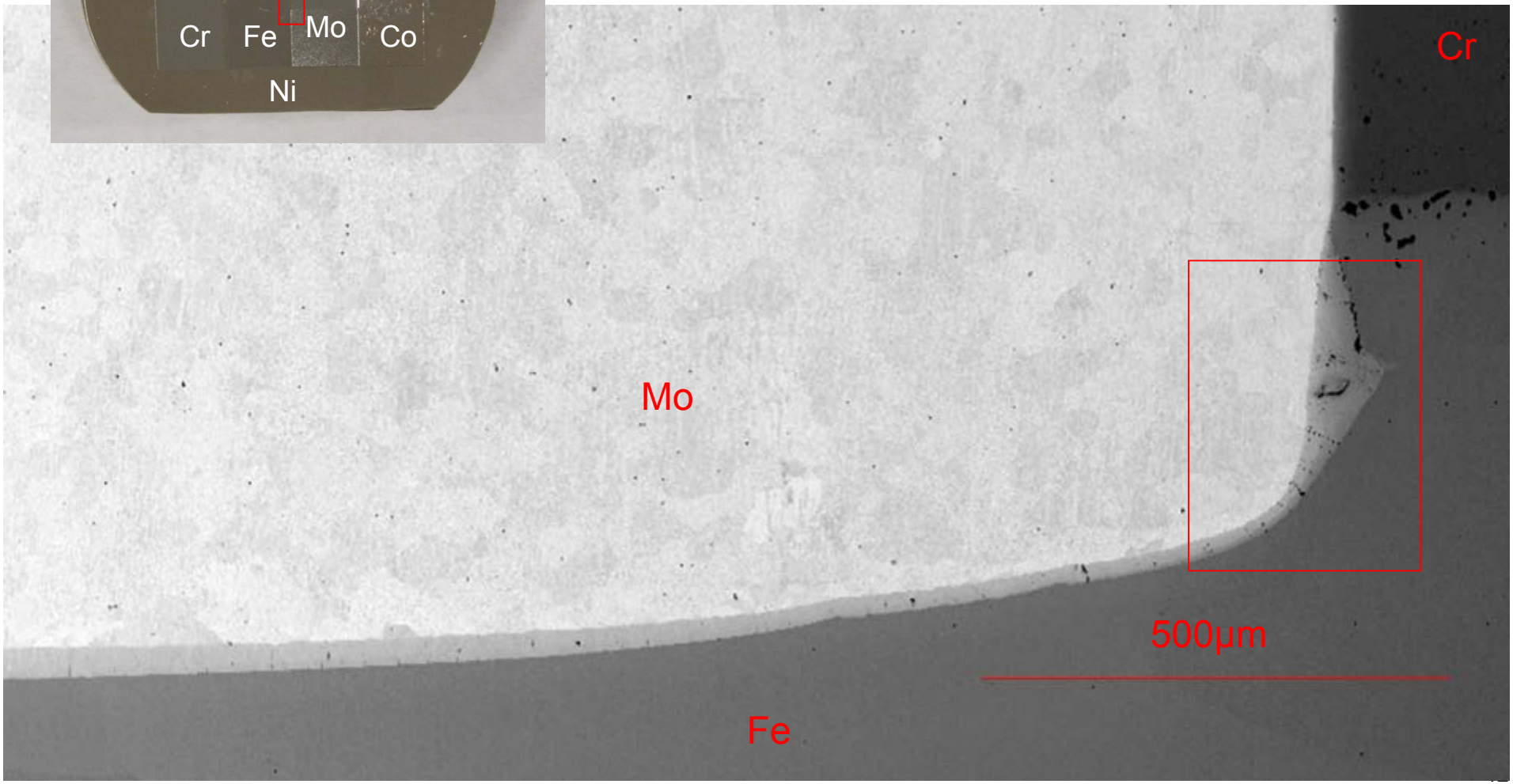
One of the two ICME examples in a NRC report.

The National Academies Press, Washington, D.C., 2012

2. Technical Approach

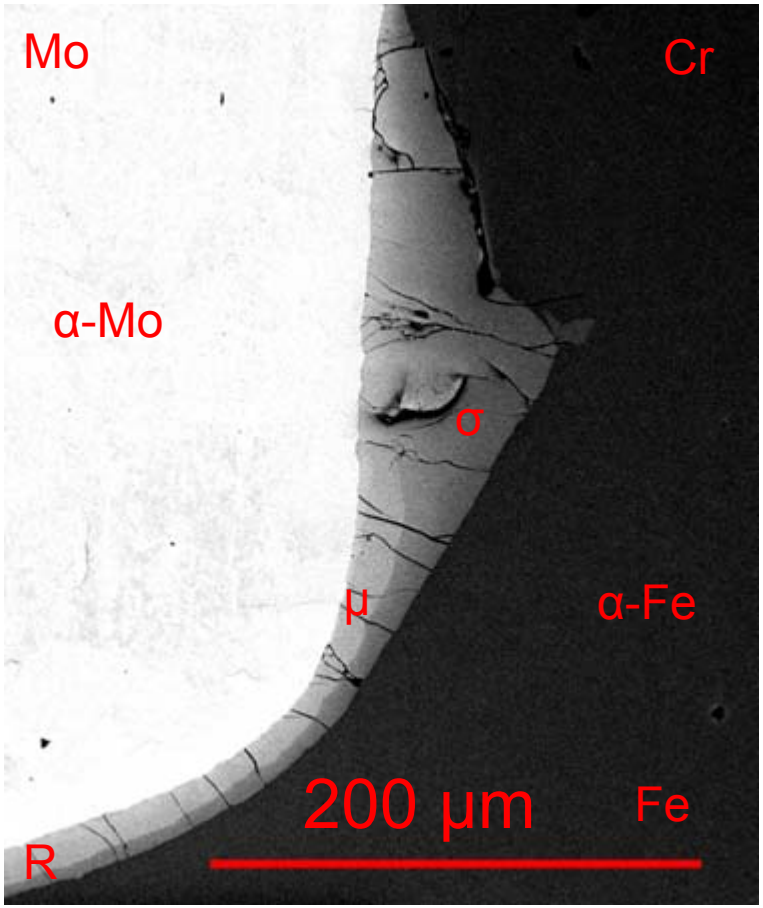


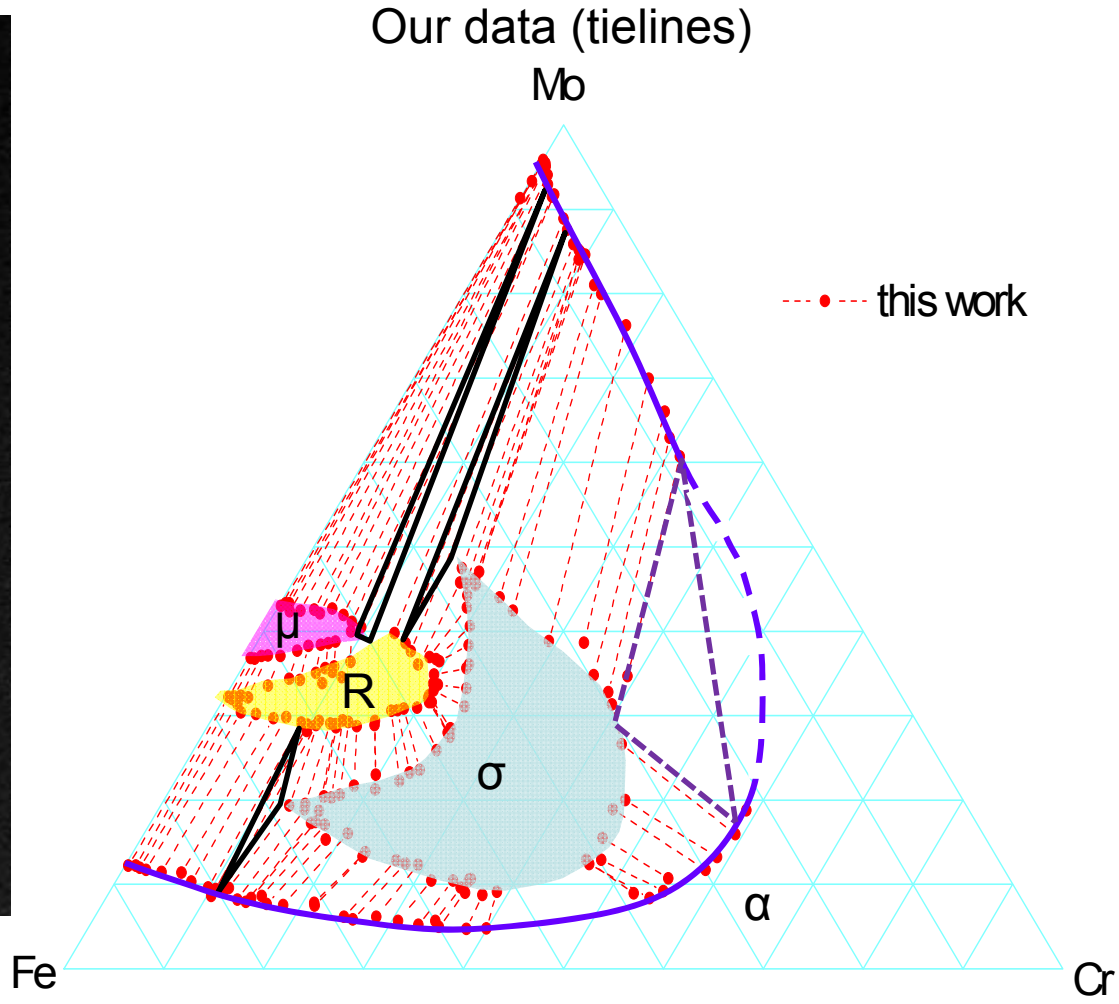
1200°C single-anneal Fe-Cr-Mo



2. Technical Approach

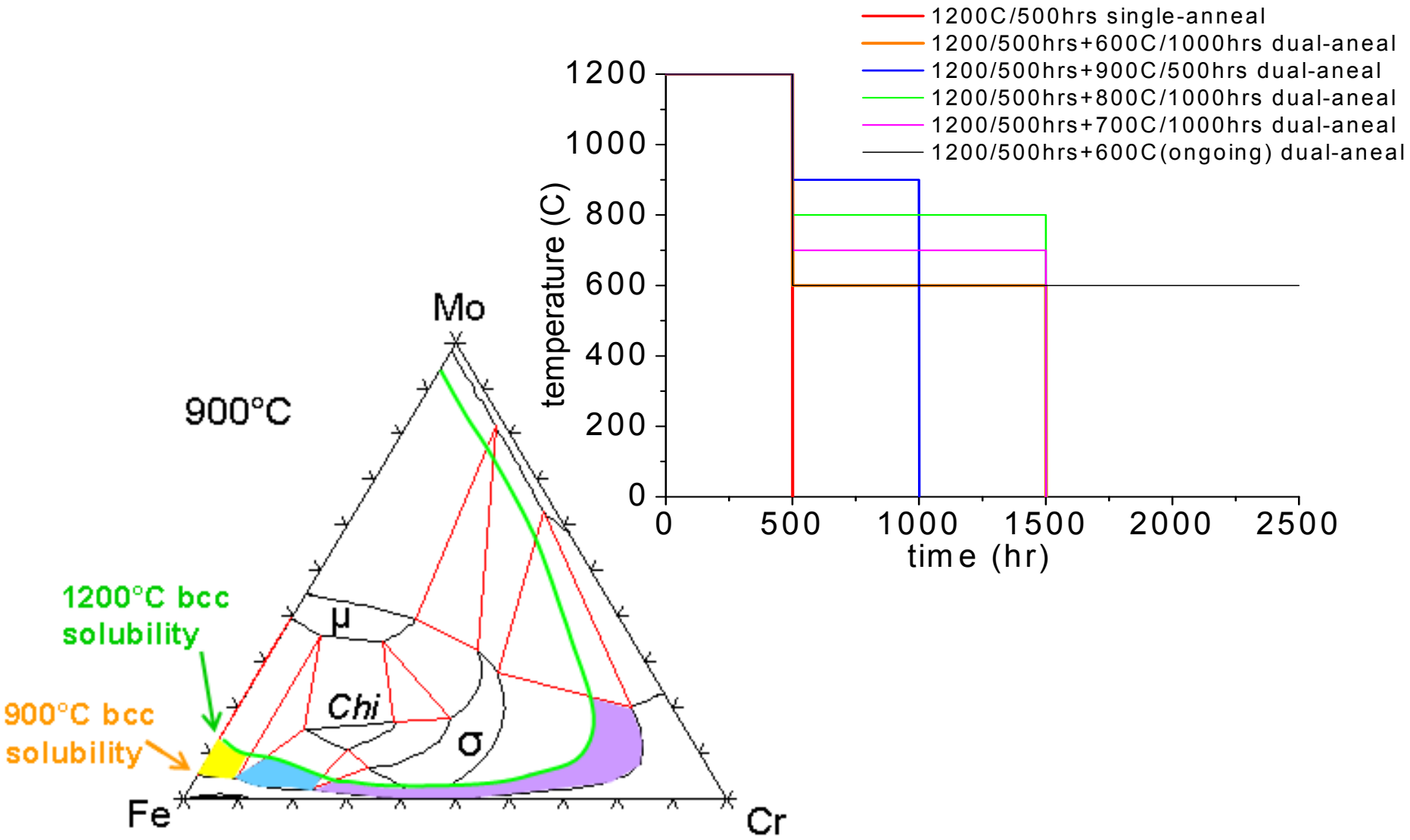
1200°C single-anneal Fe-Cr-Mo





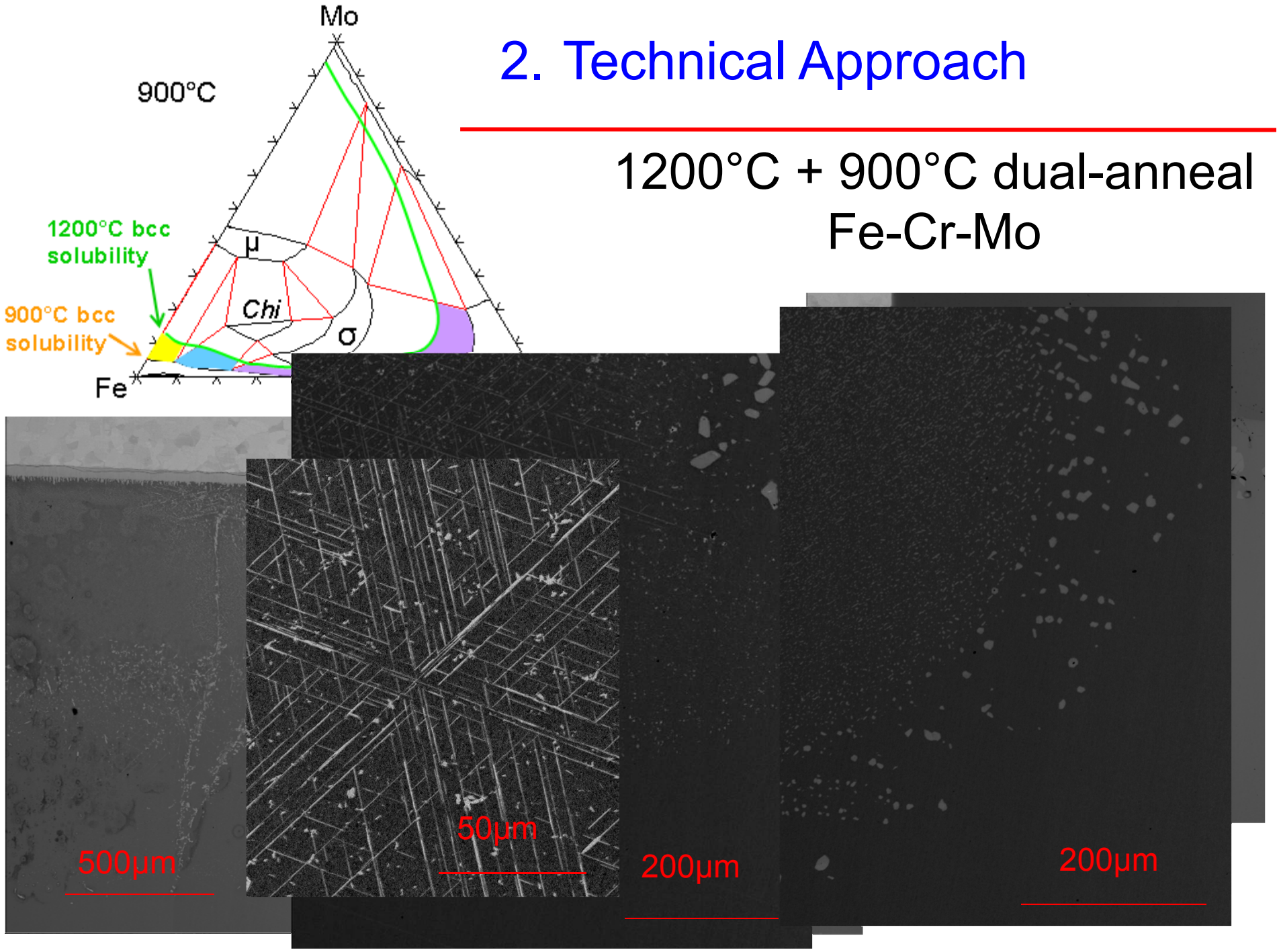
2. Technical Approach

Dual-Anneal Diffusion Multiples

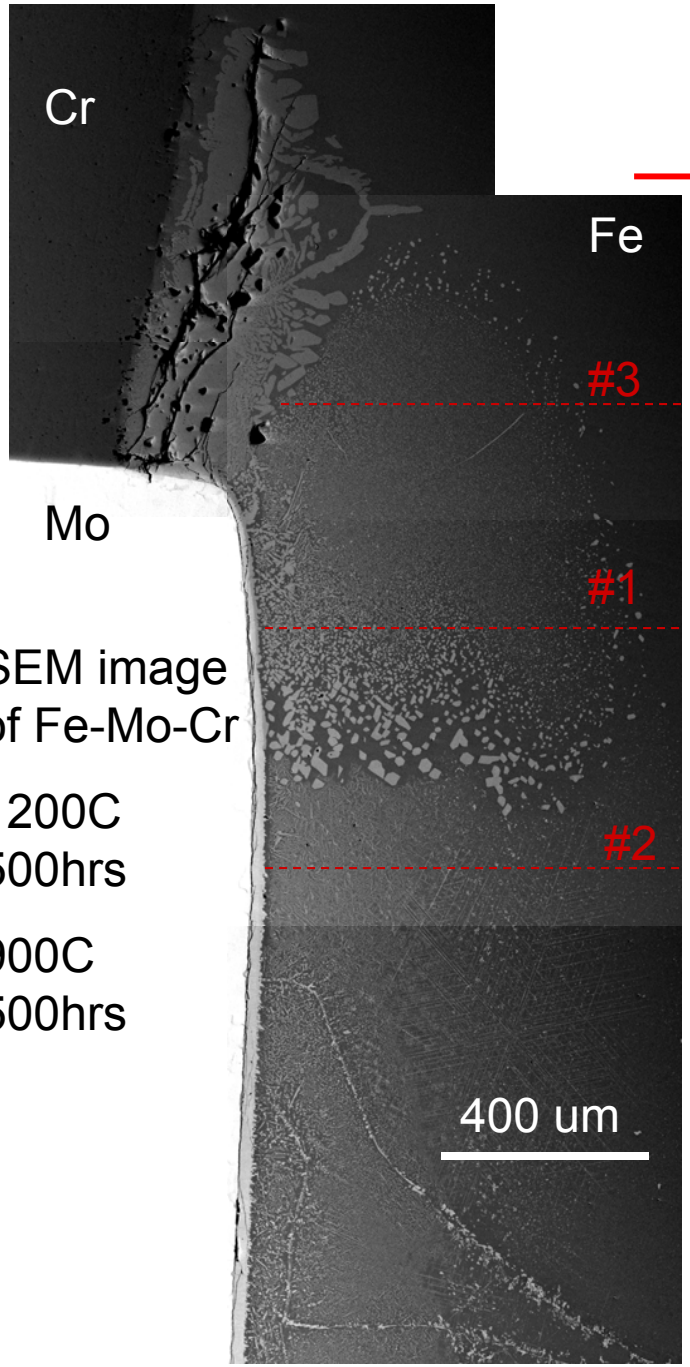


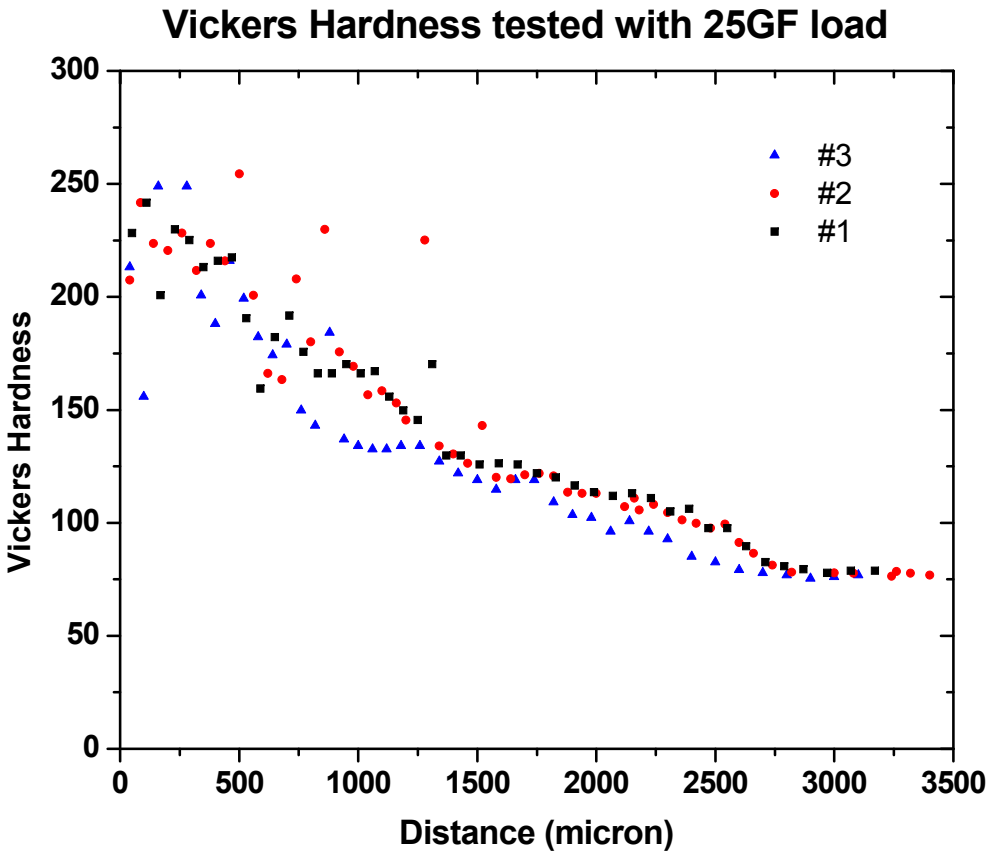
2. Technical Approach

1200°C + 900°C dual-anneal
Fe-Cr-Mo

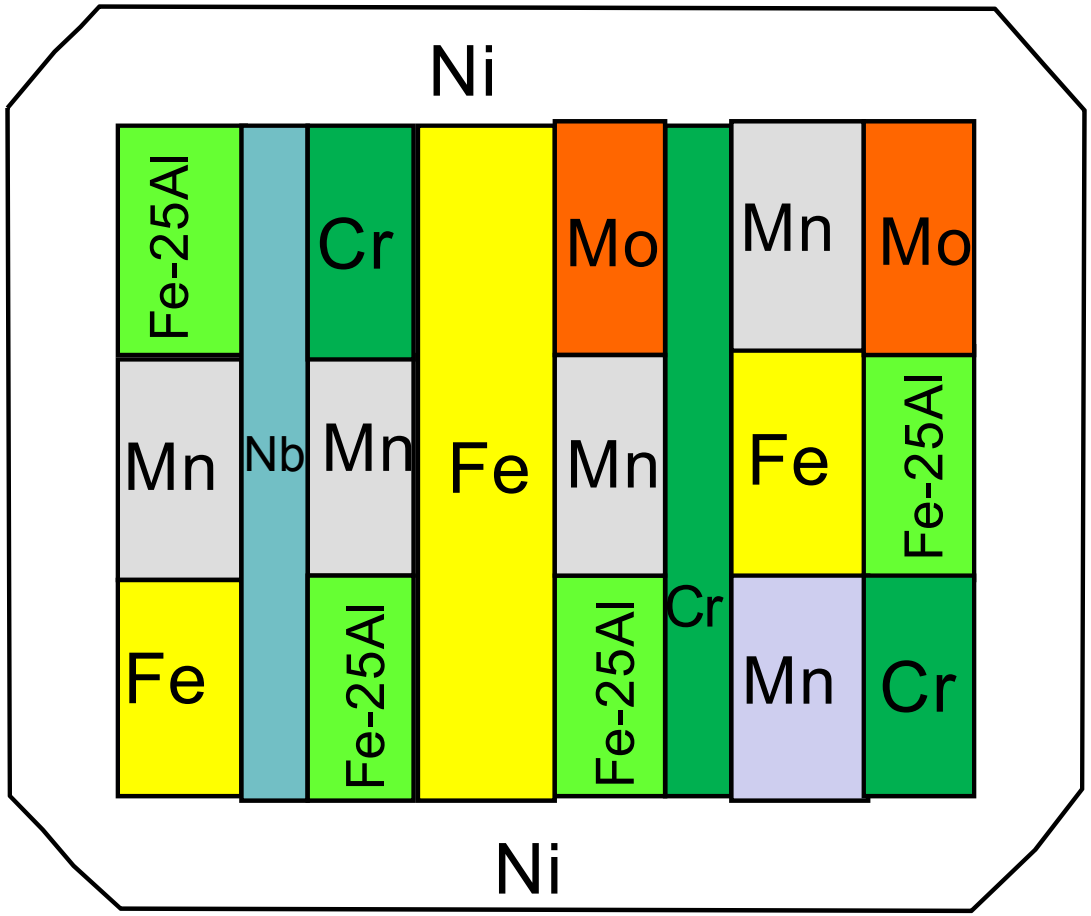


2. Technical Approach





3. Results

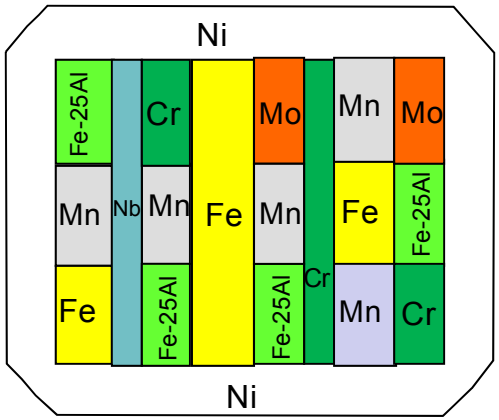


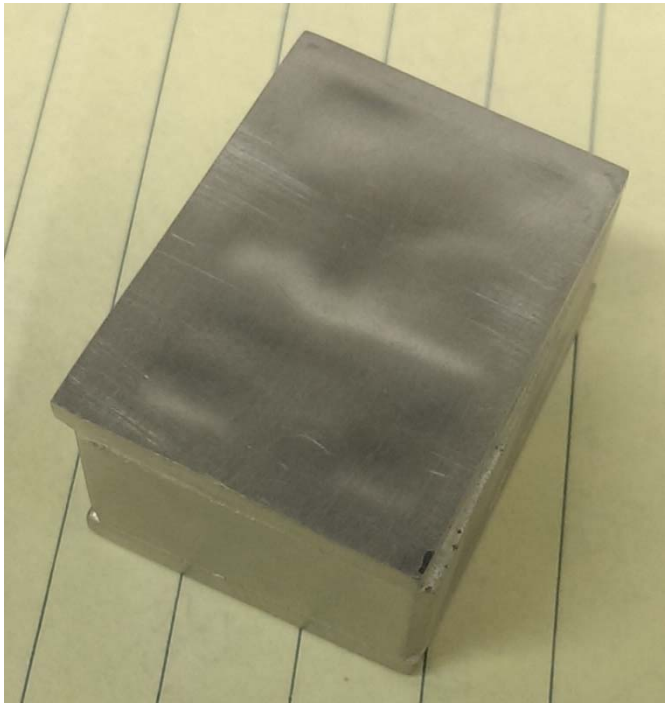
Fe-Mn-Cr
Fe-Mn-Al
Fe-Mn-Ni
Fe-Mn-Mo
Fe-Mn-Nb
Fe-Ni-Al
Fe-Ni-Mo
Fe-Ni-Nb
Fe-Cr-Ni
Fe-Cr-Nb
Ni-Mn-Cr
Ni-Mn-Mo
Ni-Mn-Nb
Ni-Mo-Nb
Ni-Cr-Nb

Fe-Mn-Ni-Al
Fe-Mn-Nb-Al
Fe-Mn-Cr-Al
Fe-Ni-Mo-Al
Fe-Ni-Cr-Al
Fe-Ni-Nb-Al.

Three such diffusion multiples are made for different temperature treatments

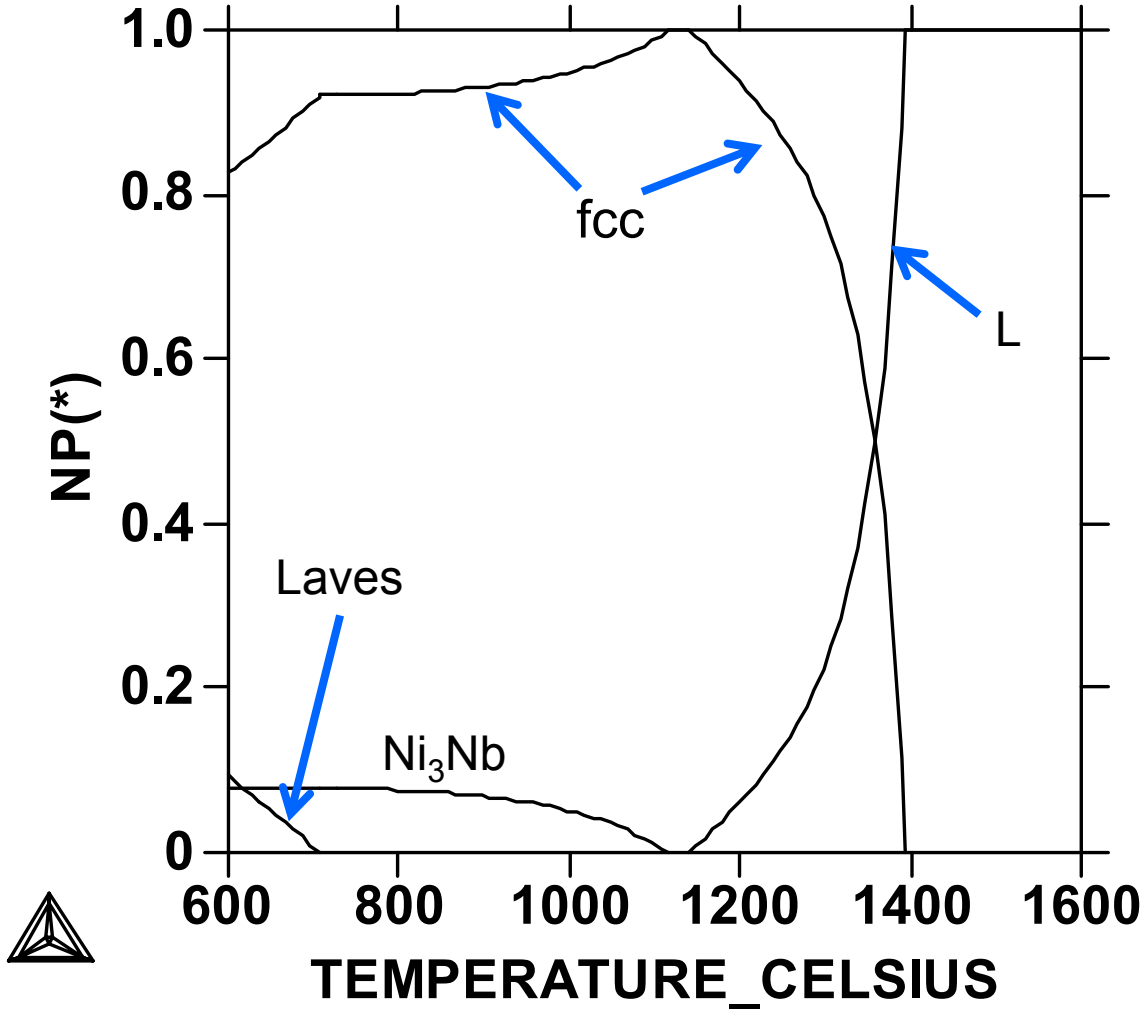
3. Results


Ni
Fe-25Al
Mn
Fe
Nb
Cr
Mn
Fe-25Al
Fe
Mo
Mn
Fe-25Al
Cr
Mn
Fe
Mn
Mo
Fe-25Al
Cr
Ni



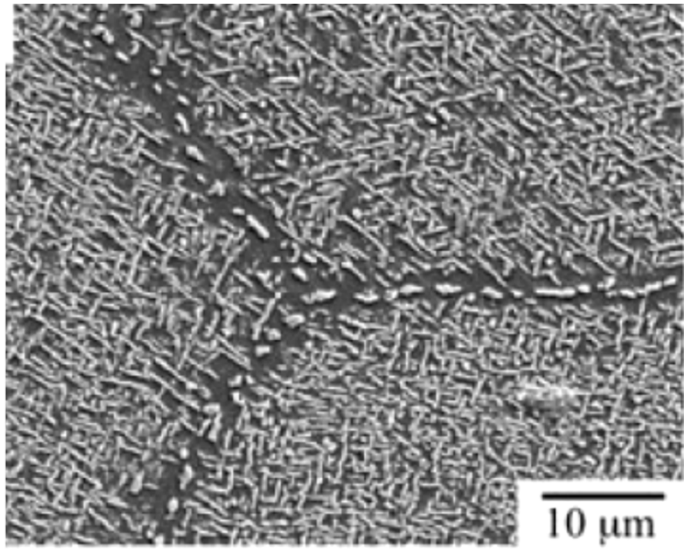
3. Results

Computational thermodynamics



Fe-20Cr-30Ni-2Nb (at.%)

Current Fe-database doesn't do a good job in predicting the phases in the Takeyama alloys



4. Summary

- We have designed and made a diffusion multiple to screen for new high temperature austenitic steel compositions (Fe-Mn-Cr-Al-Ni-Mo-Nb)
- We designed a ferritic steel with a new precipitate identified from a diffusion multiple together with thermodynamic calculations;
- We will generate large amount of data and useful information to help identify new steel compositions, especially high Mn austenitic steels.

5. Future Work

- Property measurements for the ferritic steel that has been designed;
- Generate large amount of data and useful information to help identify new steel compositions, especially high Mn austenitic steels;
- Design high Mn austenitic steels for cast and property tests.

Thank you!

DOE/UCR Award FE0008960

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