Computational Design of Weldable, High-Cr Ferritic Steel

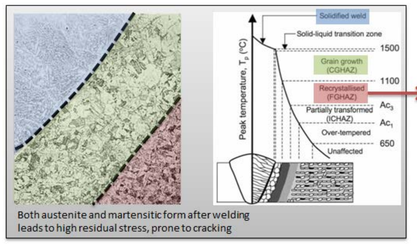
David Snyder, QuesTek Innovations LLC

Department of Energy Small Business Innovation Research (SBIR)
Phase II Grant DE-SC0006222

QuesTek® INNOVATIONS LLC
Materials by Design®
www.questek.com

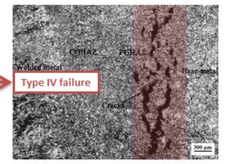
Problem Statement

- New alloys are needed to enable the efficiency goals targeted by the A-USC steam boiler programs:
  - **Improved temperature capability**
  - **Low cost** (ferritic alloys)
  - **Improved Weldability** (*lower Type IV crack susceptibility*)



Both austenite and martensitic form after welding leads to high residual stress, prone to cracking

Type IV failure



Small grain distribution leads to low resistance to grain boundary sliding , most prominent at high temperature and low creep rate

Lei Zhao, Engineering Failure Analysis, Volume 19, January 2012, Pages 22-31

Technical Objectives

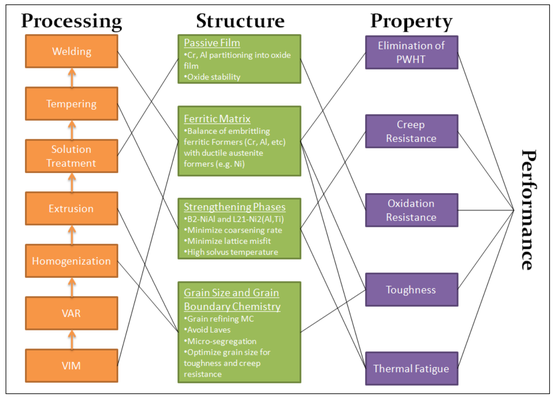
- Develop computational tools needed to design for creep, oxidation, corrosion resistance
- Develop and characterize new ferritic superalloy that addresses key issues of weldability, creep, oxidation and corrosion resistance for A-USC boiler tube applications

TMS ICME MANUFACTURING DESIGN MATERIALS

Current Materials	New Materials for AUSC Power Plant
Operates at ~600-620°C	Operates at 650-700°C
Costly PWHT	Minimal PWHT
Material: P92	Material: QuesTek's Boiler Tube Alloy

Technical Approach – Computational Materials Design and Development

Alloy Design – Flow Block Diagram



Alloy Design Strategies

Fully ferritic, 13Cr alloy

- *Avoid FCC-BCC transformation during welding that is root cause of high residual stresses, Type IV HAZ cracking in current high-Cr ferritic alloys*
- *13Cr for improved corrosion/oxidation resistance*

Optimized precipitation strengthening

- *Ordered B2 (NiAl) and MC carbide strengthening dispersions*
- *Computationally optimized for high coarsening resistance for increased operating temperature >650°*
- *Eliminate embrittling TCP phases from equilibrium at operating temperatures*
- *Precipitation during air cooling to minimize PWHT*

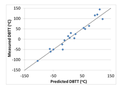
ICME-based process-structure and structure-property modeling to guide alloy design

$$DBTT = DBTT_0 + K_{GS}GS + K_{\Sigma x_i M_i}(Ti + Al) + K_{Ni}Ni + K_{Mn}Mn + K_{Cr}Cr + K_{Mo}Mo + K_{AI}Al$$

DBTT	Grain Size	TiAl*	Ni	Mn	Cr	Mo	Al
14.2	0.4	-482	-18.6	221	-1.5	0	10

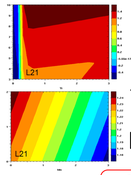
$$DBTT = 14.2 + Grain Size \cdot 0.4 - 482.0 \cdot 0.2 - 1860 \cdot W_{Ti} - 150 \cdot W_{Ti} + 1000 \cdot W_{Al}$$

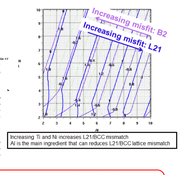
* For small Ti and Al amounts. They act as O and N getters. Anything more than 0.6 Ti and 0.1 Al should be dealt with as individual element.



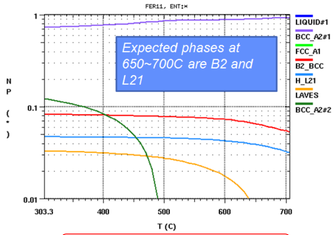
Alloy	DBTT/°C
BT1B	48.136
BT1C1	61.796

DBTT modeling





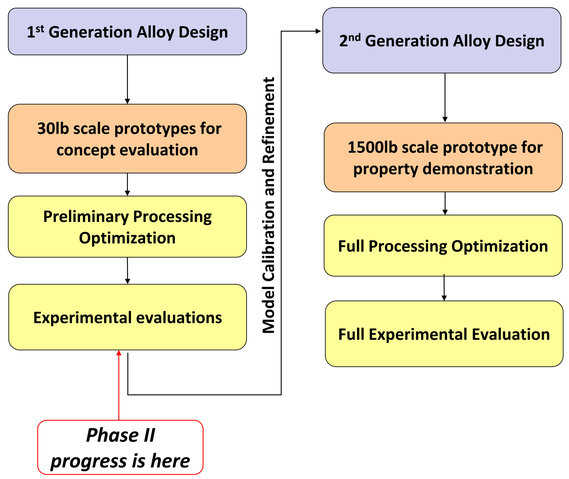
Control of Precipitate coarsening resistance



Thermodynamic step diagrams

Thermodynamics-based approach to computational designing alloys with targeted phase stability to achieve a set of key properties

Alloy prototyping strategy

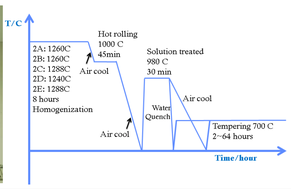


Results to Date

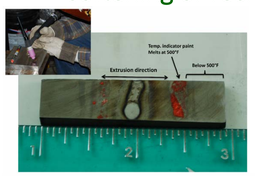
Five concept alloys have been computationally designed, and prototyped at 30lb scale

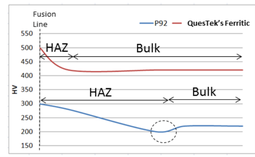
Example Design Parameters:

- *Strengthening phase fraction, coarsening rate*
- *Matrix composition and DBTT*
- *Driving force for TCP phases at operating temperature*

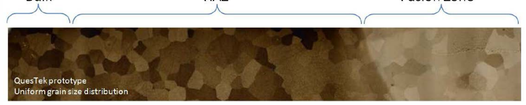


Uniform as-welded microstructure, no evidence of softening or recrystallization in HAZ

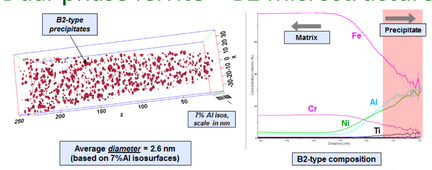




Bulk HAZ Fusion Zone

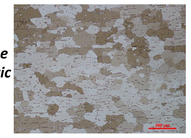


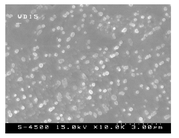
Dual-phase ferrite + B2 microstructure



Strengthening phase present as-cooled (precipitate in weld HAZ without PWHT)

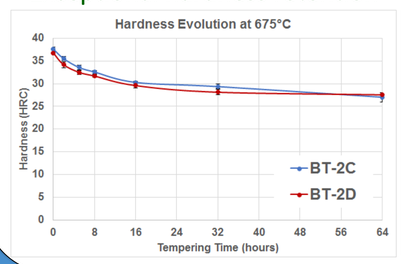
Equiaxed, fine grained ferritic structure



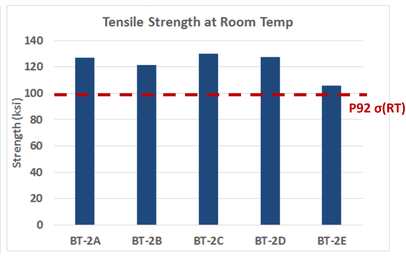


Fine B2 size retained after long term exposure >700°C

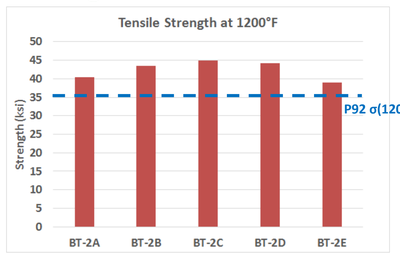
Exceptional hardness retention



RT Strength 20% > than P92



Strength at 1200F 25% > than P92



In Progress:

- Stress/Creep Rupture Testing
  - *Simulated weld HAZ*
- Steam-side Oxidation Testing
- Fireside Corrosion Testing
- Down selection and Scale-up

Next Steps

- Down selection and full process modeling
- Produce at intermediate (1500lb) scale
- Full range of characterization

Beyond Phase II

- Full commercial-scale production
- Tube formability evaluation
- ASME Boiler Code data development

B&W TIMKEN B&W CARPENTER Energy Industries Of Ohio