Advanced Design Concepts for Steels and Alloys Tailored for High-Temperature Fossil Applications (FEAA114)

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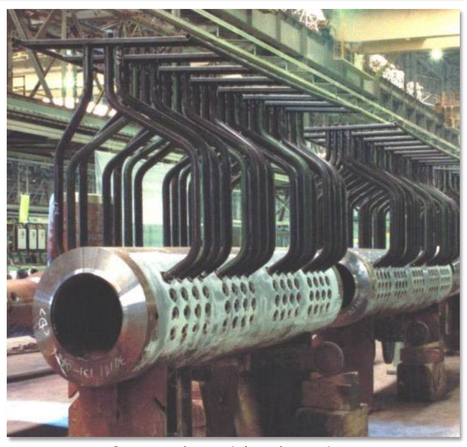
Backgrounds/Motivation

Increasing demands on structural materials capable of higher temperature operation in extreme environments

Require **a new alloy design concept** for improved **high-temperature mechanical performances** and **oxidation/ corrosion resistances**

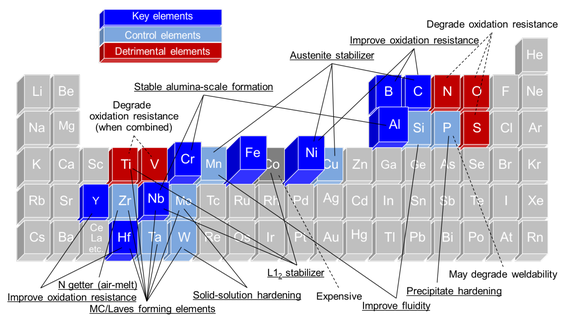


Super heat/re-heater
(Picture courtesy: F. Masuyama)

Objectives/Approaches

Propose and validate a new alloy design strategy including;

- ***Protective, external alumina-scale formation****, and*
- ***Maximized precipitation strengthening,***



Compositional guidance for alumina-forming alloys

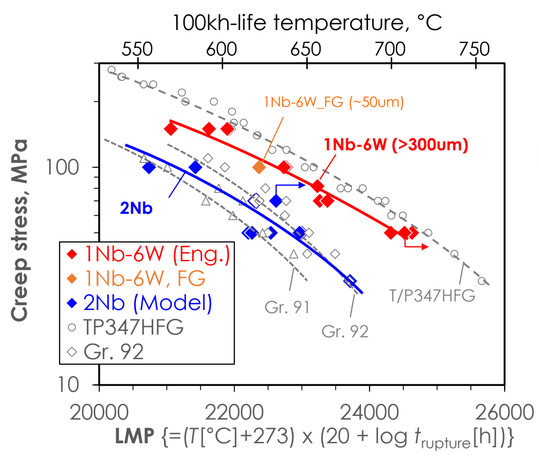
to be applied into three different classes of structural materials; **ferritic**, **austenitic**, and **Ni-base alloys**, with guide from computational thermodynamics

Previous Activities (~FY18)

High Cr Containing FeCrAl Alloys (Ferritic, FCA):

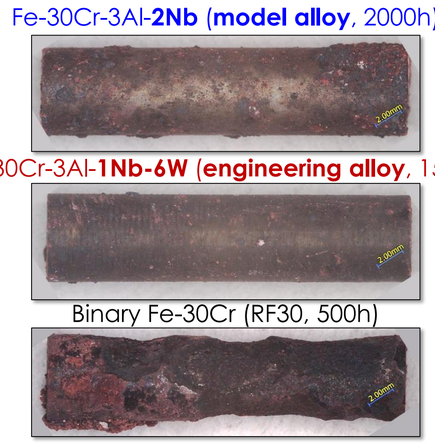
- Achieved a balanced properties (creep, oxidation, and corrosion) in newly proposed high Cr containing FeCrAl alloy, based on **Fe-30Cr-3Al-1Nb-6W** (wt.%)

Larson-Miller Parameter Plot
(tested at 650-800°C and 30-150MPa)



Ash-corrosion test
(Synthetic ash/gas, 500h cycle at 700°C)

Fe-30Cr-3Al-**2Nb** (**model alloy**, 2000h)



Fe-30Cr-3Al-**1Nb-6W** (**engineering alloy**, 1500h)

Binary Fe-30Cr (RF30, 500h)

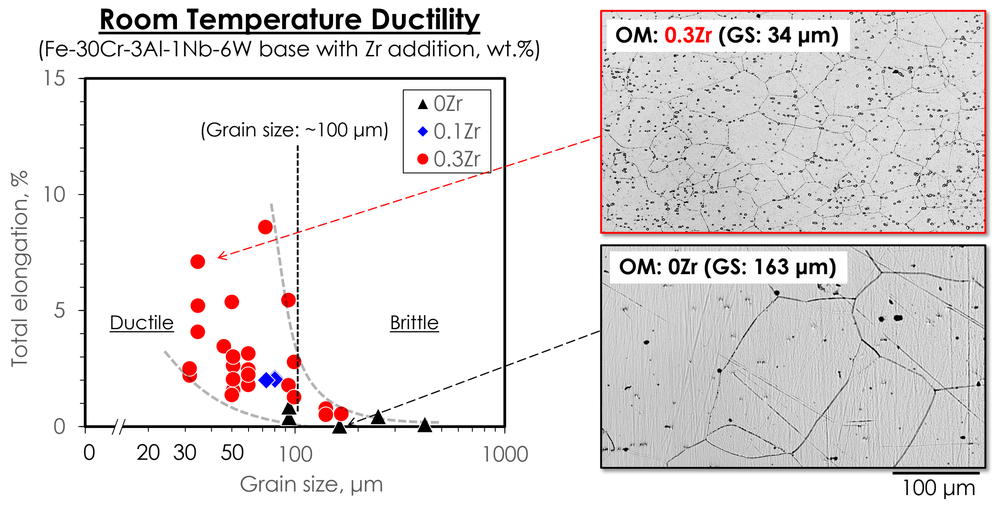
After reference "Yamamoto et al. Proceedings of ASME-ETAM 2018"

FY19 Outputs

Improvement of RT Ductility (FCA):

- Grain refinement effectively improves RT tensile ductility (GS: less than 100 μm)
- Minor alloying additions (e.g. Zr) improved stability of BCC-Fe grain size during solution heat-treatment

Room Temperature Ductility
(Fe-30Cr-3Al-1Nb-6W base with Zr addition, wt.%)

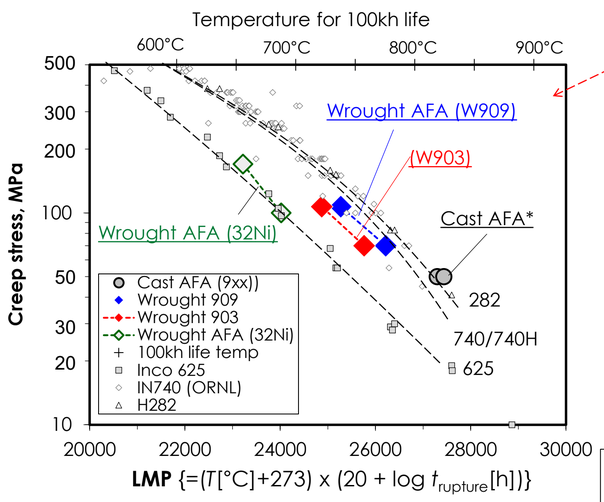


(Note: all alloys were subjected to TMT process + solution heat-treatment at 1200°C)

Excellent Creep Property (Ni base alloy, W909/903):

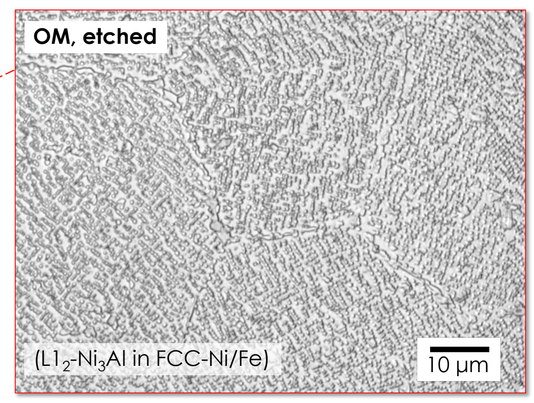
- Alumina-forming Ni-Fe base alloy "W909" exhibited creep properties close to 740H/282 (tested at 850°C)

Larson-Miller Parameter Plot
(tested at 700-850°C and 70-170MPa)



* Data courtesy: G. Muralidharan

Dense L1$_2$ Precipitates in FCC-Ni/Fe
(W909, aged at 900°C for 2400h)



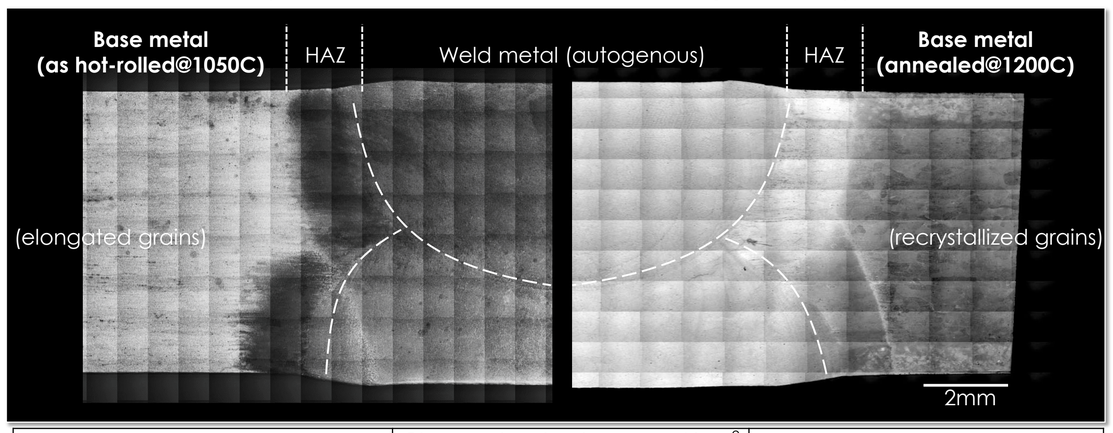
Alloy composition, wt.%

W909: Ni-Fe-Cr-Al-Nb-Ti base (Co-free)
W903: Ni-Fe-Cr-Al-Nb-Ti base (Co-free)
282: 1Fe-**57Ni**-20Cr-**10Co**-9Mo-Ti-Al base
740H: 0Fe-**51Ni**-25Cr-**20Co**-2Nb-Ti-Al base
625: 5Fe-**62Ni**-21Cr-**1Co**-9Mo-4Nb-Ti-Al base

Minimized Crack Formation in Weldments (FCA):

- Grain refinement (+ modified PWHT) reduced crack susceptibility, and improved the impact toughness

Cross-sectional Microstructure
(Fe-30Cr-3Al-1Nb-6W base, As-GTAW, Autogenous weld)



Specimens	Charpy absorbed energy, J/cm^2		Remarks
	RT	**200°C**	
Base, as-rolled	**<1.7**	**51**	**Zr-modified, as-rolled at 1050°C**
Base, annealed	**1.7**	**32**	**Zr-modified, annealed at 1200°C**
Weld metal + PWHT	**1.7**	**0.7**	**Zr-modified, as-welded**
Base, non-GS refinement (1Nb-6W)	0.7	-	Coarse grains
Base, non-GS refinement (2Nb)	1.1	-	Coarse grains

Summary/Wrap Up

- **Validation of the alloy design concept was completed**
- **<u>High Cr FeCrAl ferritic alloy</u> (Fe-30Cr-3Al-1Nb-6W base):**
  - *Achieved attractive, balanced property combination*
  - *Submitted patent application of the alloy series*
  - *Ready to move to a development of industrial grade materials*
- **<u>Alumina-forming Ni-Fe base alloys</u> (Ni-Fe-Cr-Al-Nb-Ti base, Co-free):**
  - *Excellent creep performance close to 740H/282*

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