Effects of Exposures on Superalloys for Space Applications

T. P. Gabb, A. Garg, J. Gayda

The industry is demanding longer term service at high temperatures for nickel-base superalloys in gas turbine engine as well as potential space applications. However, longer term service can severely tax alloy phase stability, to the potential detriment of mechanical properties. Cast Mar-M247LC and wrought Haynes 230 superalloys were exposed and creep tested for extended times at elevated temperature. Microstructure and phase evaluations were then undertaken for comparisons.

Effects of Exposures on Superalloys for Space Applications

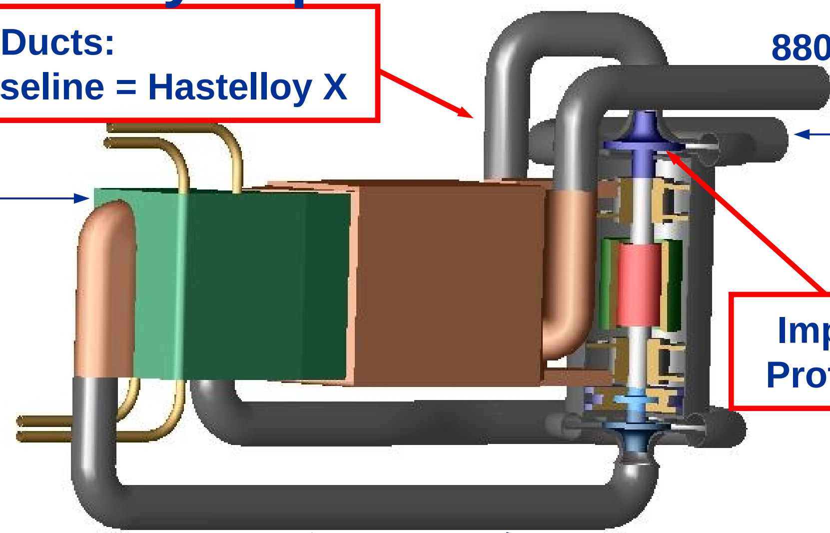
Tim Gabb[1], Anita Garg[2] , John Gayda[1]

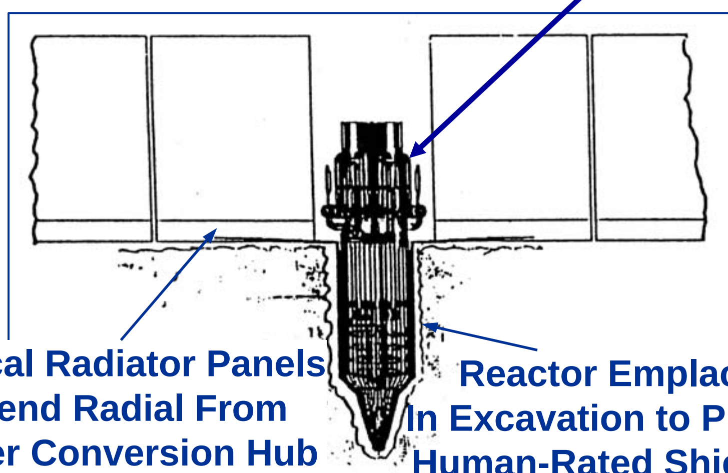
Properties and Performance of High Temperature Alloys and Coatings

February 26, 2007

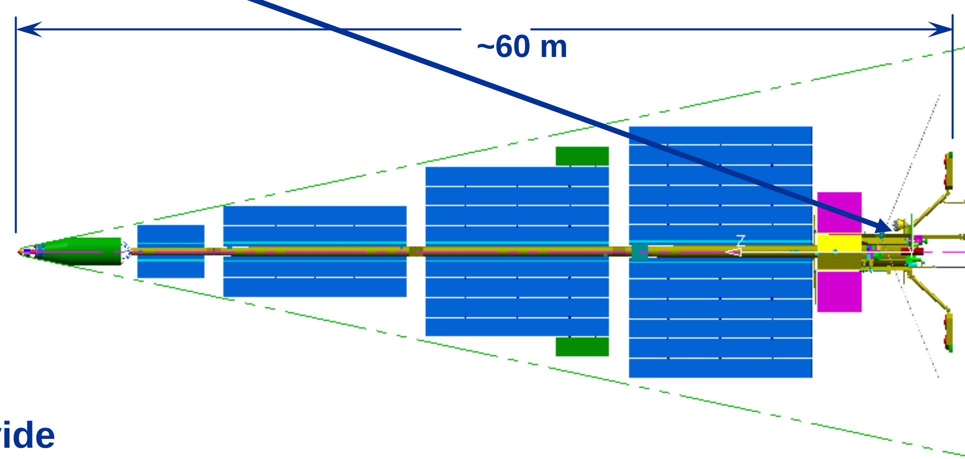
1. NASA Glenn Research Center
2. University of Toledo/NASA GRC

Notional Brayton Cycle for Power Generation in Space Will Need Superalloy Impeller and Ducts





500 kW-Class Lunar Power Systems



Jupiter Icy Moons Orbiter Design

Requirements

- Mild pressures < 1.4 MPa	- High temperatures up to 1150K
- Minimal on-off cycles <100	- Long operation up to 50,000 h
- Inert environment of He-Xe	- No repairs usually possible

Statement of Problem

- The required temperatures and times are high for formable, weldable duct superalloys: sufficient creep resistance here?

-The temperatures and times could cause γ' precipitate coarsening in impeller superalloys: affecting creep, strength, and high cycle fatigue resistance?

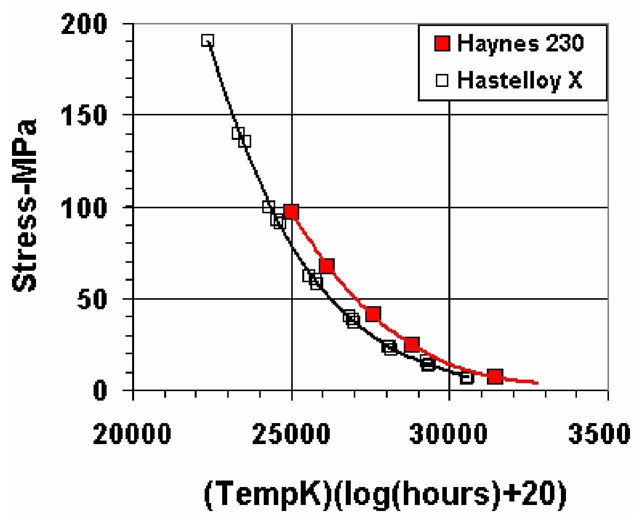
-In both components, phase instabilities and harmful topological close packed phases are possible: σ, μ, η, δ; continuous carbide films forming?

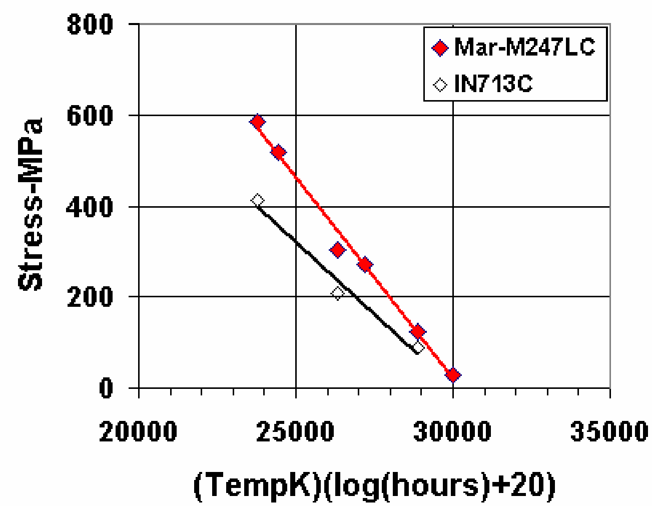
Objective

- Screen exposure issues for improved duct and impeller superalloys:

Duct: Haynes 230® Impeller: Mar-M247LC®

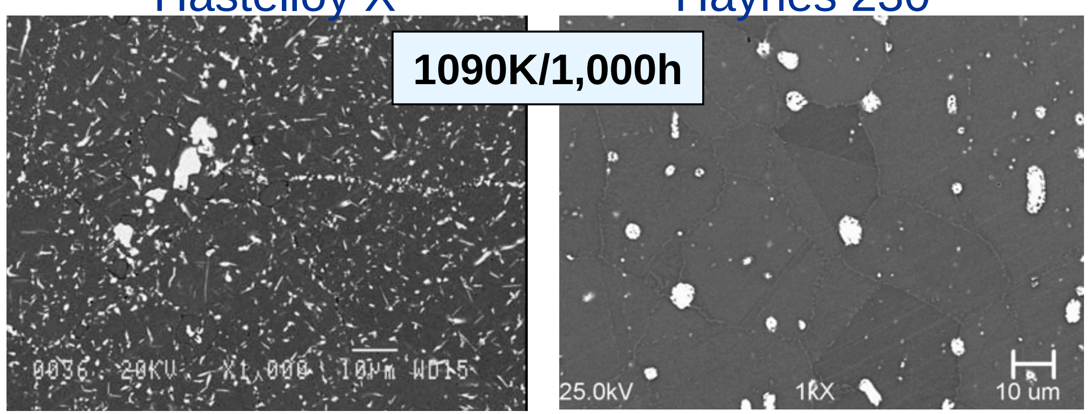
Improved Creep-Rupture Life





Improved Phase Stability

Hastelloy X Haynes 230



M_6C, $M_{23}C_6$, σ M_6C and $M_{23}C_6$

®Haynes International ®Cannon-Muskegon

Materials

- Haynes 230
  - -Hot rolled plate, solution annealed + rapid air quenched
- Mar-M247LC
  - -Cast + hot isostatic pressed as 1.9 cm dia., 16 cm long round bars, solution annealed 1490K/2h + gas quenched, aged 1145K/20h

Procedures

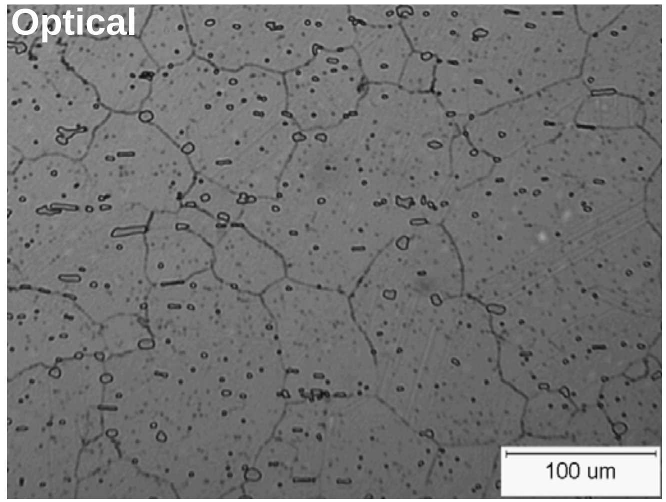
- Exposed samples at 1090 and 1200K for 1,000; 3,240; 10,000 h
- Performed microstructural evaluations
  - Scanning Electron Microscope (SEM), Field Emission SEM, Transmission Electron Microscope, X-ray diffraction
- Tested samples from material exposed at 1090K / 3,240 h
  - -Haynes 230: creep   -Mar-M247LC: creep, tensile, high cycle fatigue

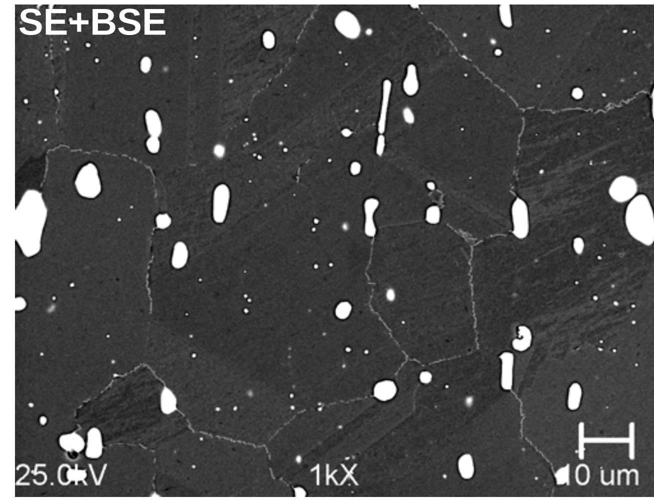
Chemistries and Initial Microstructures

Element - wt.%	Al	B	C	Co	Cr	Cu	Fe	Hf	La	Mn	Mo	Ni	Si	Ta	Ti	W	Zr
Mar-M247LC	5.60	0.015	0.090	9.40	8.3			1.4		0.02	0.50	Bal.	0.01	3.20	0.70	9.50	0.011
Haynes 230	0.29	0.002	0.110	0.22	21.9	0.04	1.12		0.02	0.49	1.29	Bal.	0.39			13.87	0.011

Haynes 230 had $(W,Cr)_6C$ and $(Cr,W)_{23}C_6$ carbide phases in a γ matrix

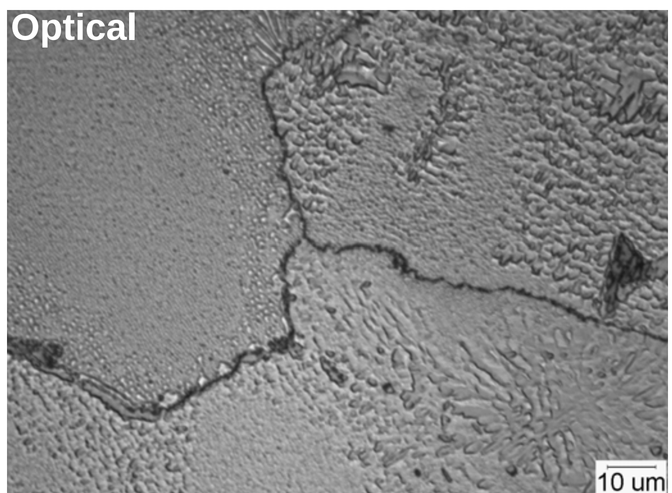
33 μm grain width

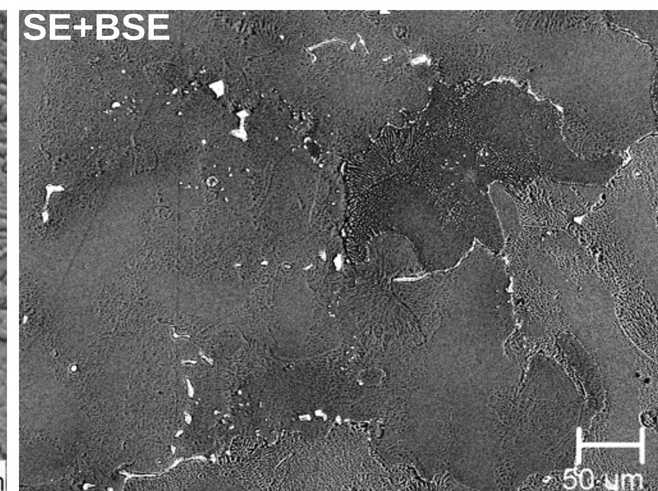




Mar-M247LC had (Hf,Ta)C and trace $(Cr,W)_{23}C_6$ carbides in a γ matrix, with γ' precipitates

700 μm grain width

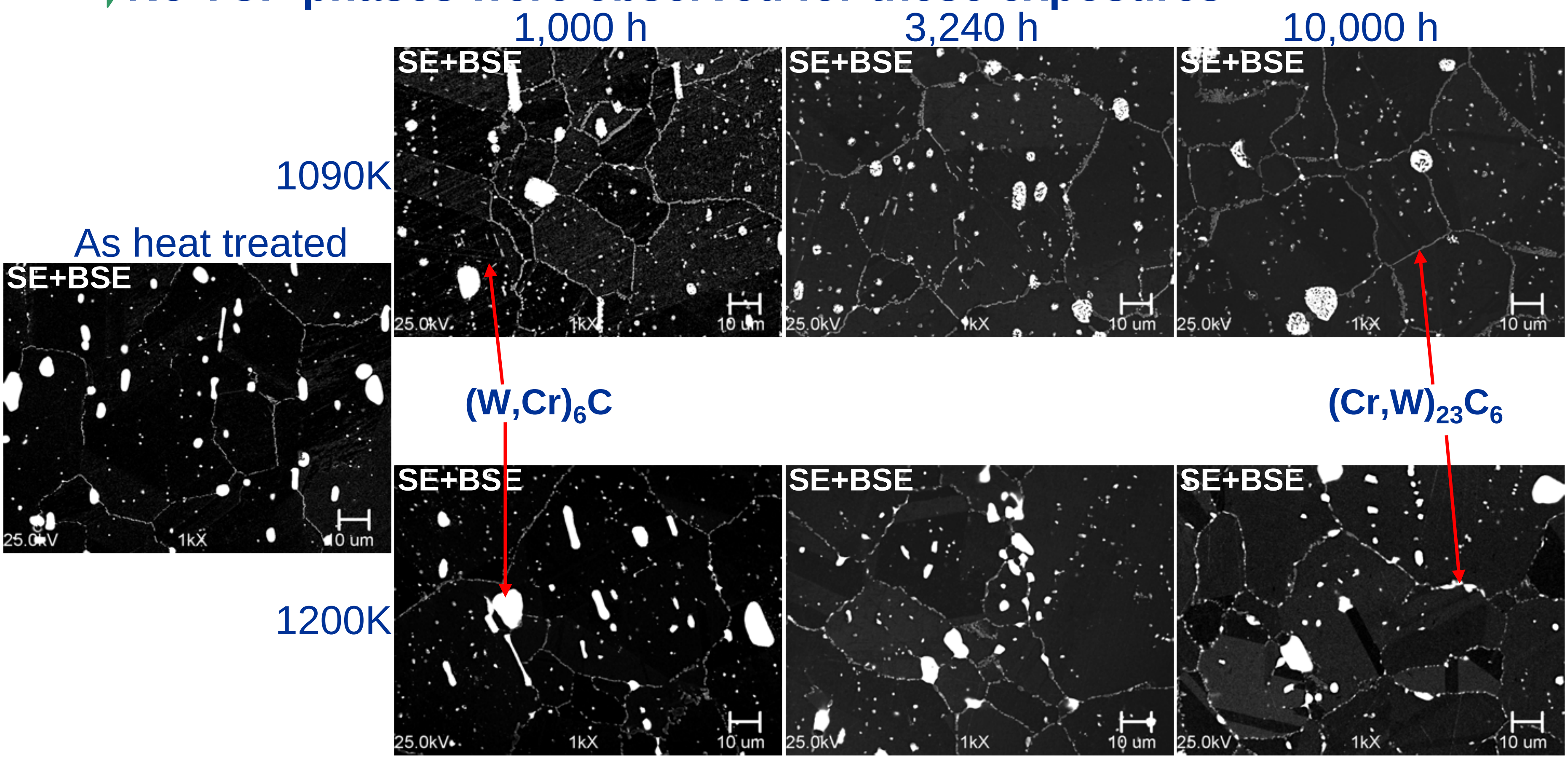




SE+BSE - Mixed Secondary Electron + Back Scattered Electron Images

Haynes 230: Exposure Effects on Microstructure

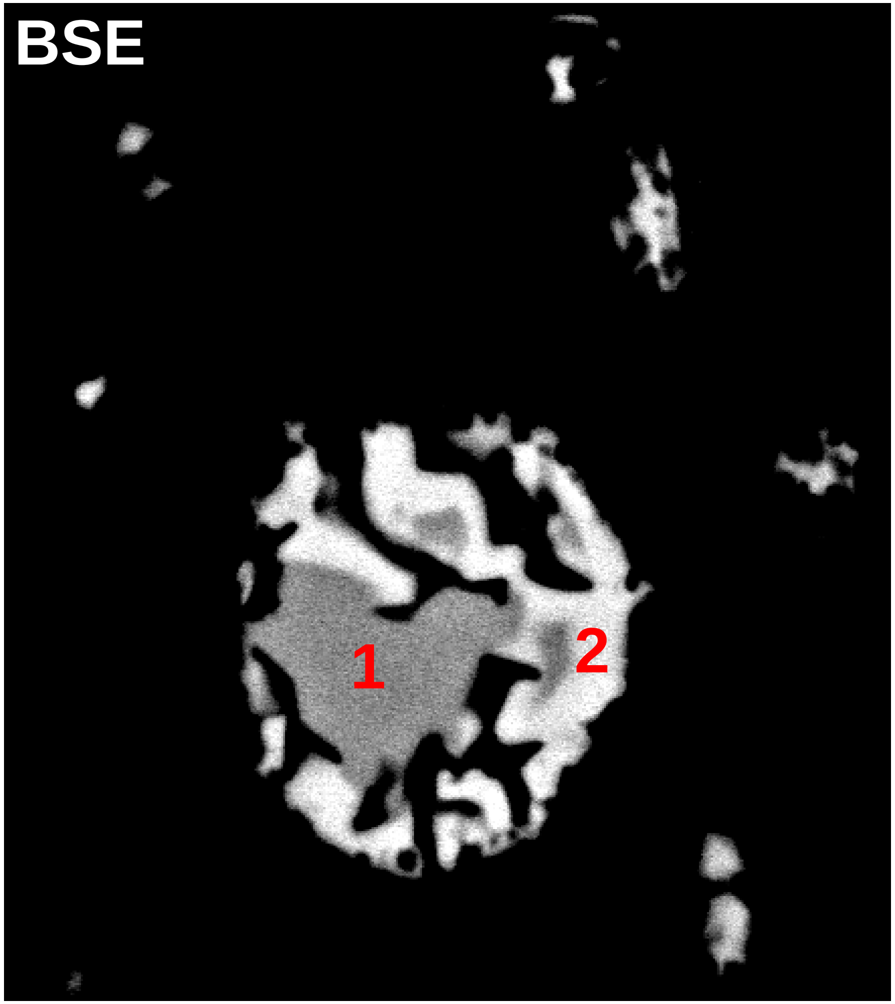
No TCP phases were observed for these exposures

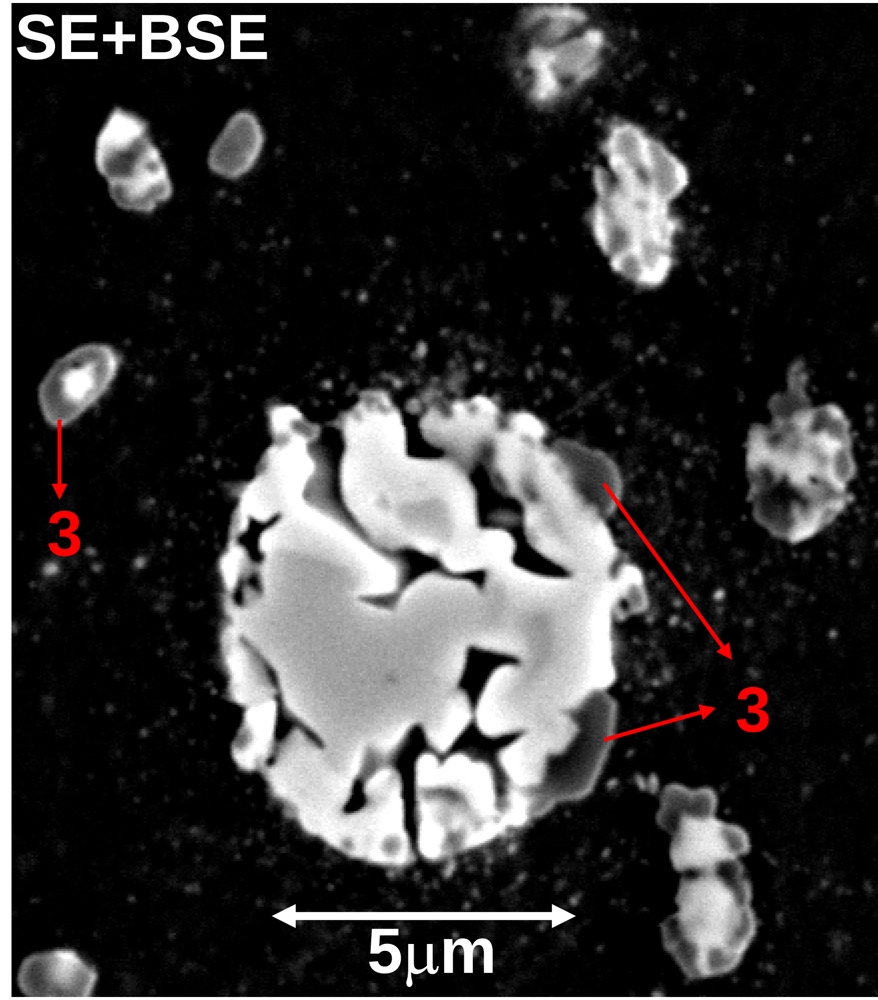


- (Cr,W)$_{23}$C$_6$ content appears to increase
- Larger (W,Cr)$_6$C is changing within grains for exposures at 1090K
- Mixed SE+BSE imaging allows both carbides to be discerned

Haynes 230 Exposure Effects on Carbides at 1090K

Exposed 1090K / 3,240 h





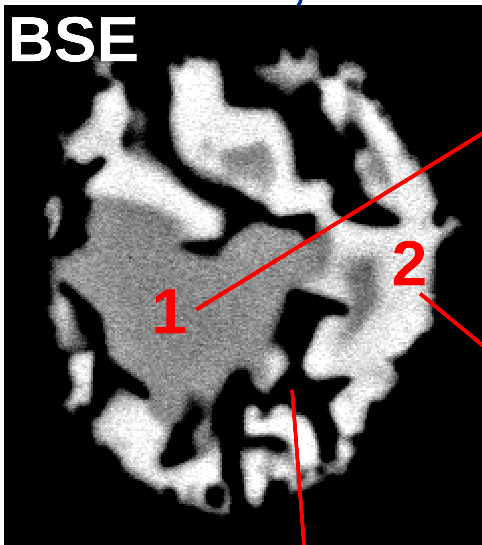
1,2 : M_6C

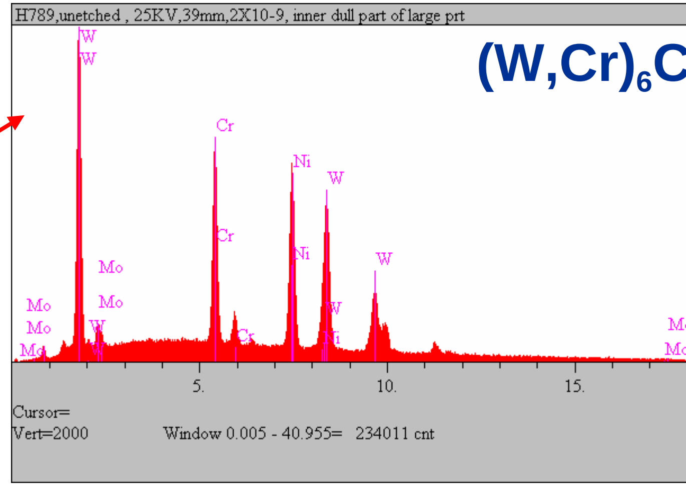
3 : $M_{23}C_6$

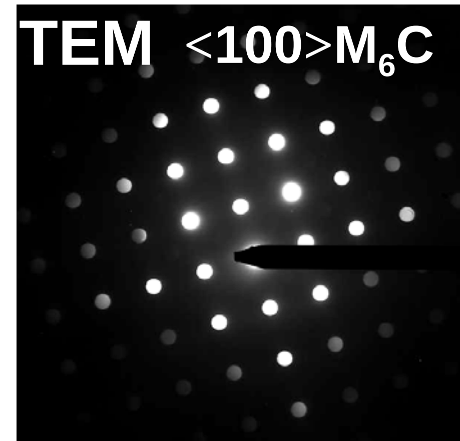
- M_6C carbides within grains are transforming in part to $M_{23}C_6$, but there's more going on

Haynes 230: Exposure Effects on Carbides at 1090K

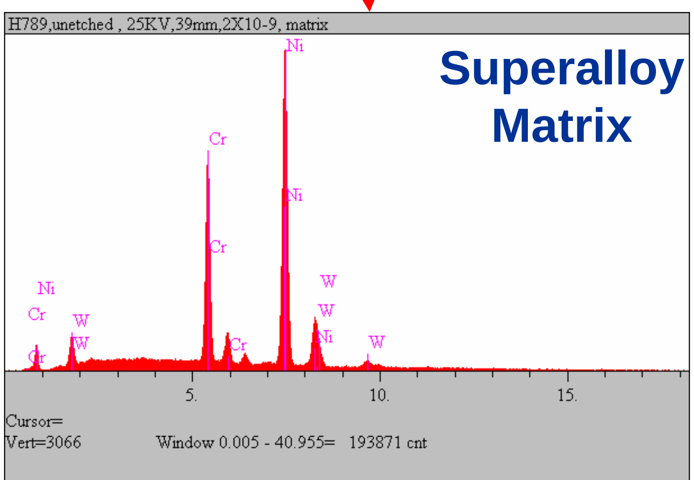
1090 K / 3,240 h

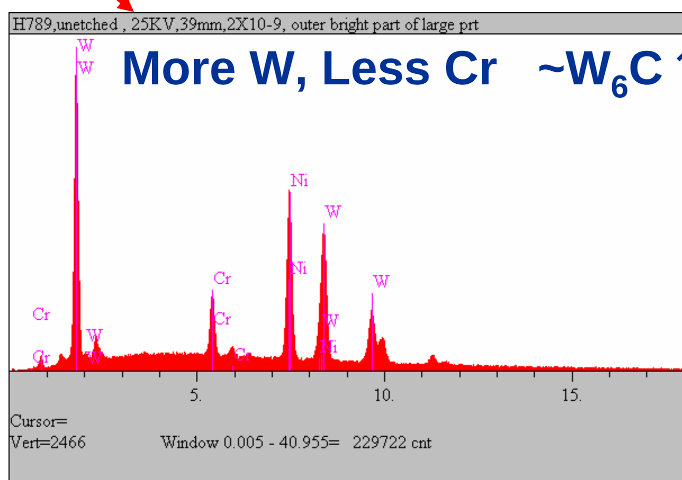






Diamond Cubic M$_6$C

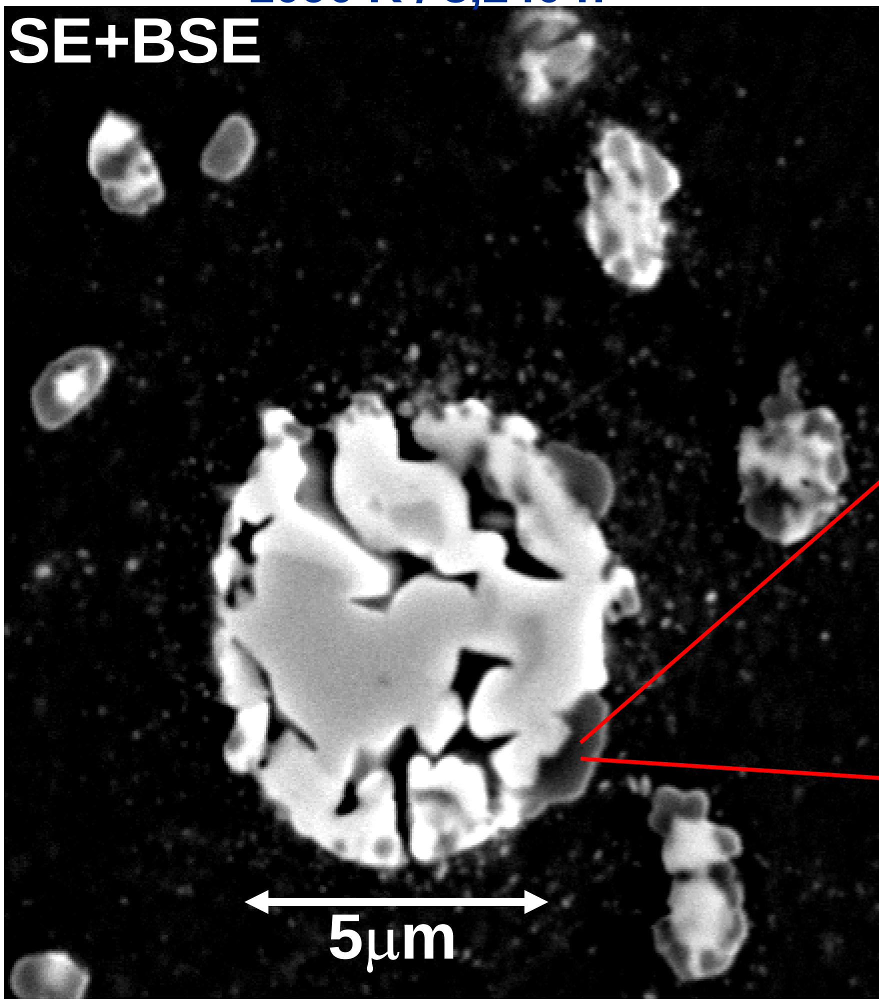


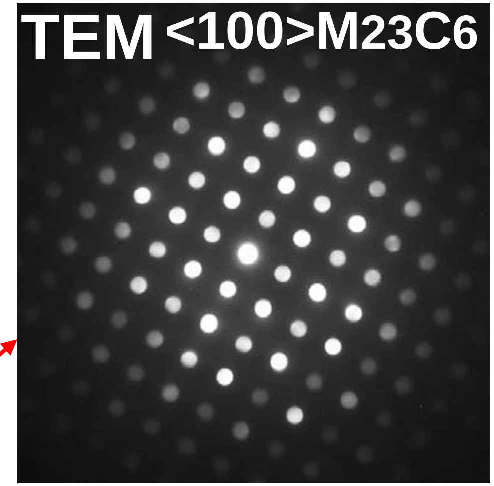


- Cr is diffusing out of M$_6$C, which changes BSE contrast

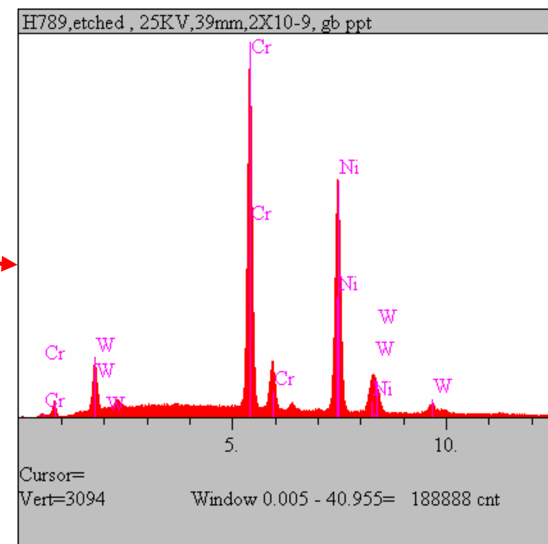
Haynes 230: Exposure Effects on Carbides

1090 K / 3,240 h



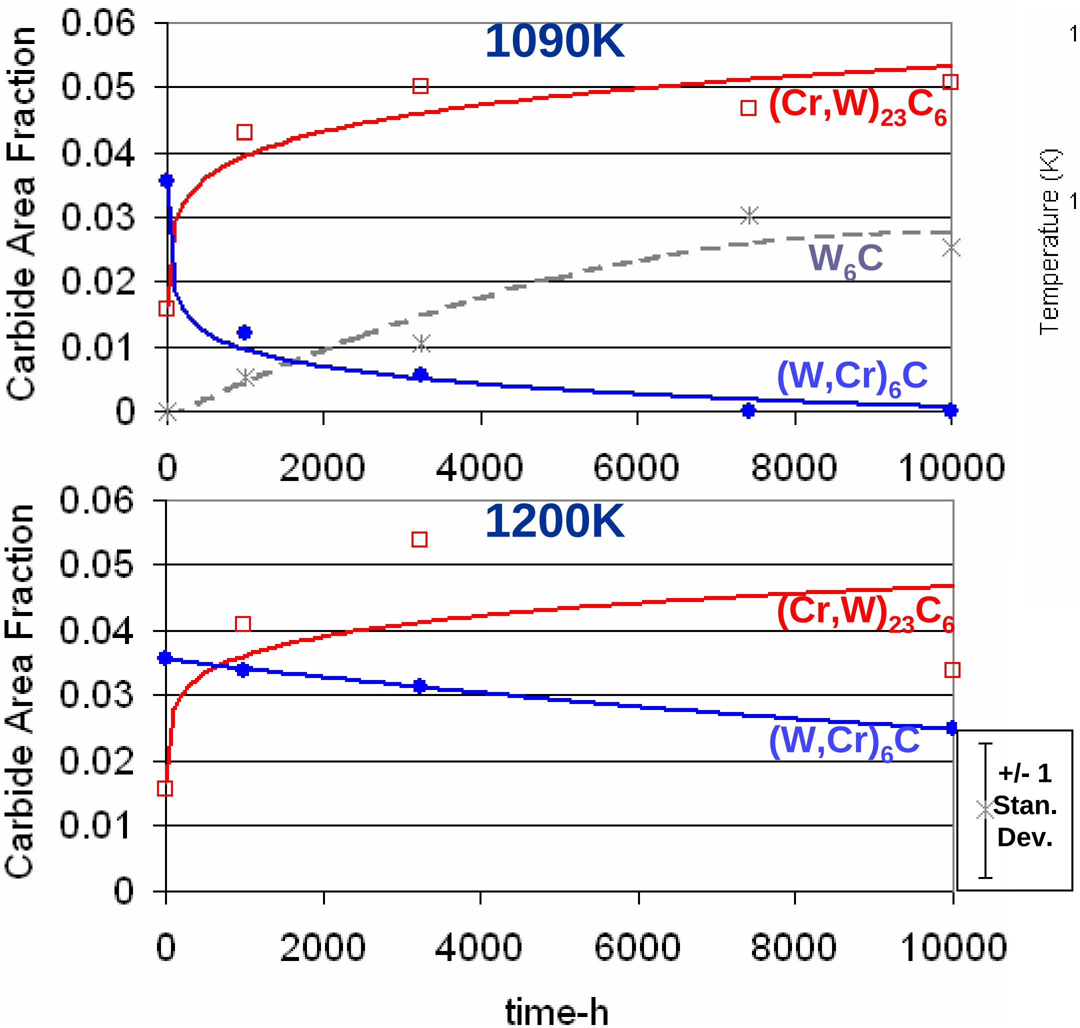


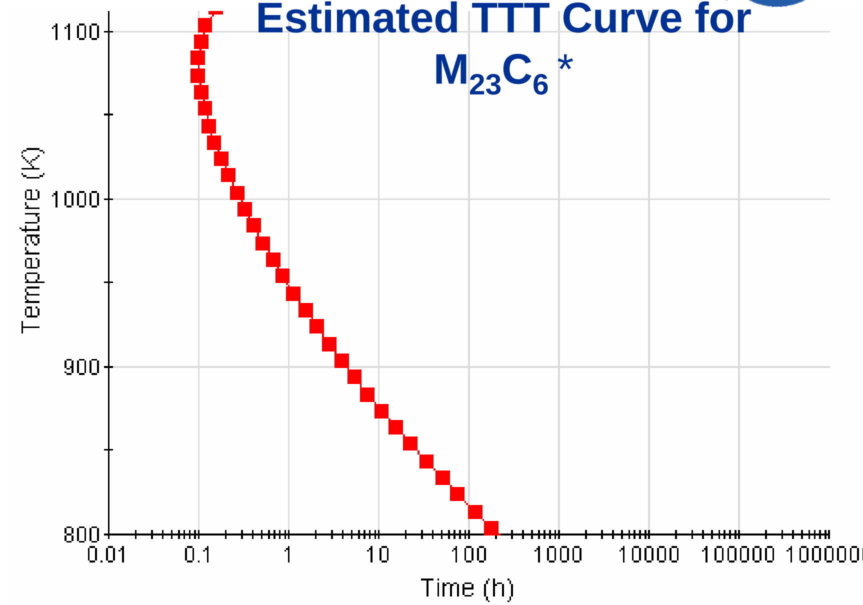
FCC $M_{23}C_6$



Phase 3 Was Identified as $(Cr,W)_{23}C_6$

Haynes 230: Exposure Effects on Carbides

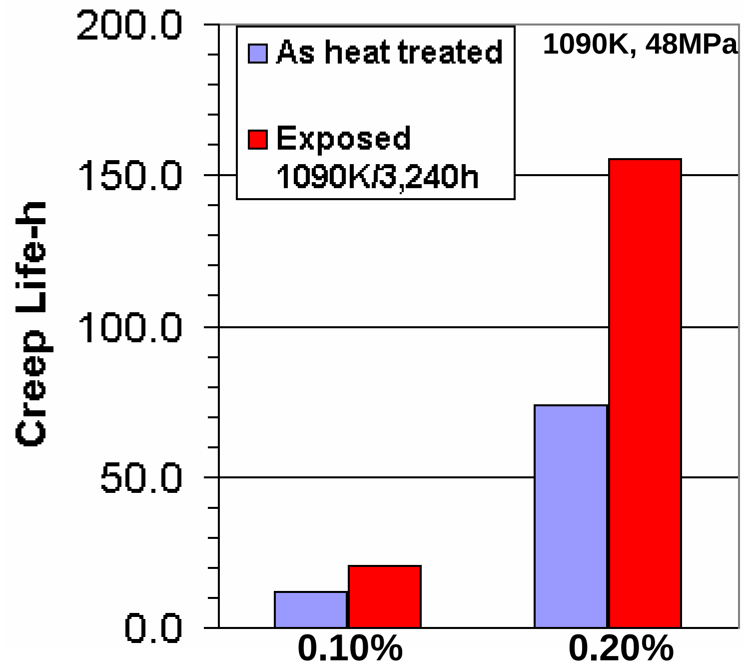




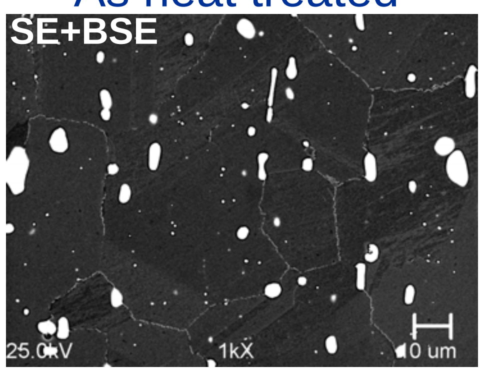
- $(Cr,W)_{23}C_6$ content rapidly increases, then stabilizes during exposures at both 1090 and 1200K
- $(W,Cr)_6C$ content within grains rapidly decreases during exposure at 1090K

*JMatPro-Ni 4.0

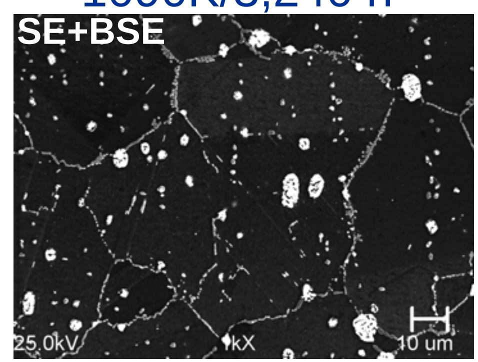
Haynes 230: Exposure Effects on Key Property-Creep



As heat treated



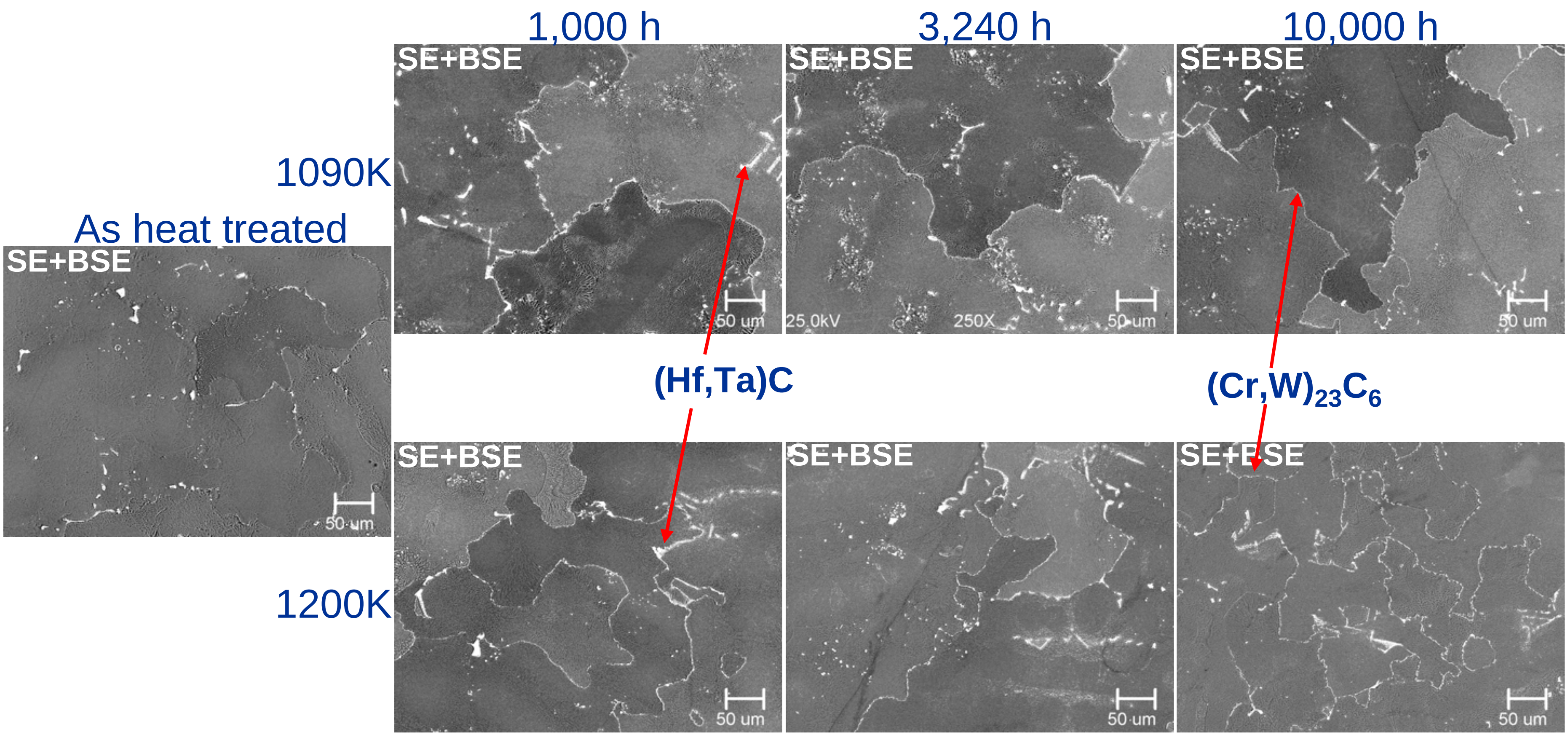
1090K/3,240 h



- 1090K / 3,240 h exposure moderately improves creep resistance at 1090K / 48 MPa
- Can be attributed to the increase in carbide frequency

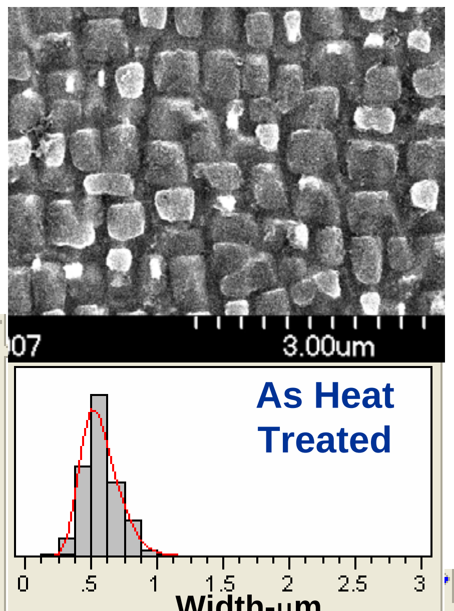
Mar-M247LC: Exposure Effects on Carbides

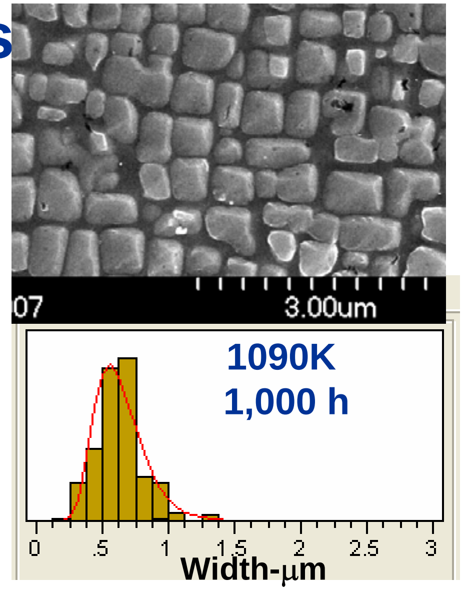
No TCP phases were observed for these exposures

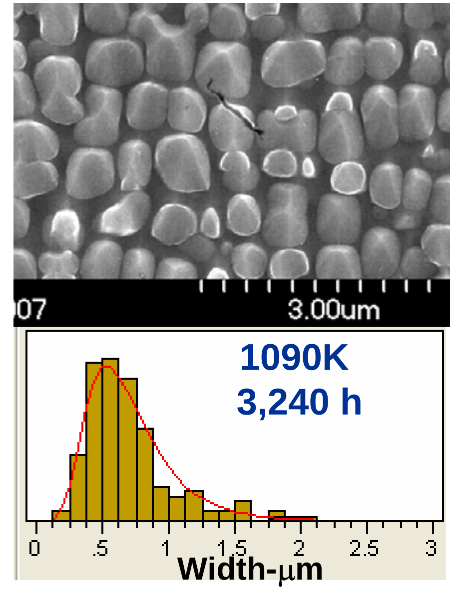


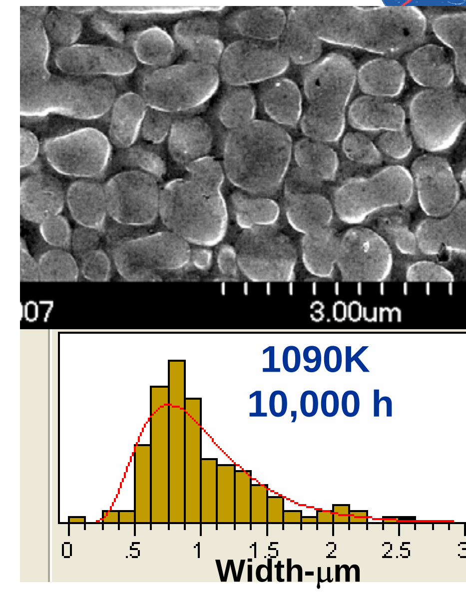
- $(Cr,W)_{23}C_6$ content appears to increase at the grain boundaries

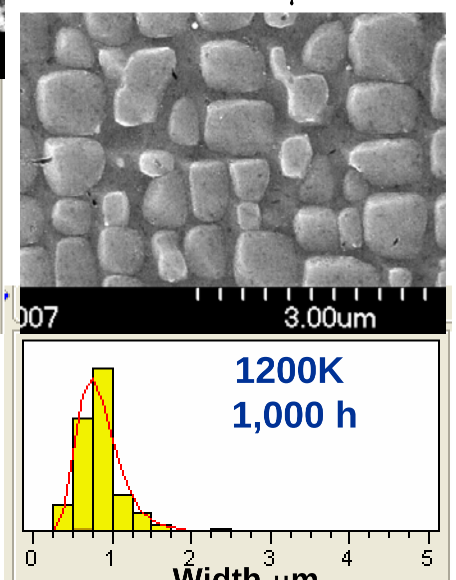
Mar-M247LC: Exposure Effects on γ' Precipitates in Dendrite Cores

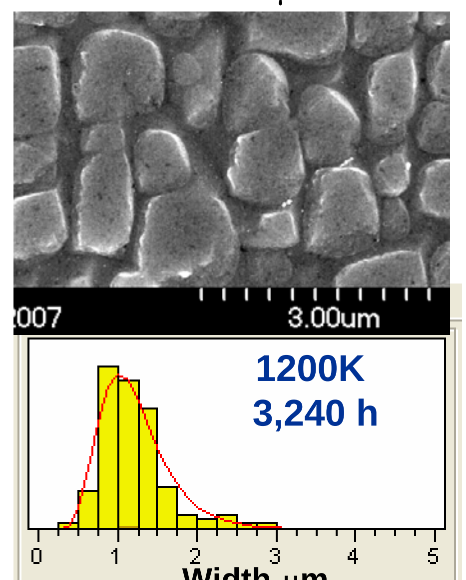


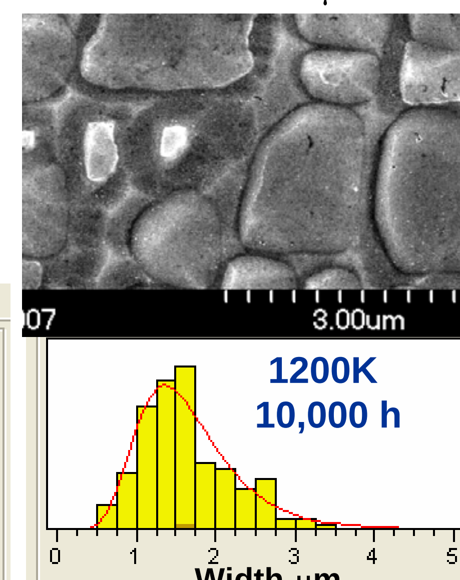








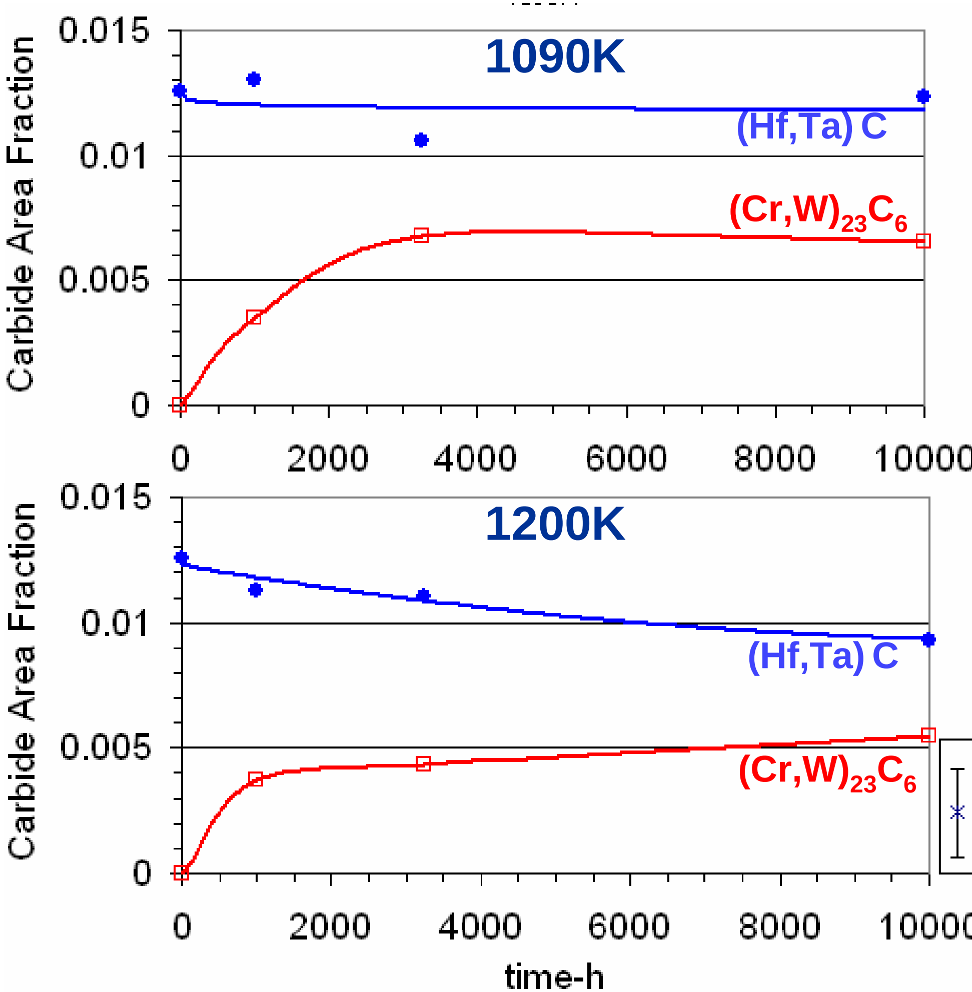




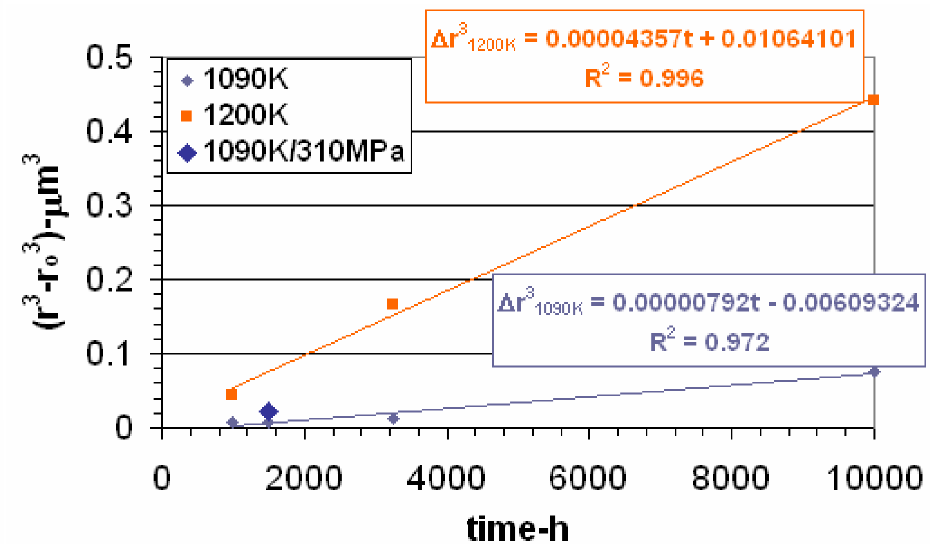
- Coarsening occurs during exposures at both 1090 and 1200K

Mar-M247LC: Summary of Exposure Effects

Carbide Contents



γ' Coarsening

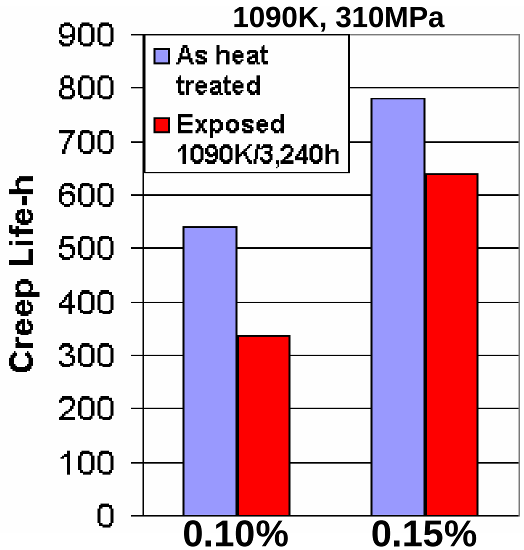


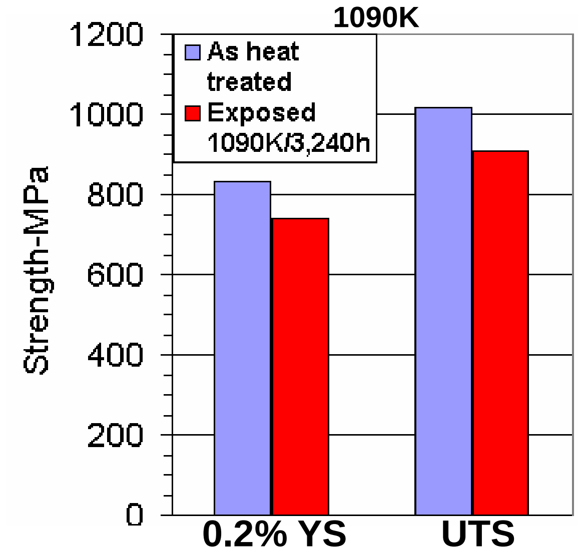
Predictable Coarsening
$r^3 - r_o^3 = Kt$
Consistent with
LSW** theory

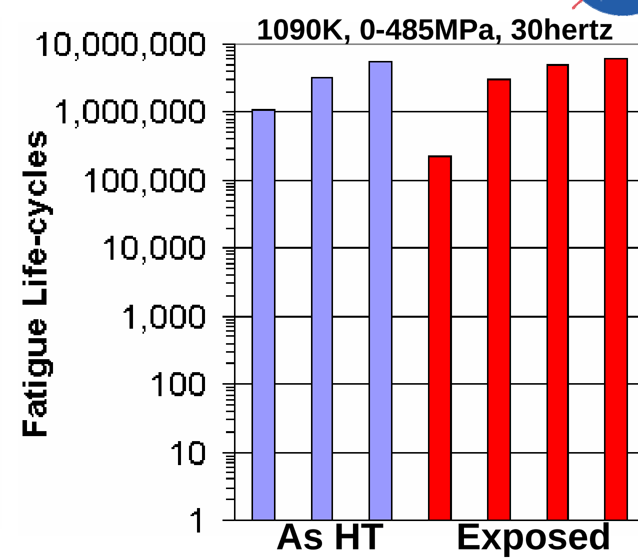
-$(Cr,W)_{23}C_6$ content rapidly increases, then stabilizes at grain boundaries
- γ' precipitates continually coarsen, at predictable rates

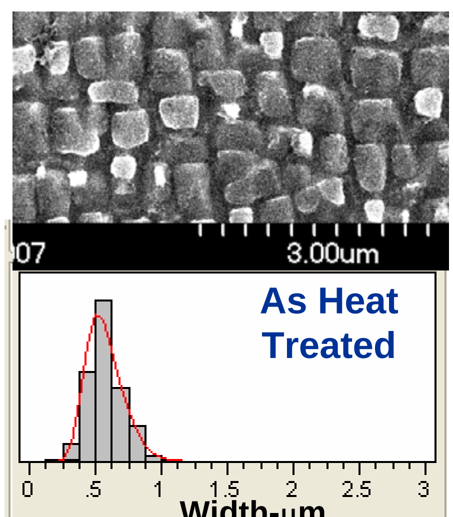
**Lifshitz-Slyozov-Wagner theory

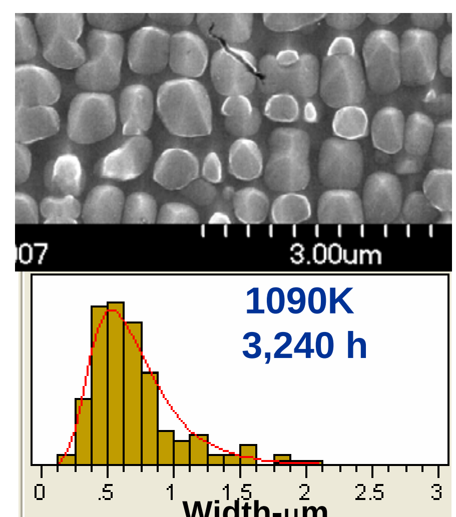
Mar-M247LC: Exposure Effects on Relevant Properties











- Creep life and strength moderately reduced, mean high cycle fatigue life maintained
- Can be attributed to the coarsening of γ' precipitates

Summary of Results

Haynes 230 and Mar-M247LC stabilities assessed in exposure tests

1) Haynes 230

- No harmful TCP phases found
- Some changes in carbides: increase in number density, partial transformation of M_6C to $M_{23}C_6$
- Creep after 1090K / 3,240 h exposure not harmed

2) Mar-M247LC

- No harmful TCP phases found
- Continued, predictable coarsening of γ' precipitates
- Creep and tensile properties moderately reduced, mean fatigue life sustained after 1090K/3,240h exposure

Conclusions

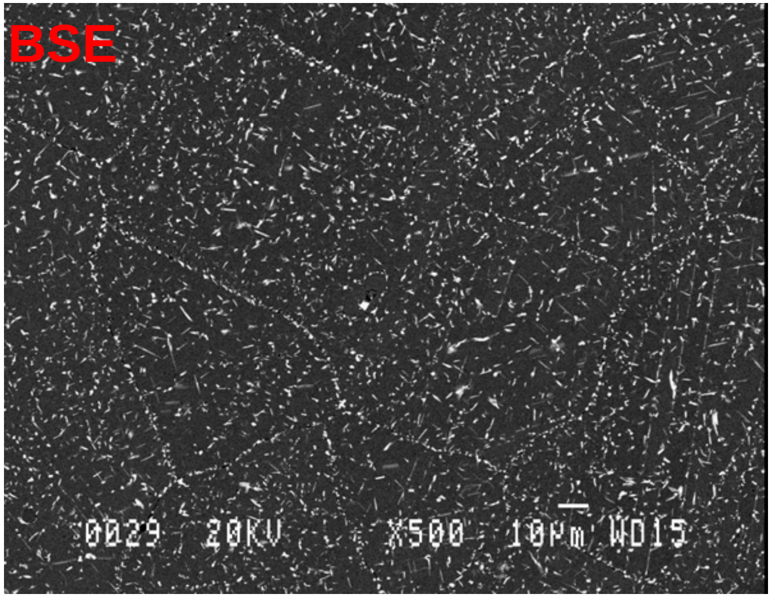
Improved duct and impeller superalloys look promising in initial exposure assessments

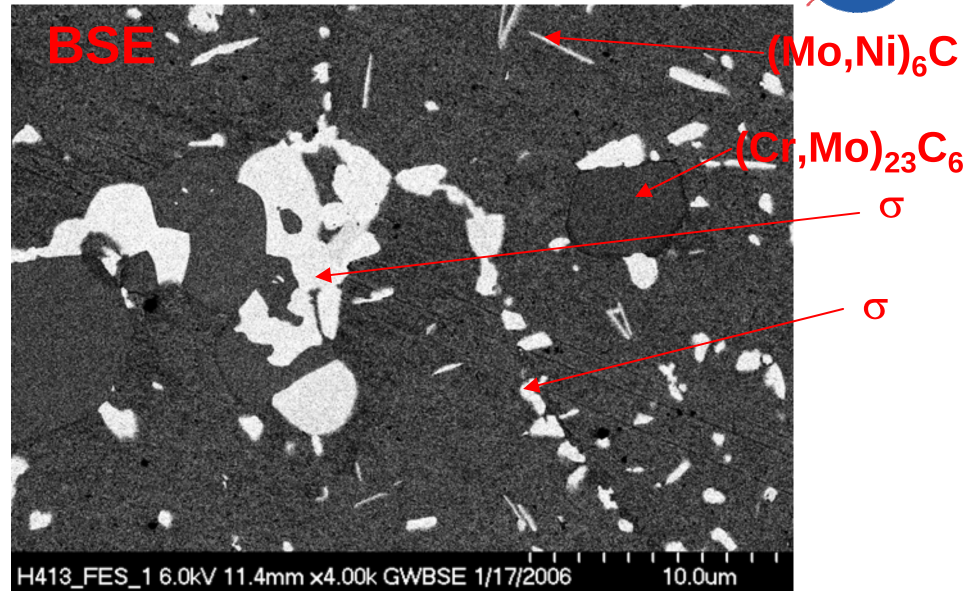
- Microstructures:
  - No harmful TCP phases uncovered
  - Carbide changes appear to not be harmful
  - Predictable γ' coarsening in Mar-M247LC

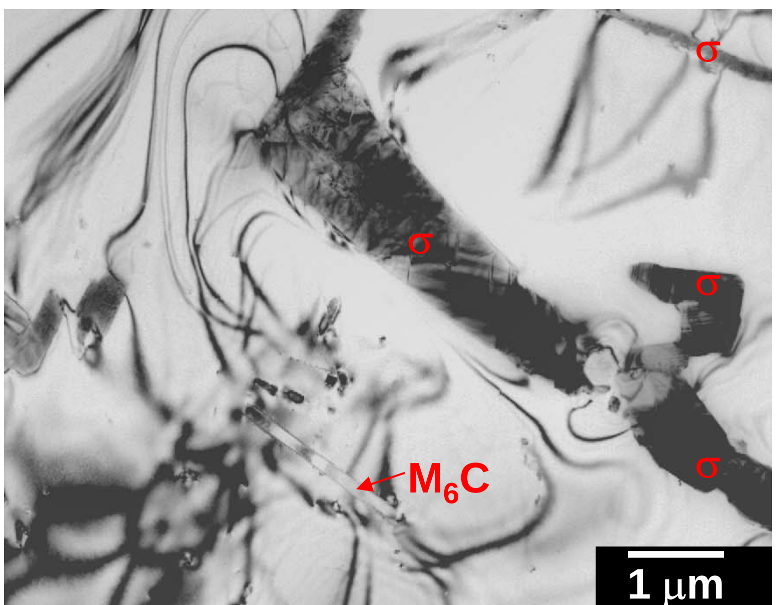
- Mechanical properties:
  - Haynes 230: creep sustained
  - Mar-M247LC: creep, tensile moderately reduced, mean HCF life sustained

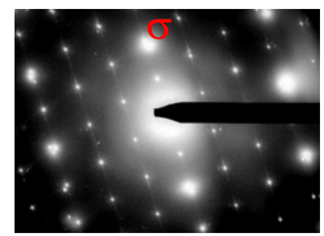
- More exposure temperatures/times and subsequent mechanical tests would be needed to support component design

Hastelloy X Exposed 1090K/1,000 h







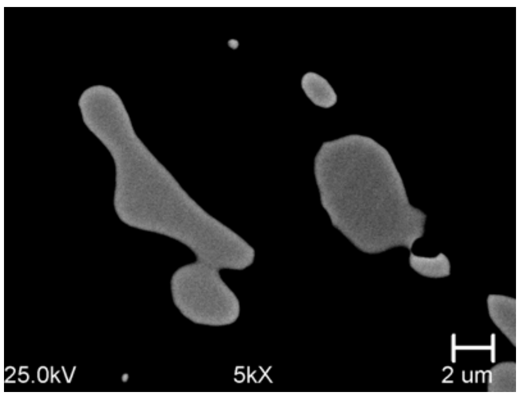


$[112]_\gamma \parallel [110]_\sigma \; (1\ 1\ \text{-}1)_\gamma \parallel (\text{-}1\ 1\ 1)_\sigma$

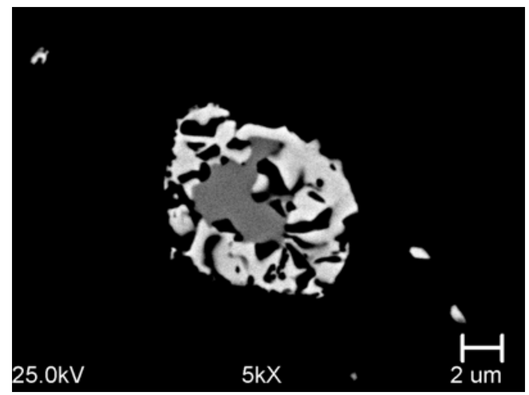
Phases Found With Exposure

σ ~ 6 area %

(Mo,Ni)$_6$C ~ 1 area %



As HT



Exposed 1090K / 3,240 h