Creep-Testing Foils and Sheets of Alloy 625 for Microturbine Recuperators

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Background

Temperature and water vapor enhanced oxidation are the primary factors affecting degradation, with stress and creep becoming factors at higher temperatures and longer times

- **Temperature**
- **Environment (combustion gases can lead to corrosion)**
- **Mechanical Stress (pressure differential can induce creep deformation)**

To Achieve DOE Advanced Microturbines Program Goal (efficiency >40%), Microturbines will operate at higher temperatures and stresses.

- **Resistance to creep critical for useful component life**

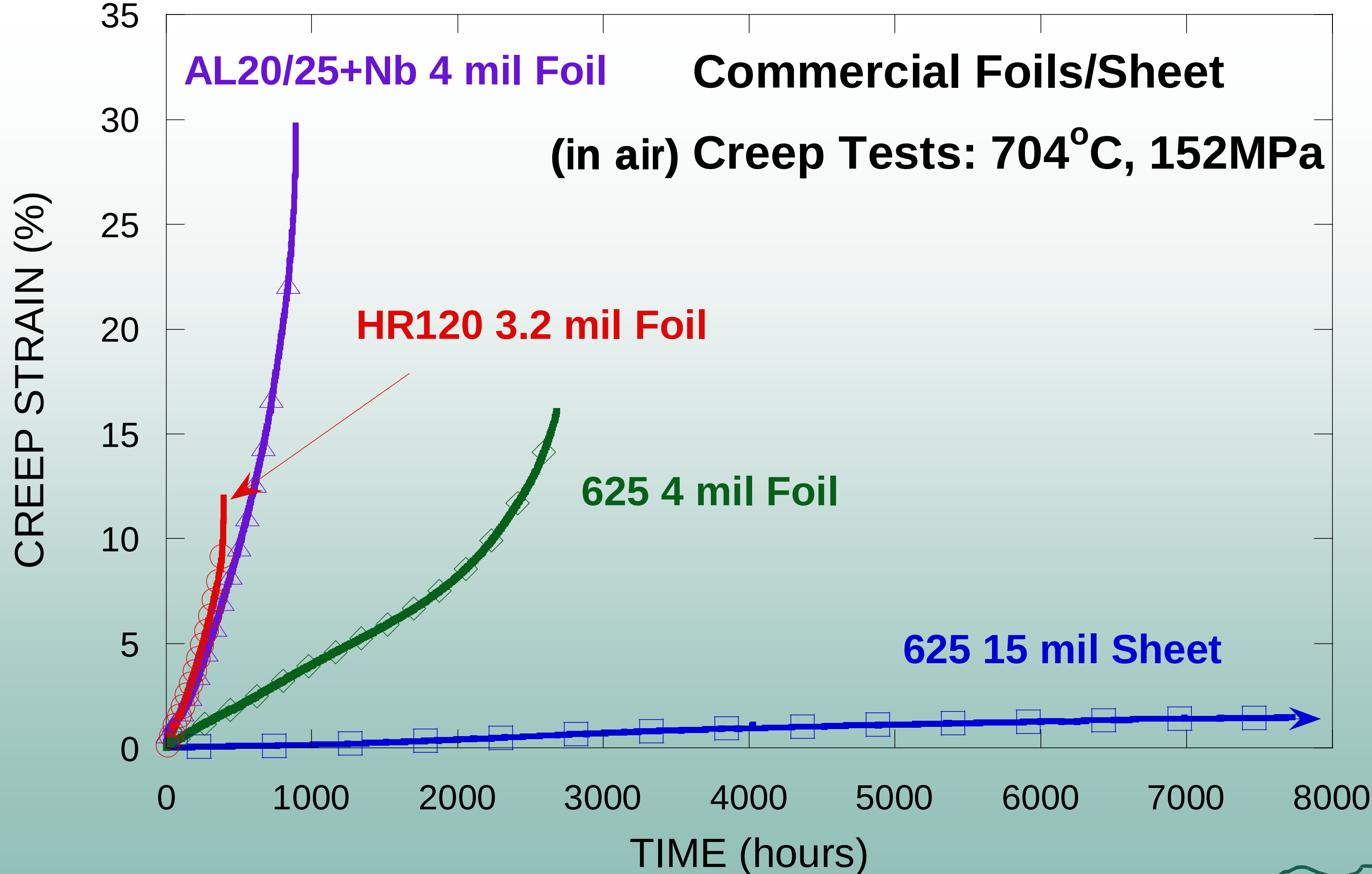
Advanced Austenitic Commercial Sheet and Foils Have Been Evaluated For Use In Recuperators

(Alloy Compositions (wt.%))

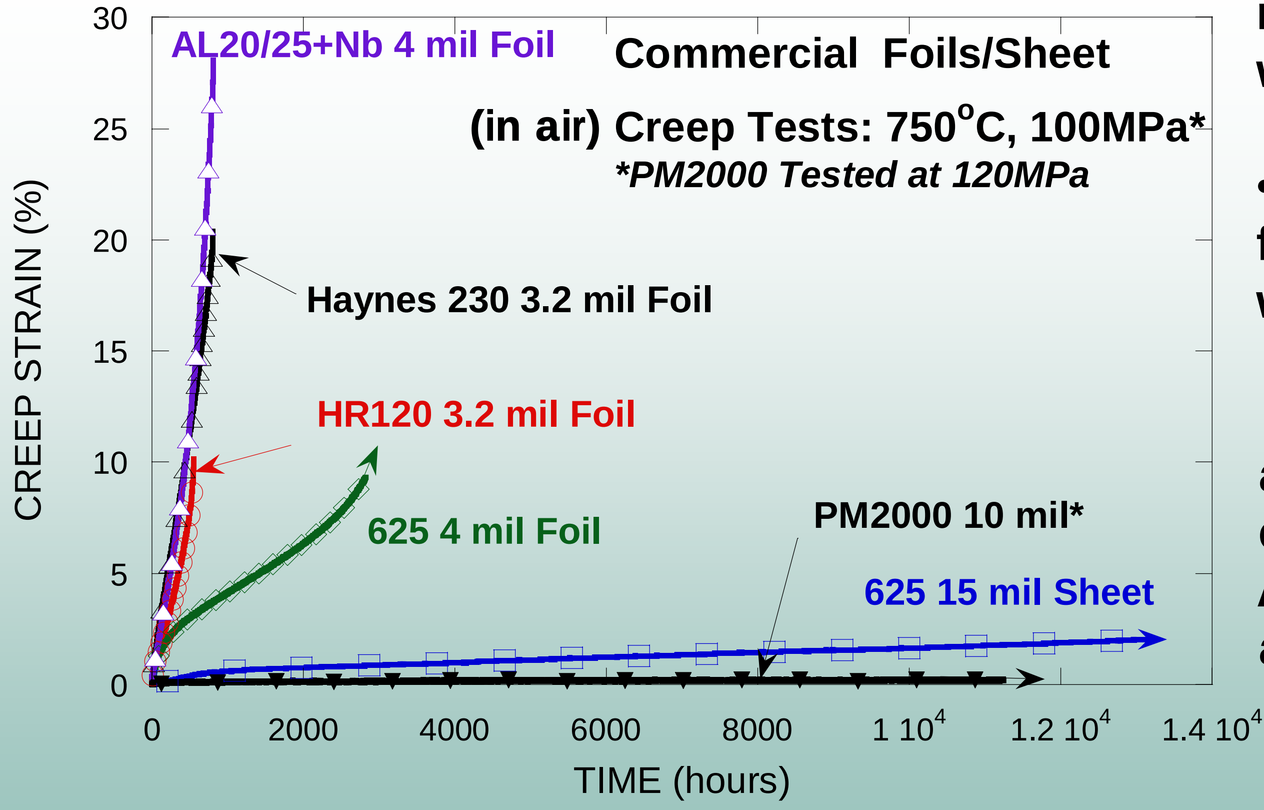
- AL 20/25+Nb
  - Fe-20Cr-25Ni-1.6Mo-1Mn-0.4Si-0.14Nb
- Haynes 120
  - Fe -25Cr-33Ni-1Mn-1Mo-0.05C-0.7Nb-0.2N
- PM2000
  - Fe-19Cr-5Al-0.4Ti-0.5Y_2O_3 (oxide-dispersed FeCrAl)
- Haynes 230
  - Ni-22Cr-14W-2Mo-3Fe-5Co-0.5Mn-0.4Si-0.3Al-0.1C-0.02La-.015B
- Alloy 625
  - Ni-21Cr-4.4Fe-9Mo-3.6Nb-0.02C-0.23Ti-0.16Al

**625 Supplied by ATI Allegheny Ludlum;
Other Sheet and Foils Supplied by Either Microturbine OEMs or Foil Producers**

Creep Tests of Sheets and Foils at 704°C Have Been Performed

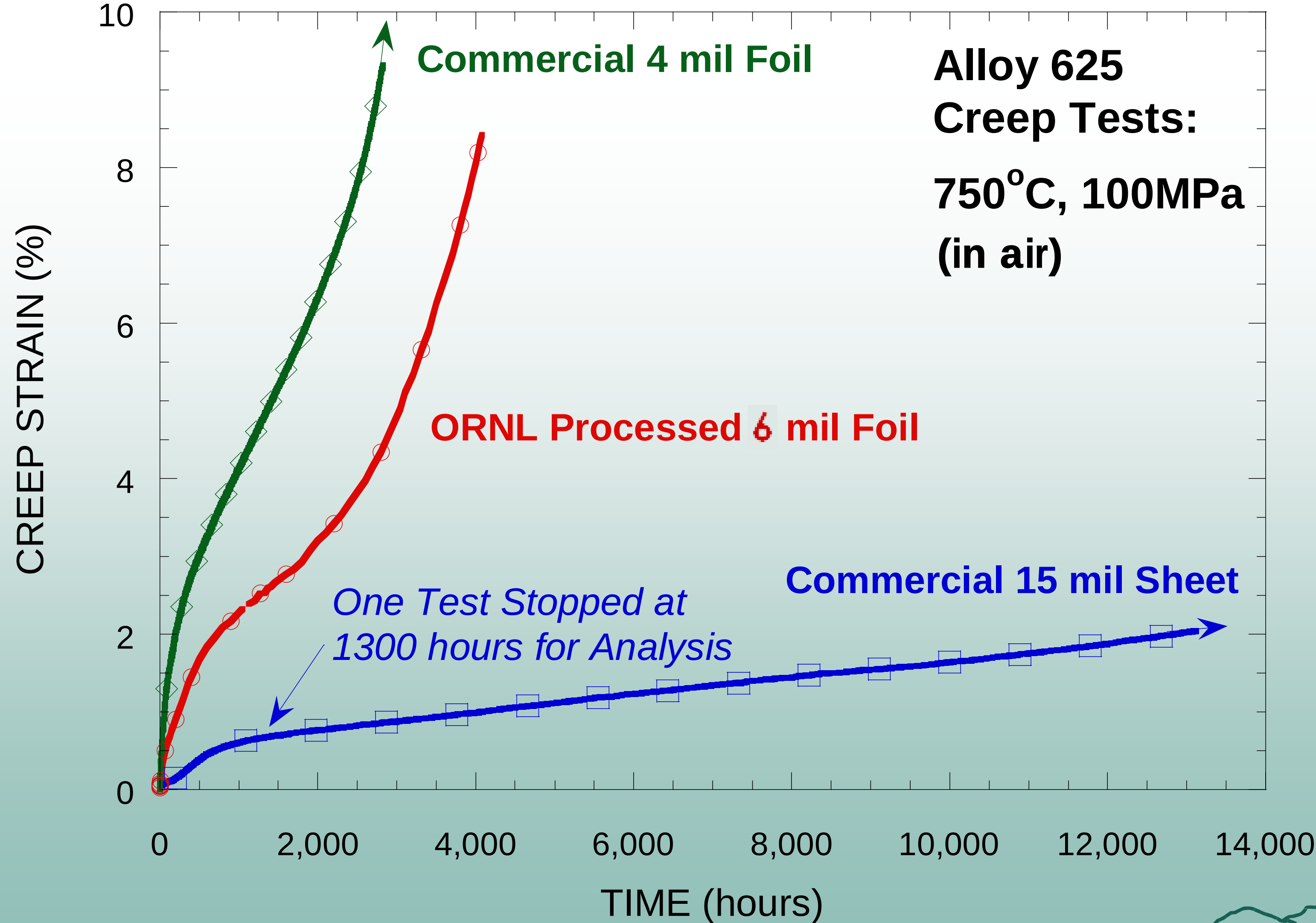


Creep Tests of Sheets and Foils at 750°C Have Been Performed



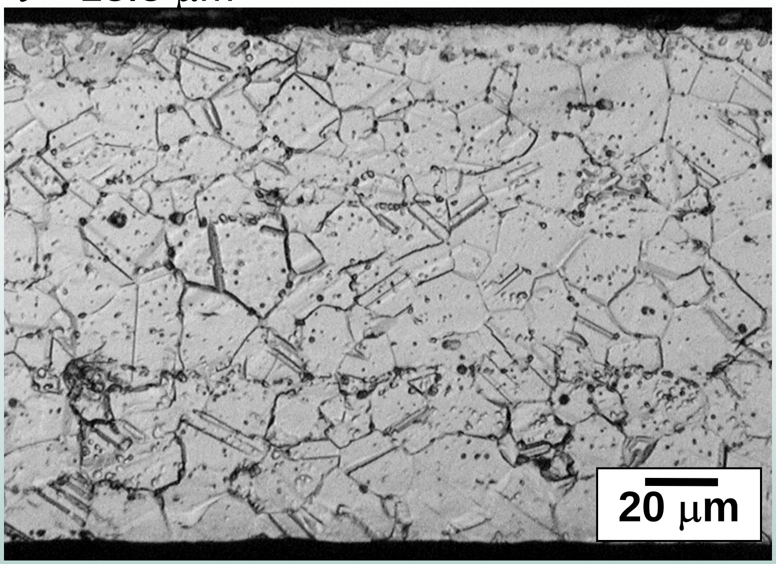
- Behavior of foil is not necessarily that of wrought product
- Material ranking for foils not same as wrought form
- For high temperature applications (e.g., fuel cells, heat exchangers), Alloy 625 may be most attractive.

Microstructures of Alloy 625 Sheets and Foils in Uncrept and Creep Condition (750^{o}C, 100 MPa) Have Been Examined



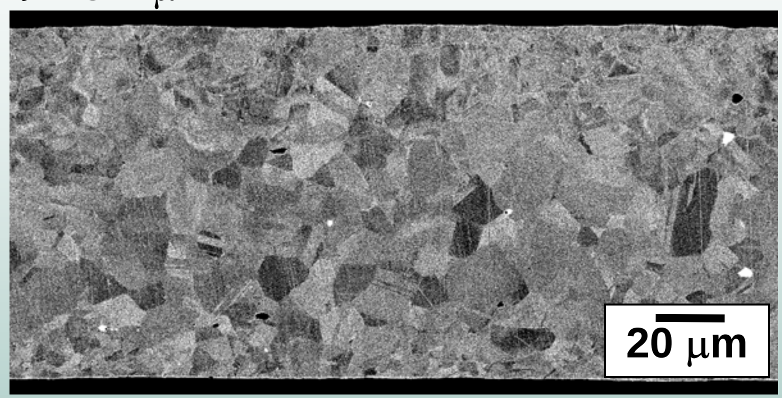
Average Grain Diameter of Alloy 625 Foils Estimated from $\bar{l}$, Mean Lineal Intercept Length

$\bar{l}$ = 13.3 µm



ORNL Processed 6 mil (152 µm) foil
Optical micrograph,
uncrept foil in cross-section

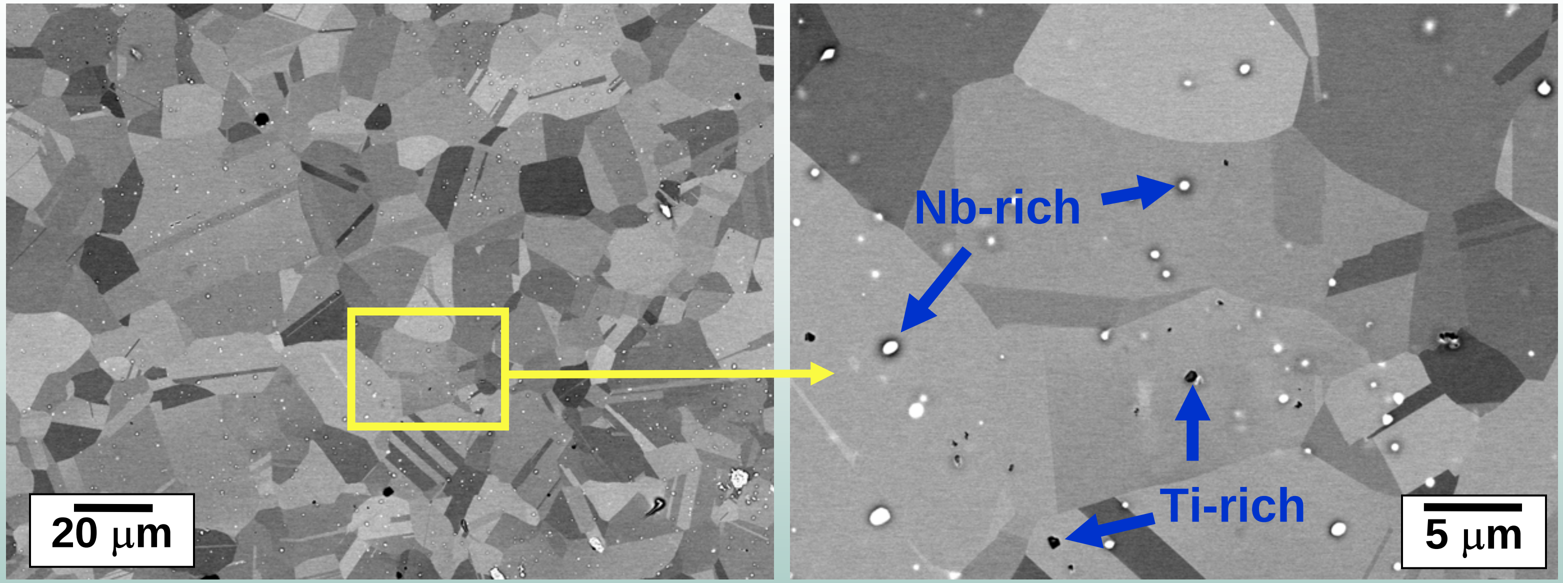
$\bar{l}$ = 8.7 µm



AL supplied 4 mil (100 µm) foil
BSE SEM image,
uncrept foil in cross-section

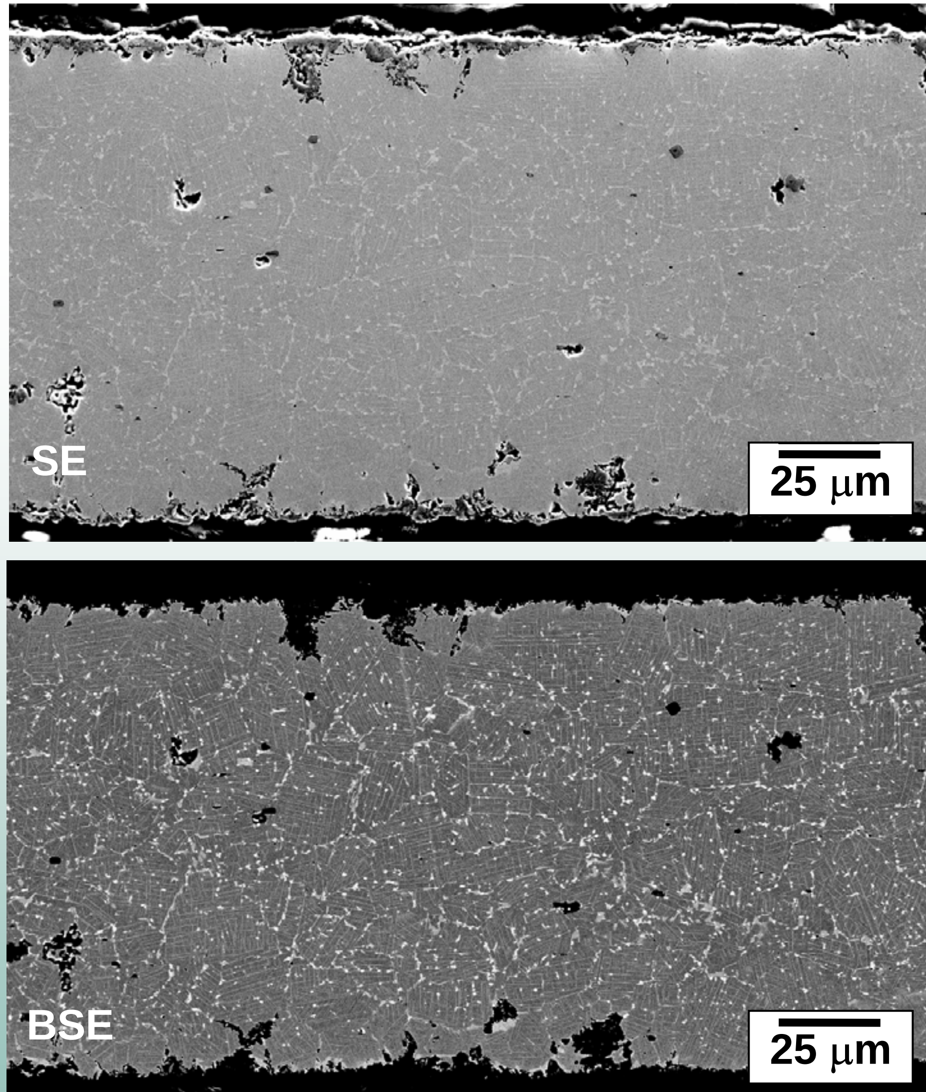
Uncrept 6 mil (152 μm) Alloy 625 Foils Have Clean Grain Boundaries, and Some Nb/Ti-Rich MX type Precipitates

ORNL processed foil



SEM BSE images, plan view of electropolished TEM Disks

ORNL Processed 6 mil foil,
Crept 750^{o}C, 100 MPa, 4510 h



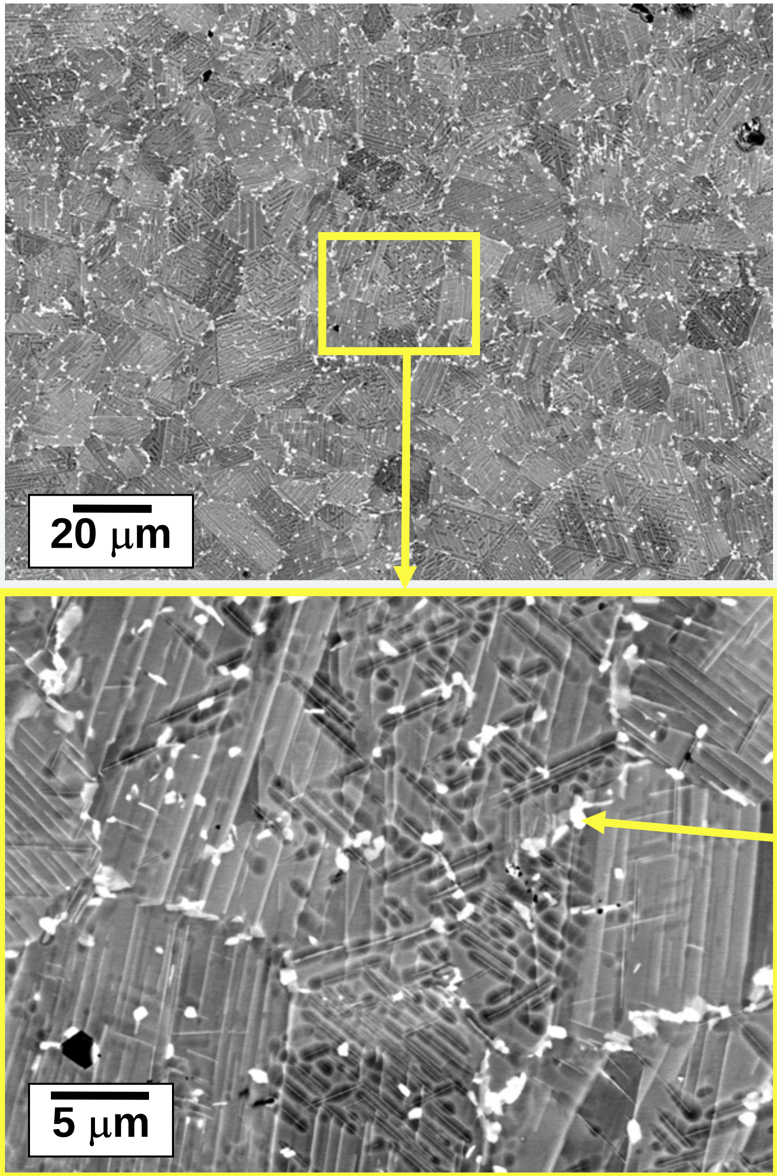
SEM Images, Same Field-of-View

Significant Changes in Microstructure Occur During Creep-testing 0.006" Alloy 625

- **Oxide develops on surface, with deepest penetration into foil along grain boundaries**

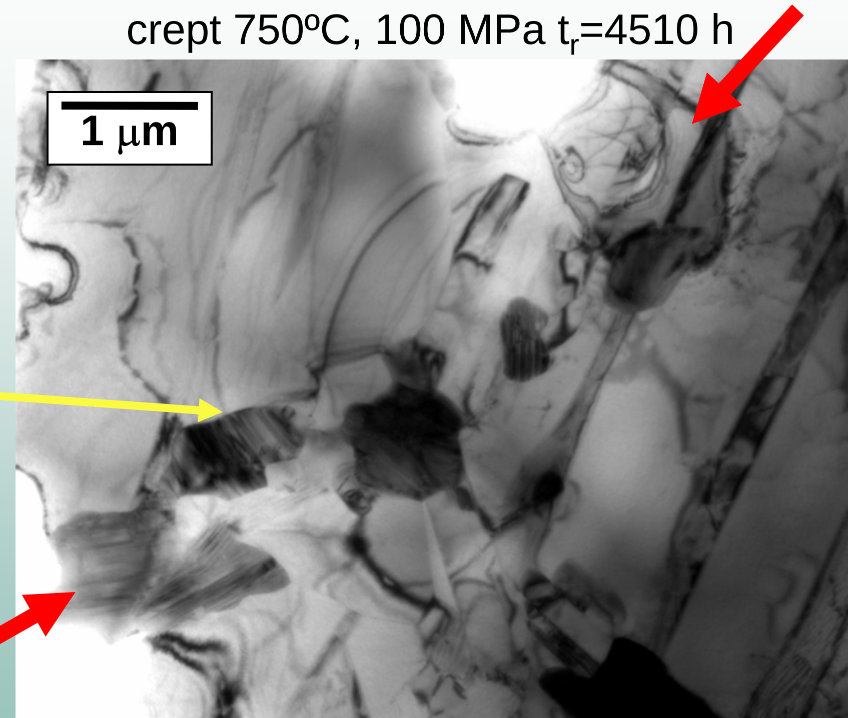
- **Precipitate formation in grain boundaries**

During Creep Testing, Alloy 625 Develops Grain Boundary Precipitates and a Phase, Having a Plate Morphology, Within Grains



SEM BSE images from electropolished TEM Disk

ORNL Processed 6 mil foil
crept 750ºC, 100 MPa t_r=4510 h



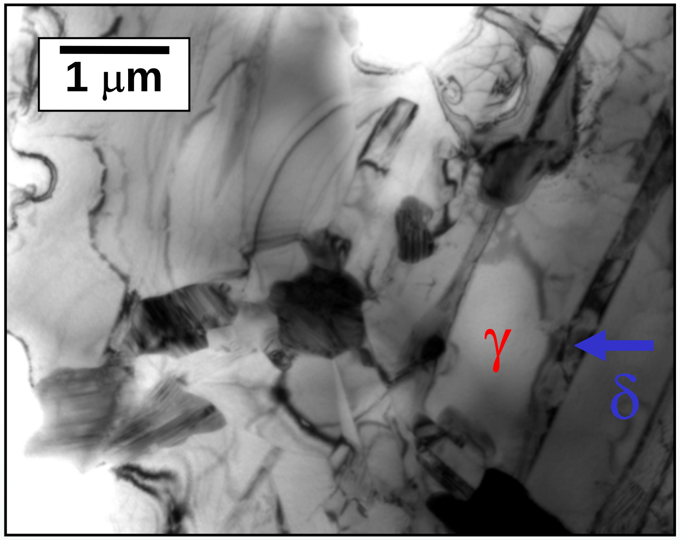
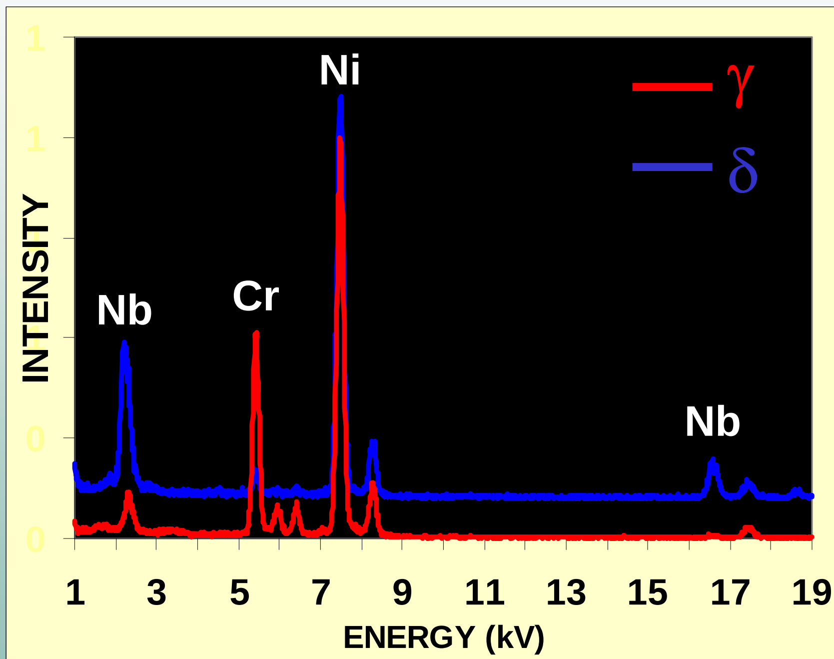
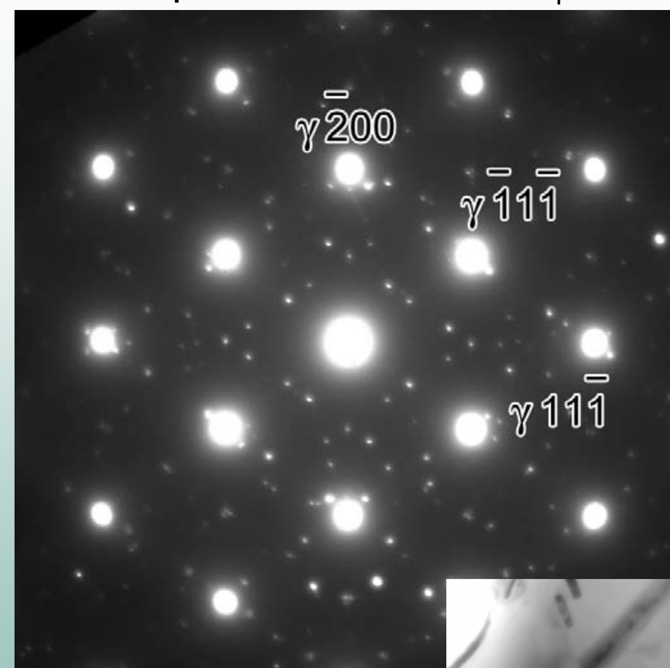


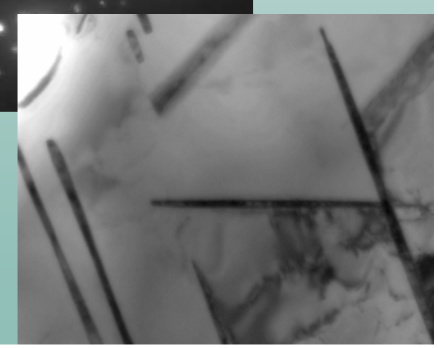
Plate Phase in Crept Alloy 625 Is Identified as Equilibrium Orthorhombic δ (Ni_3Nb)



Alloy 625, crept 750ºC, 100 MPa t_r=4510 h



B = [011] $_\gamma$



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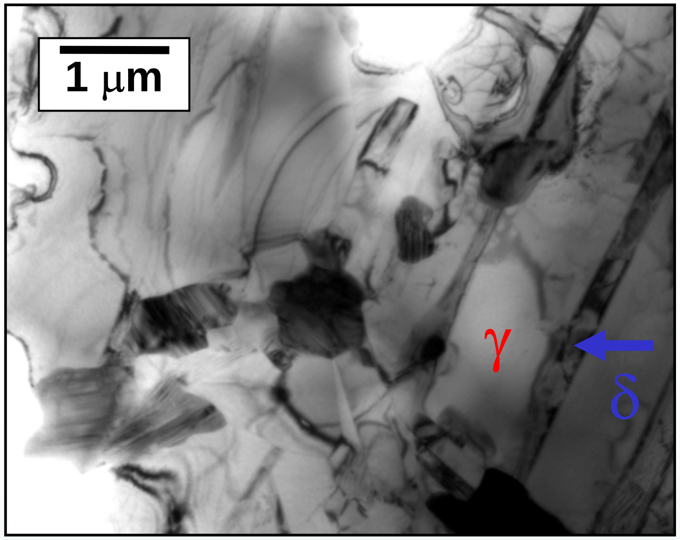
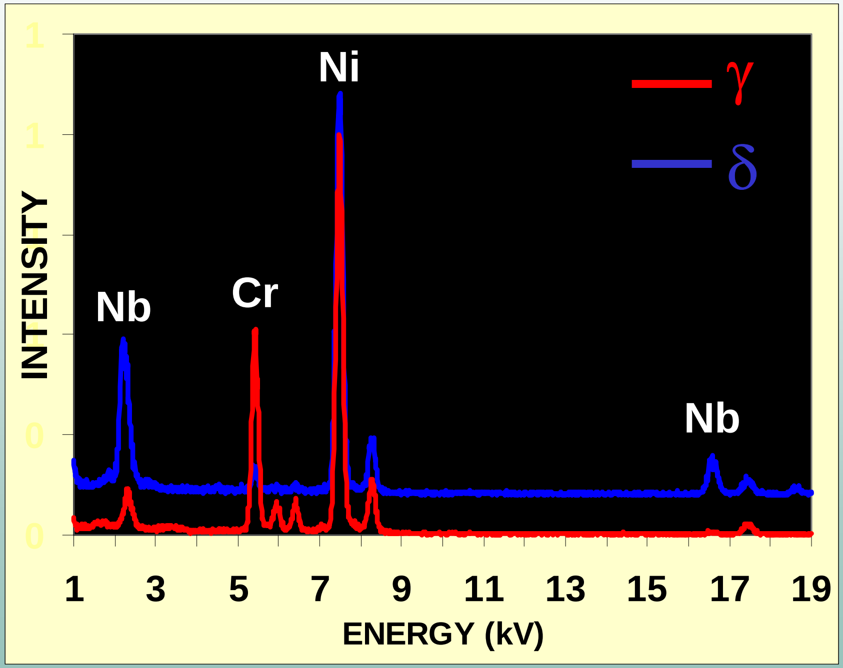
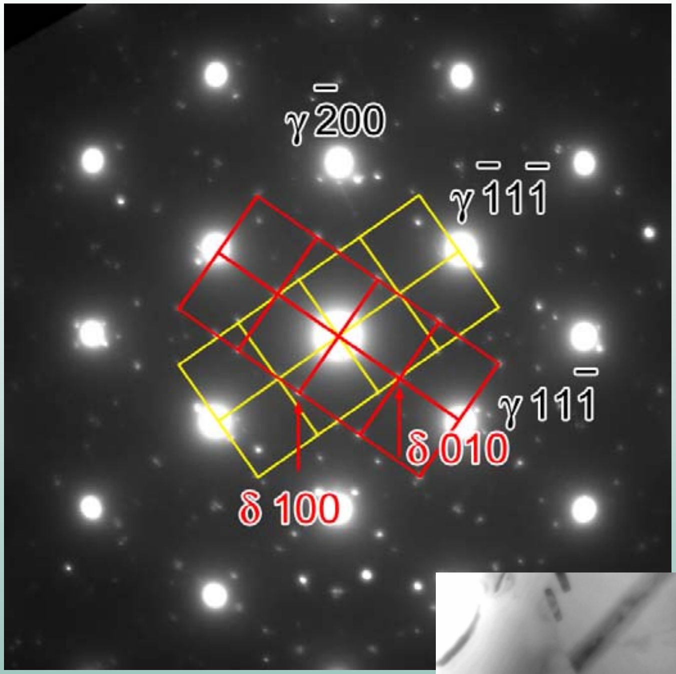


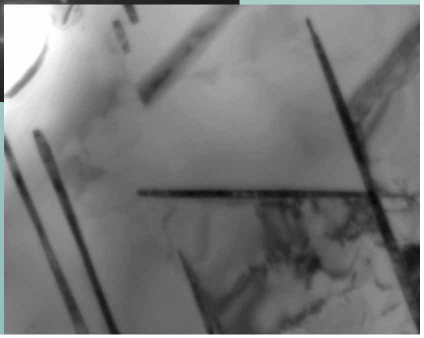


$[01\bar{1}]\ \gamma \parallel [100]\ \delta$

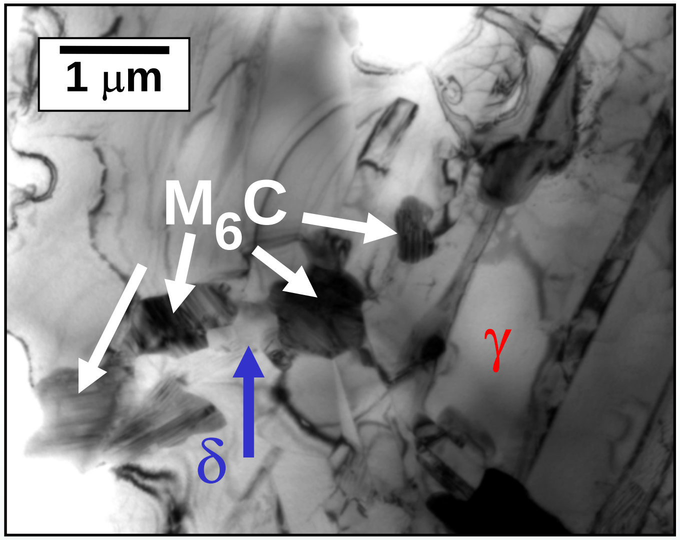
$(11\bar{1})\ \gamma \parallel (010)\ \delta$



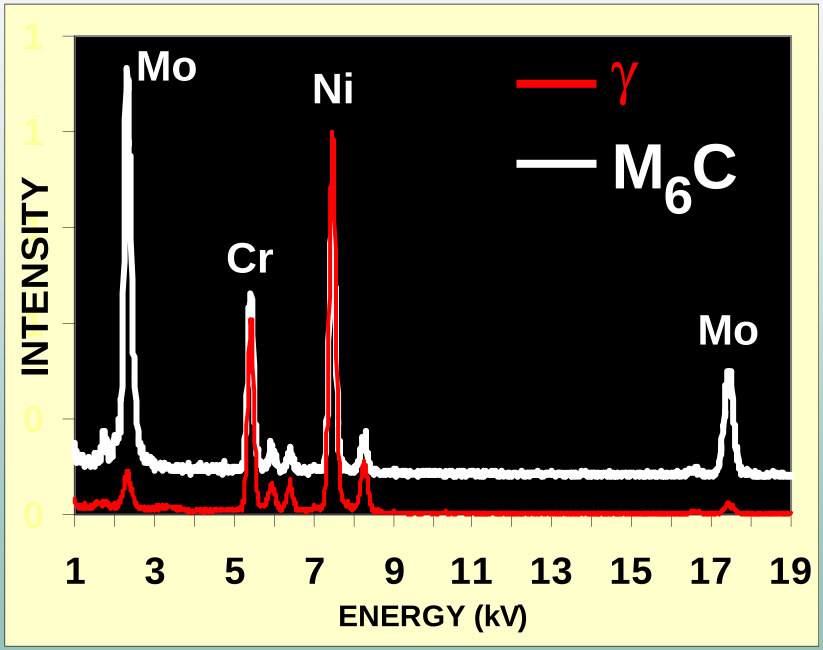
(2 rotational variants)

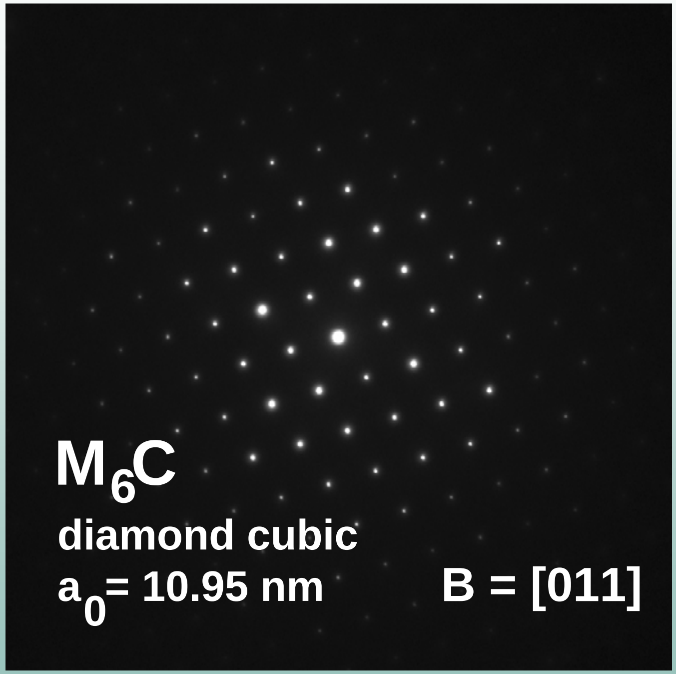


Grain Boundaries in Crept 6 mil Alloy 625 are Stabilized with M_6C Precipitates (some δ also)

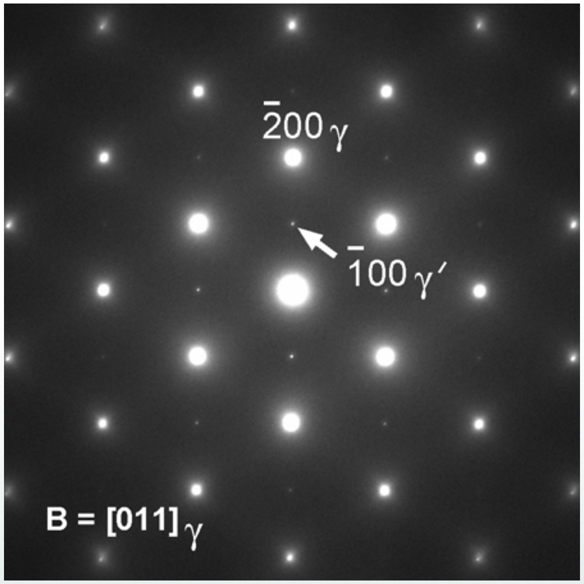


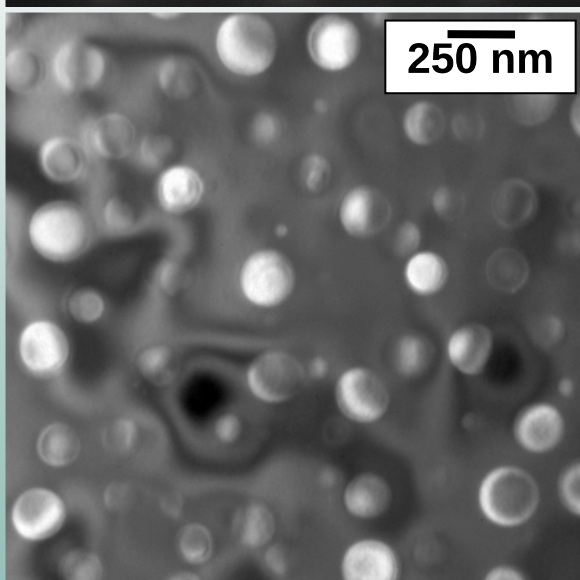
crept 750ºC, 100 MPa





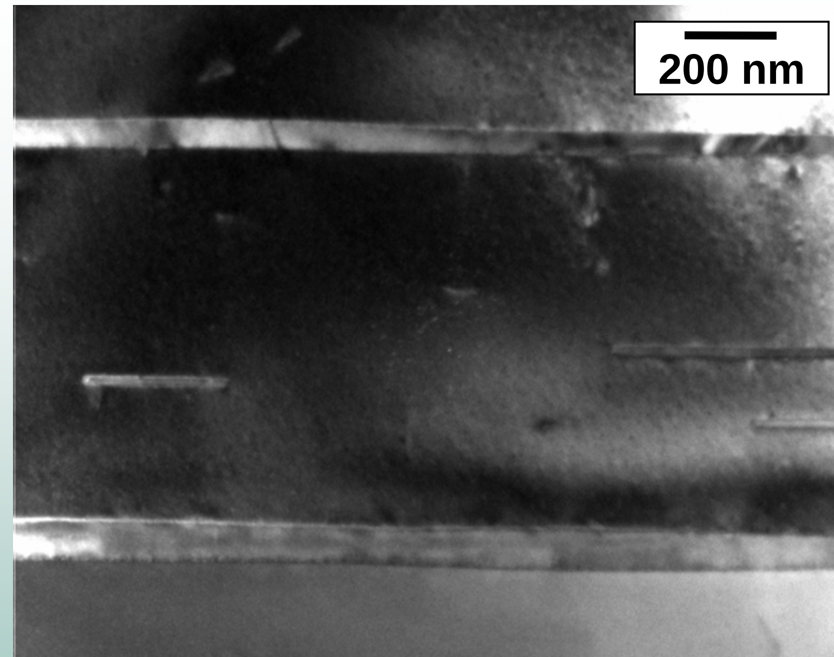
Service-Aged Pyromet 31V (Ni-22Cr-15Fe)





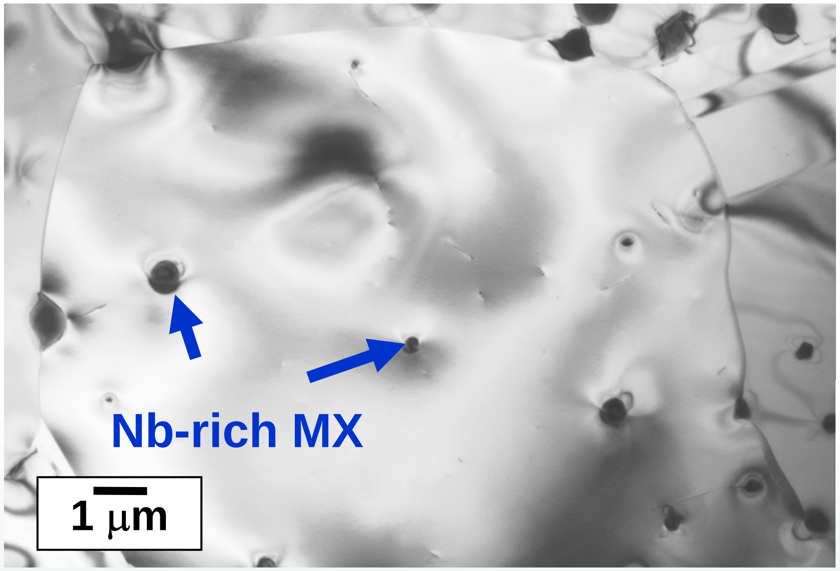
Centered Dark Field Imaging in TEM Can Reveal γ' Within γ

TEM Dark Field Image, Centered Midway Between (000) and $(\bar{2}00)_{\gamma}$



ORNL Processed 6 mil foil, Crept 750°C, 100 MPa, 4510 h

During Creep Testing At 750ºC Alloy 625 Foil Does Not Develop a Finely Dispersed Precipitate Phase



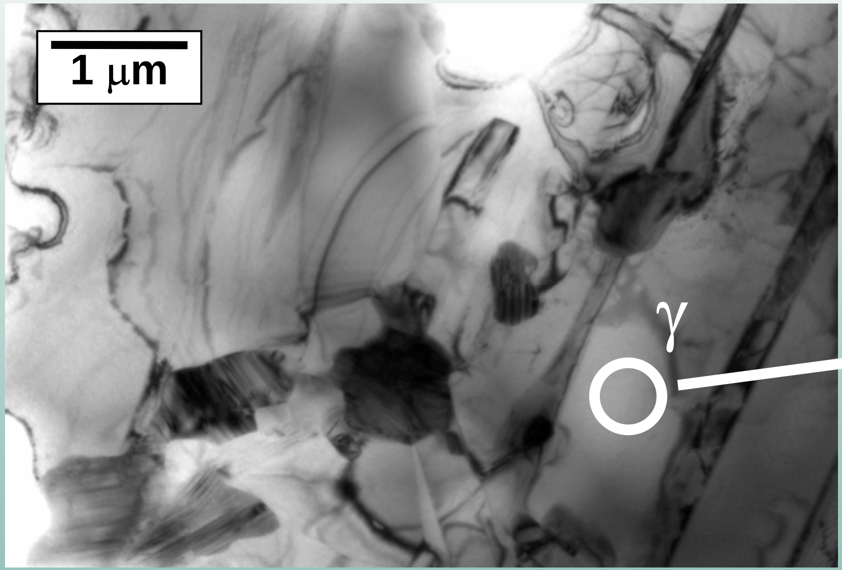
uncrept

MX consumed by δ laths

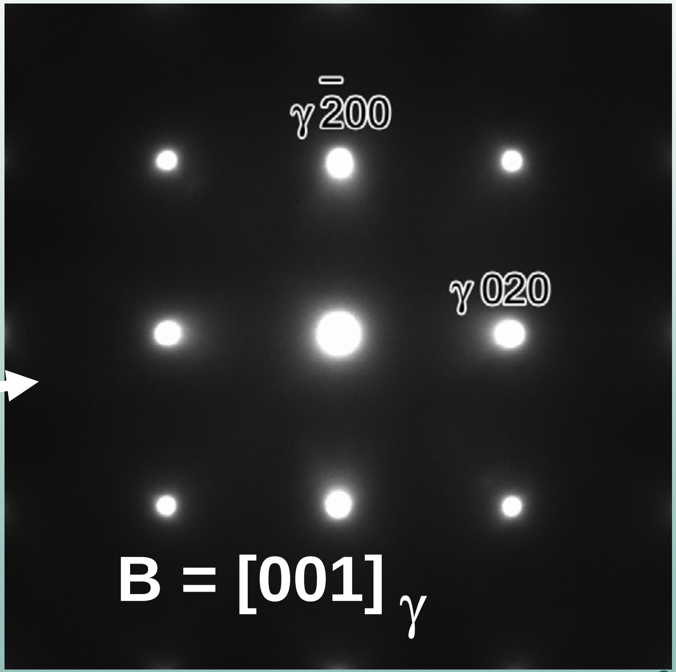
No γ' $Ni_3(Al,Ti)$

No γ'' (metastable Ni_3Nb)

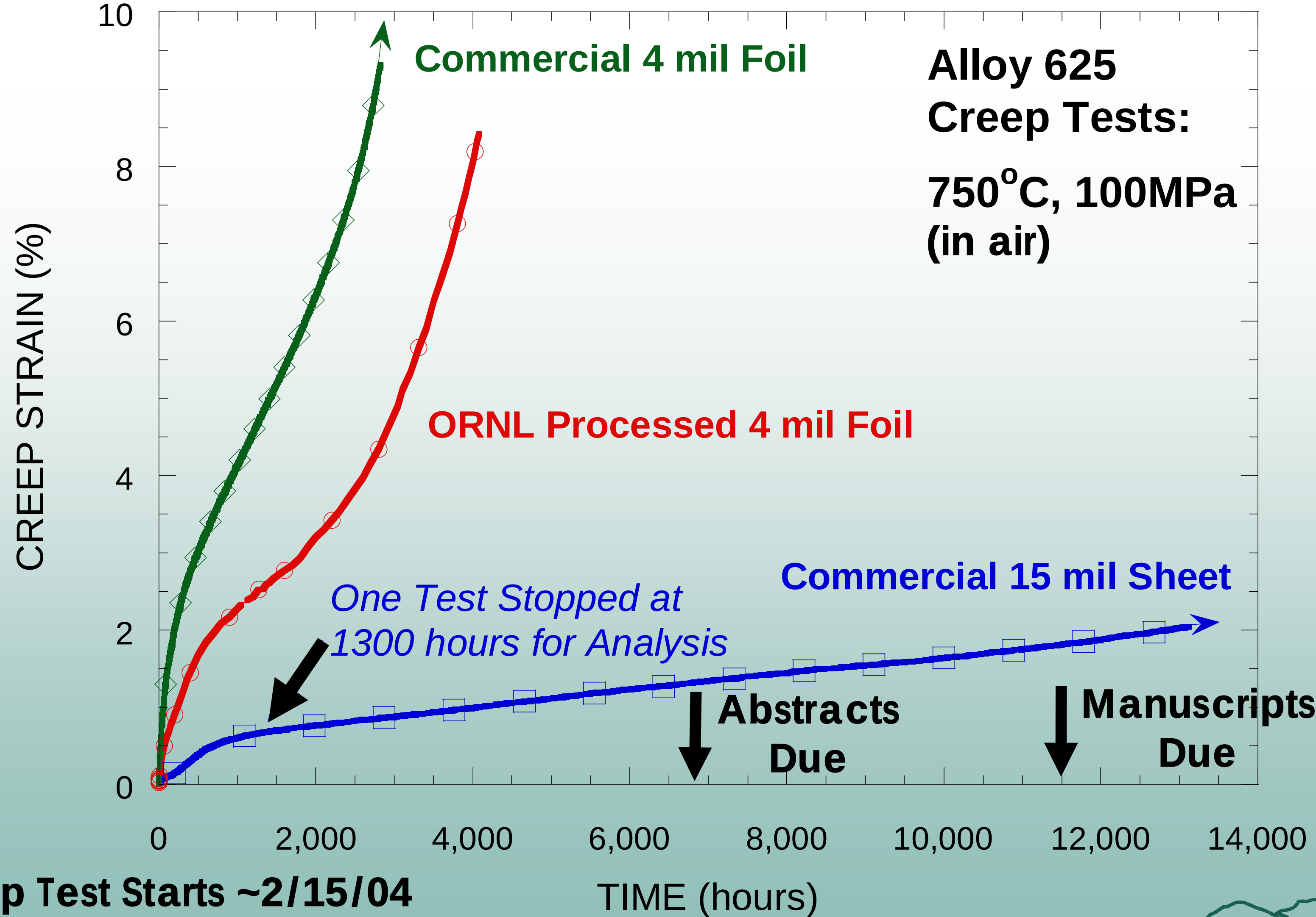
No topologically close-packed phases (e.g. μ, σ) observed



crept 750ºC, 100 MPa



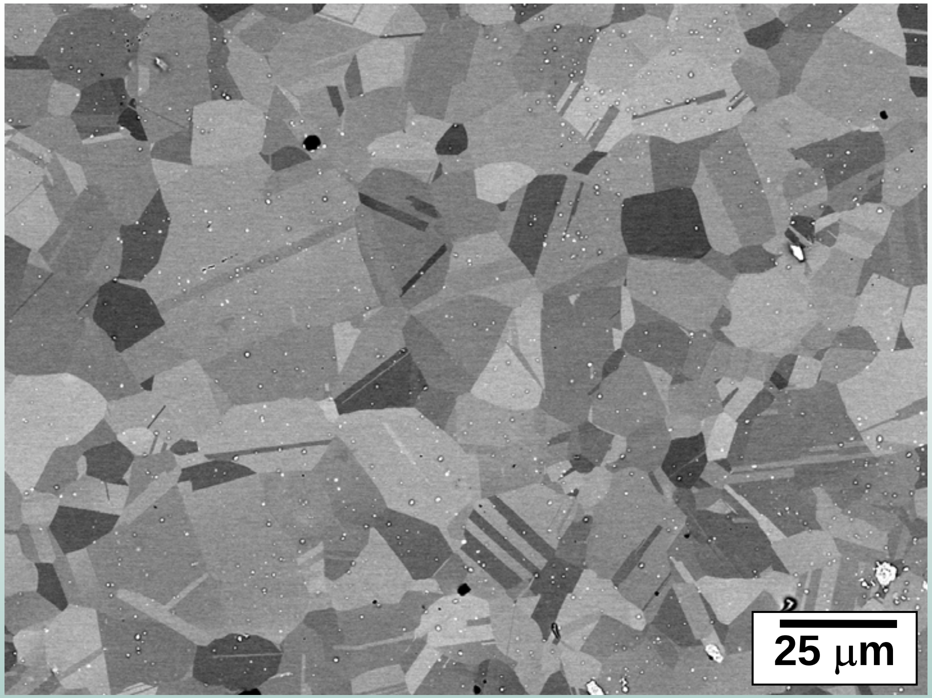
Microstructure of Alloy 625 Foils in Both Uncrept and Crept Condition (750^{o}C, 100 MPa) Have Been Examined



Creep Test Starts ~2/15/04

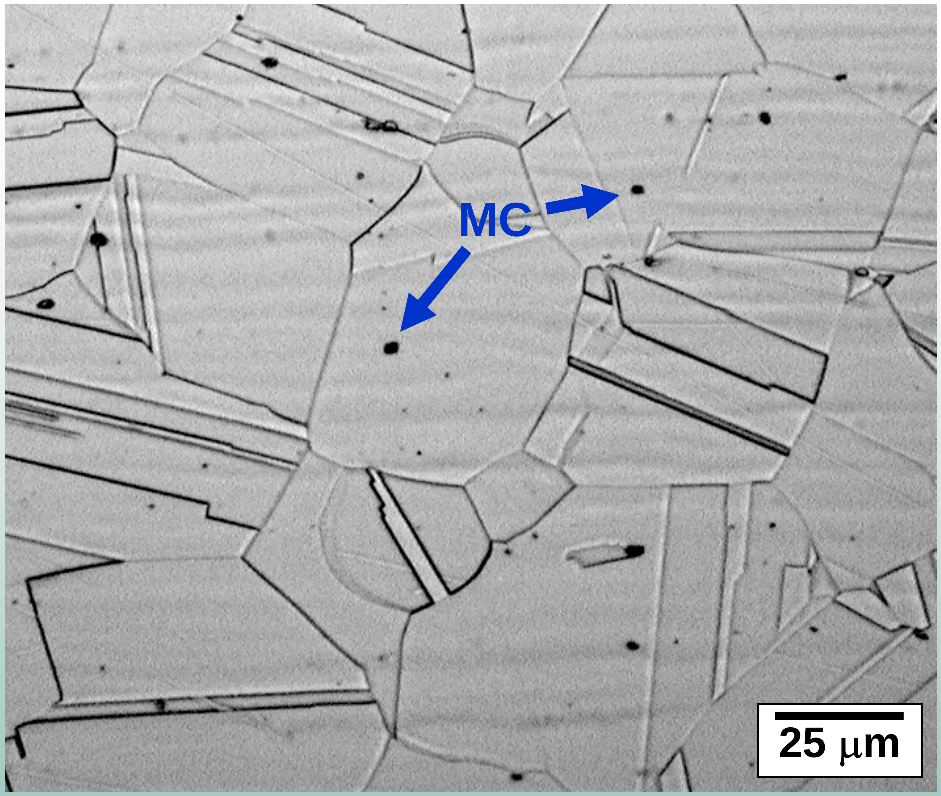
Other Than Having Significantly Larger Grain Size, As-Processed 15 mil Alloy 625 Sheet Is Similar to 6 mil Foil

$\bar{\ell}$ = 13.3 μm



ORNL Processed 6 mil (100 μm) foil BSE SEM Image, uncrept foil, plan view

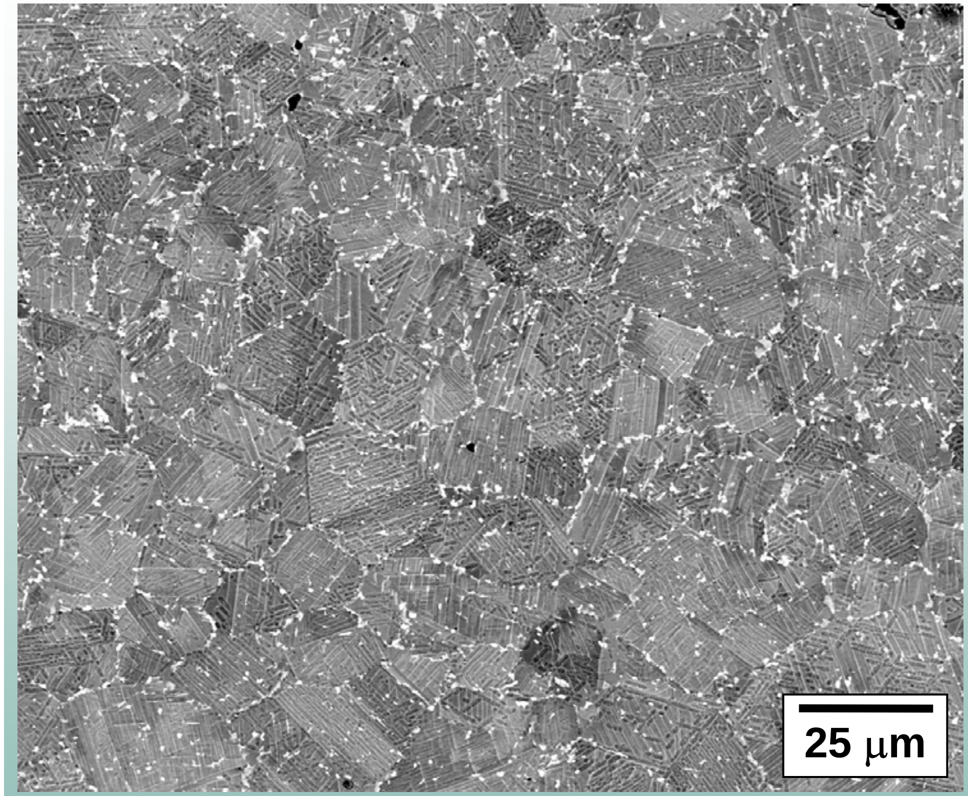
$\bar{\ell}$ = 38.7 μm



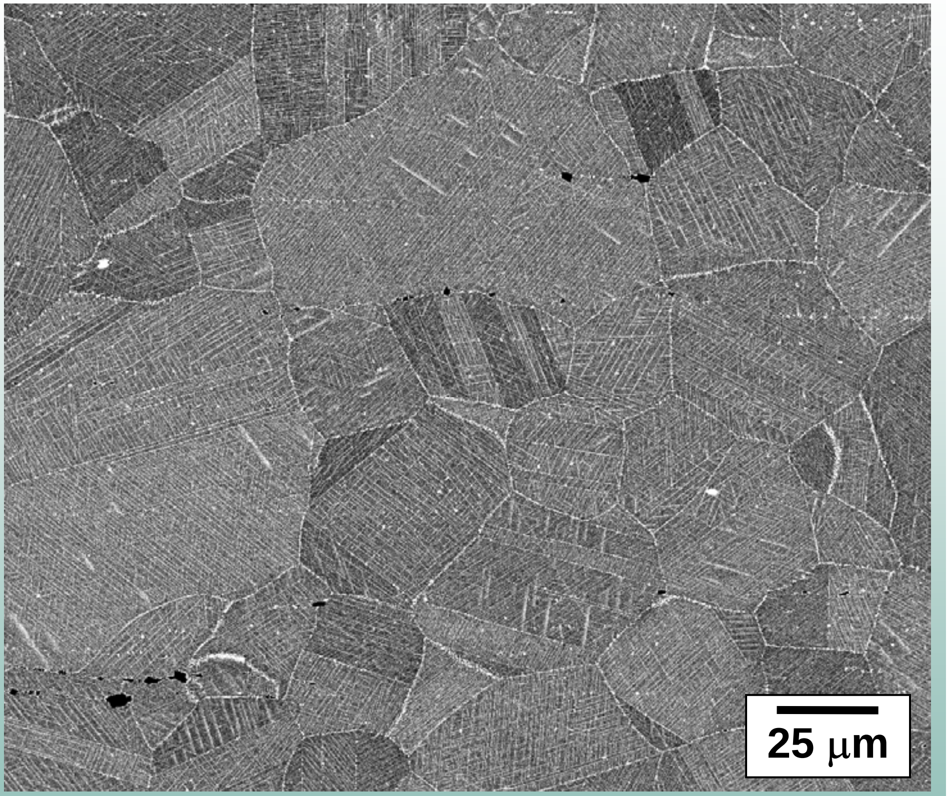
15 mil (375 μm) foil Optical micrograph, uncrept foil, cross-section view

15 mil Alloy 625 Sheet, Creep-Tested to Reach Steady-State, Develops Morphology Similar to Creep-Tested 6 mil Foil

ORNL Processed 6 mil foil crept 750^{o}C, 100 MPa t_r=4510 h

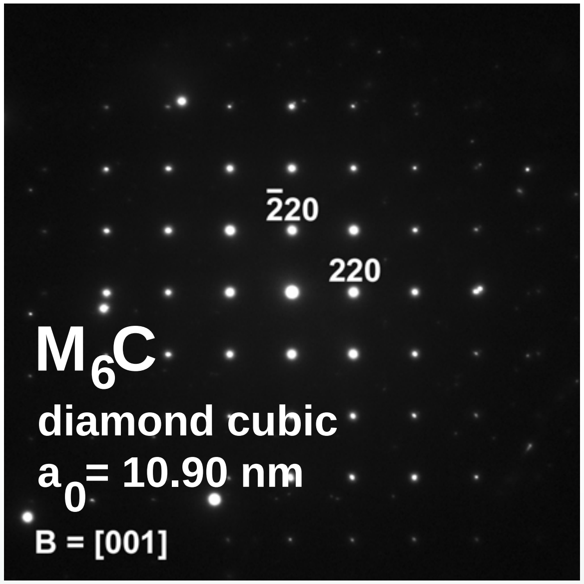


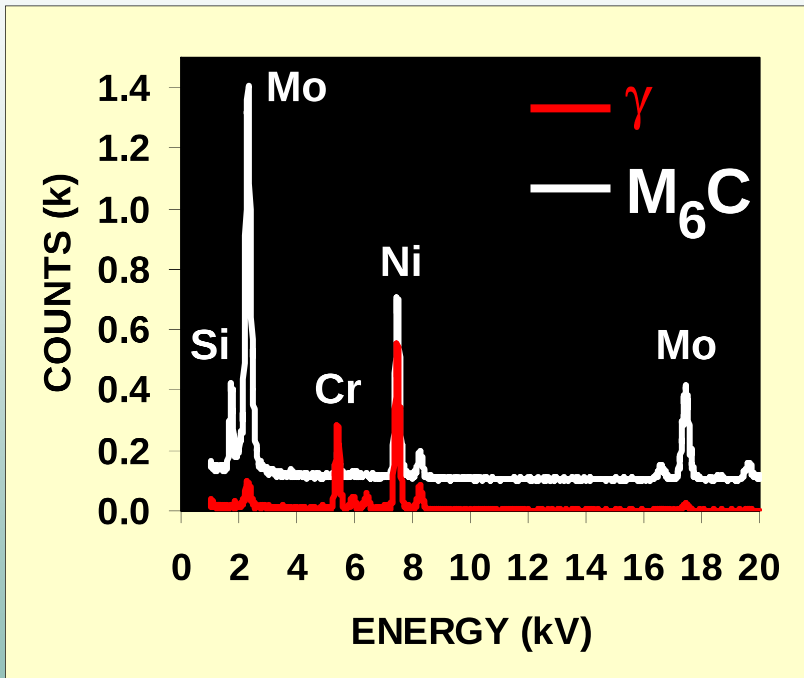
15 mil Sheet, Crept 750^{o}C, 100 MPa 1300 h (Interrupted)



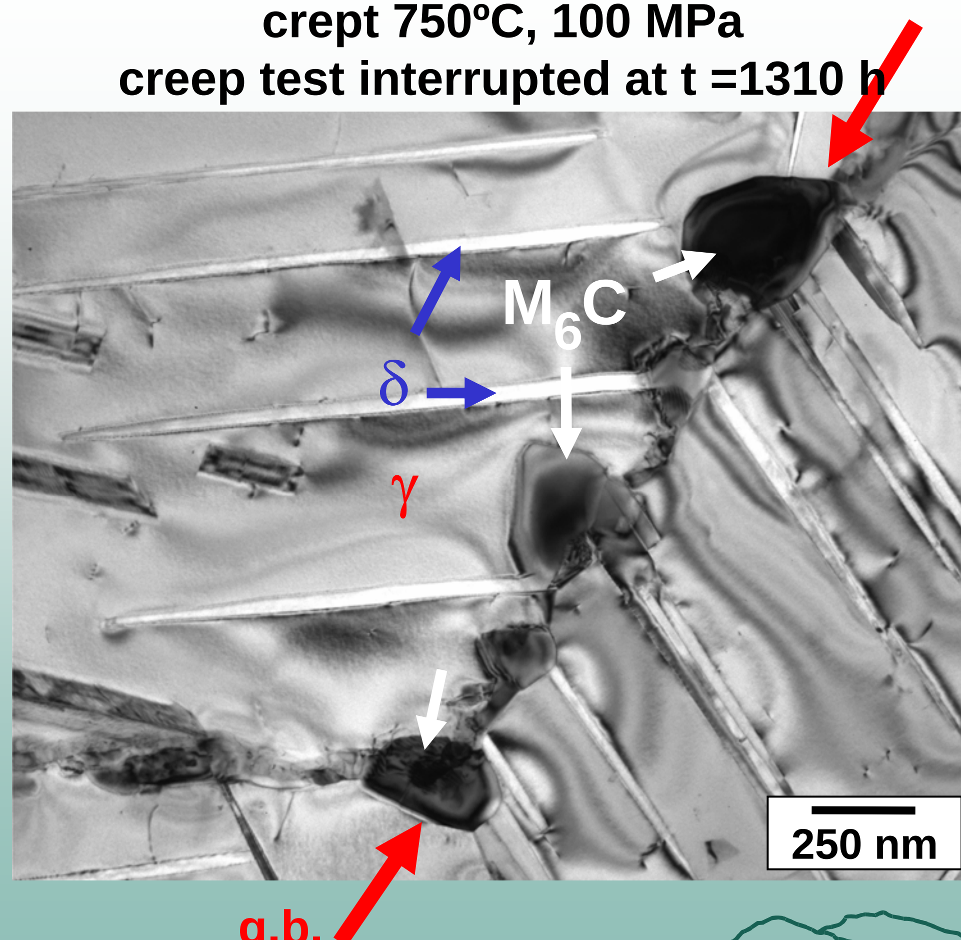
BSE SEM Images

Grain Boundaries in Crept 15 mil Alloy 625 are Stabilized with M_6C Precipitates (some δ also)





15 mil (375 μm) foil
crept 750ºC, 100 MPa
creep test interrupted at t =1310 h



Summary

- Foils and sheet of Alloy 625, considered for use in recuperators, have been investigated
  - Creep behavior of foil is not that of the sheet
    - (available creep data for candidate materials in sheet form may not be extended to same material as a foil)
  - During creep testing at 750^{o}C, 100MPa
    - Precipitation of M_6C and δ phases, which stabilize grain boundaries during creep
    - No precipitation of finely dispersed phases within austenite
    - No embrittling topologically close-pack phases (e.g. σ, μ, Laves)
  - Difference in creep behavior due differences in grain size
    - Additional processing to obtain foil resulted in reduction in grain size, thereby increasing potential for grain boundary sliding and creep rate