Karlsruhe Institute of Technology

Creep Strength Of Chromium-Containing Conventional And ODS Steels In Oxygen-Controlled Pb At 650°C

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Overview

- Creep-rupture tests in oxygen-controlled heavy liquid metal (Pb) in comparison to air

- Tested material:
  - Conventional f/m steels T91 and P92
  - F/m 9Cr-, ferritic 12Cr- and 14Cr-ODS steels

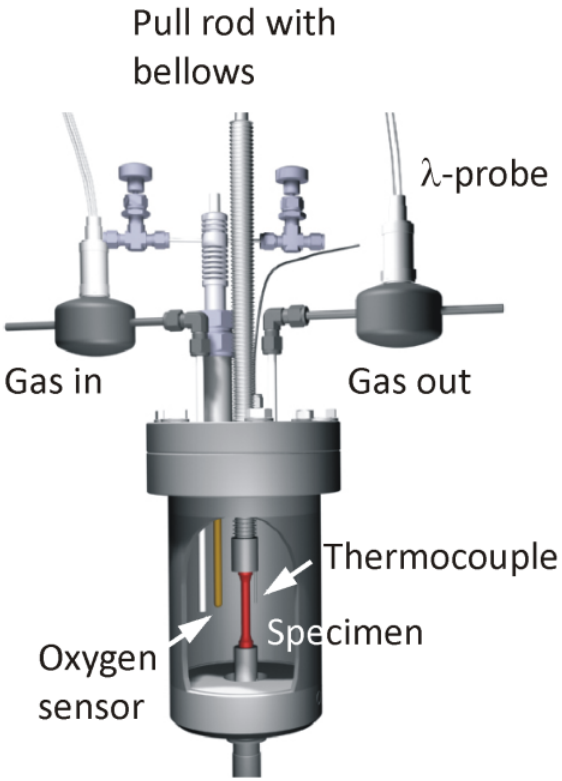
- Experimental conditions:
  - Enviroments: (i) oxygen-controlled Pb (c_o=10^{-6} mass%)
  - (ii) air
  - Temperature: 650°C
  - Stress range: facilitating short- (~1 h) and long-term (~10,000 h) tests

Attractiveness of ODS:

✓ High-temperature strength and resistance to neutron irradiation.

✓ High oxidation resistance reached through Cr (9-14 mass%) and fine-grained structure with oxide particles.

Creep-rupture tests in oxygen-controlled heavy liquid metal (Pb)



CRISLA-capsule for HLM

Continuous control of oxygen concentration in Pb

Measurements:

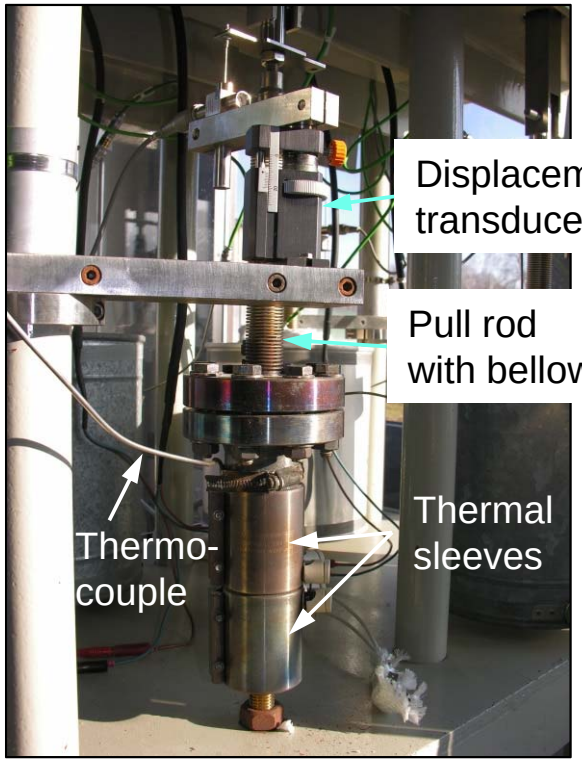
- Oxygen activity close to the specimen
- λ-sensors in gas -inlet and -outlet
- Temperature of Pb
- Gas flow (Ar, Ar/H_2 and synthetic air)

Conditions:

- stagnant Pb or LBE (900 ml)
- T_{max} = 650°C
- $c_o{}^{max} = c_{HLM}{}^{saturation}$
- $c_o{}^{min} = 10^{-8}–10^{-9}$ mass %

CRISLA Facility:

- 5 independent capsules for HLM
- 3 independent capsules for air (gas)



CRISLA-capsule for gas

Tested materials

9Cr-ODS (plates)

Fe	Cr	Mo	Mn	Ni	Y*
bal	8.8	1.92	0.33	0.21	0.34

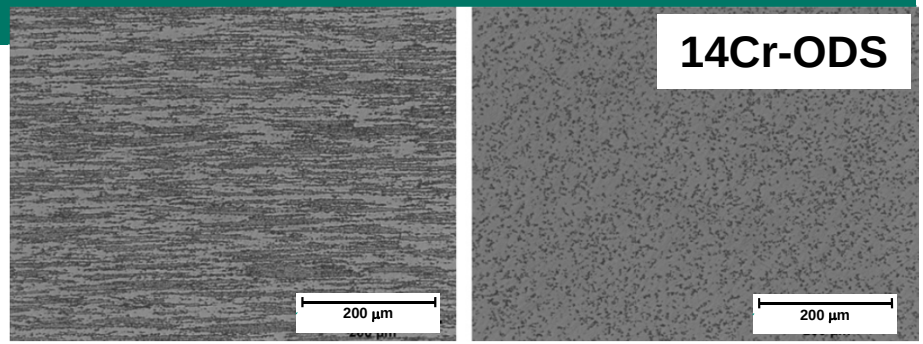
12Cr-ODS (plates)

Fe	Cr	Mo	W	Ti	Mn	Ni	Y*
bal	12.2	<0.01	1.94	0.25	<0.01	<0.01	0.17

14Cr-ODS (bars)

Fe	Cr	W	Ti	Mn	Y*
bal	13.45	0.88	0.39	0.27	0.22

* as Y_2O_3



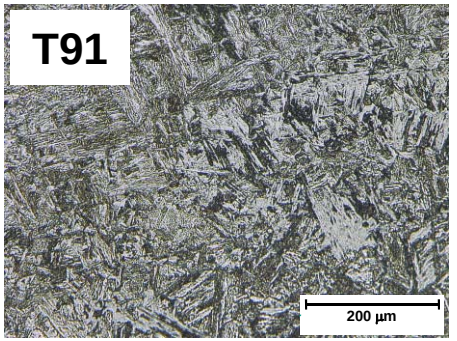
Extrusion/rolling direction

T91

Fe	Cr	Mo	Mn	Si	V
bal	8.99	0.89	0.38	0.22	0.21

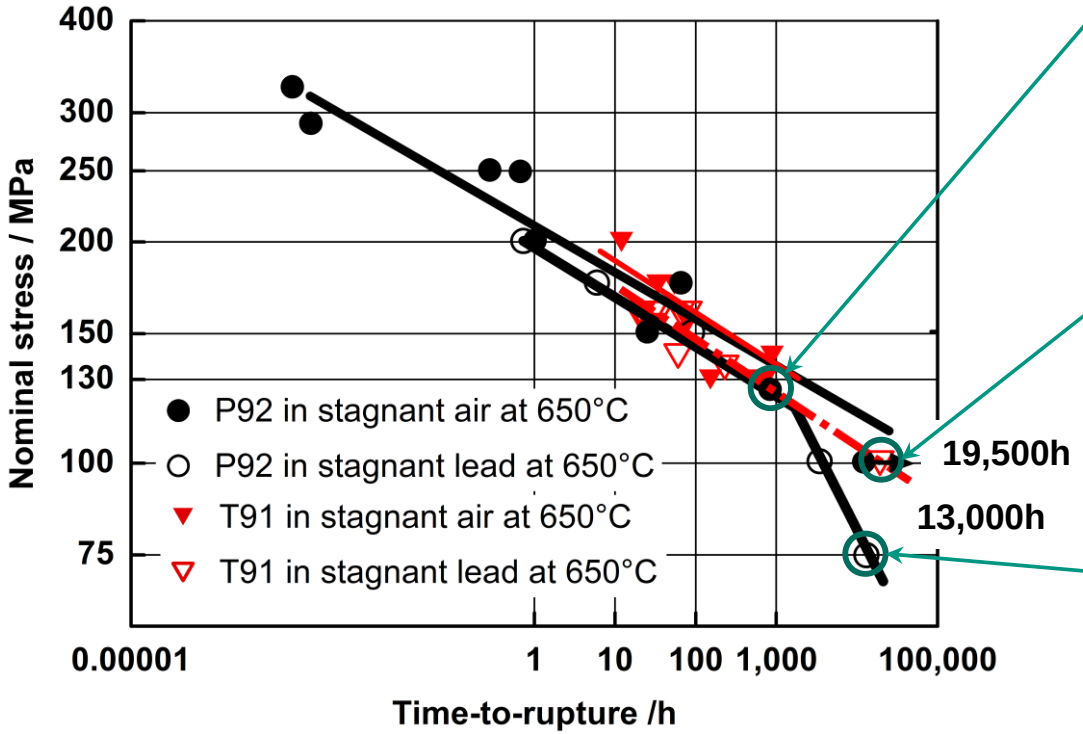
P92

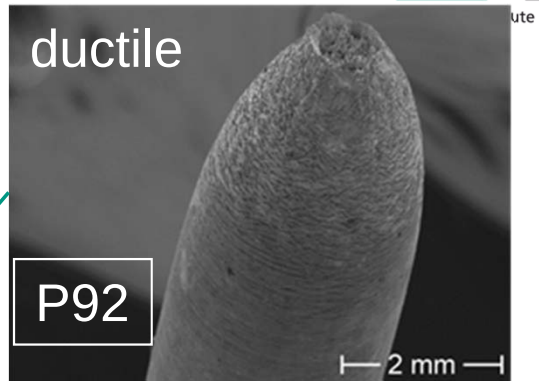
Fe	Cr	Mo	W	Mn	V
bal	8.99	0.49	1.75	0.43	0.2

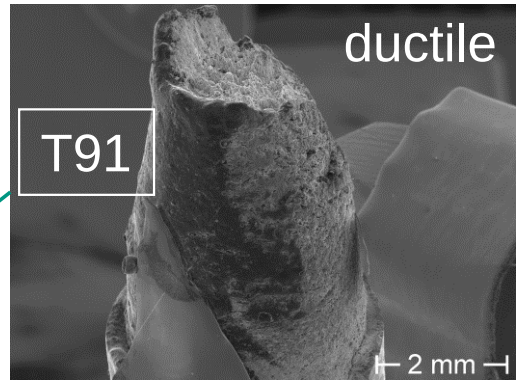


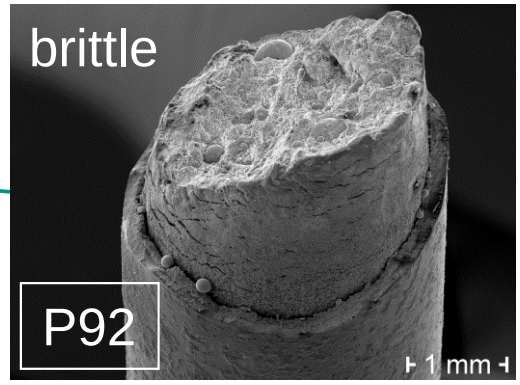
Results for T91 and P92

- ✓ Generally ductile behaviour.
- ✓ Insignificant difference between Pb and air.
- ✓ P92 shows brittle rupture mode at 75 MPa (t_R=13,000h).



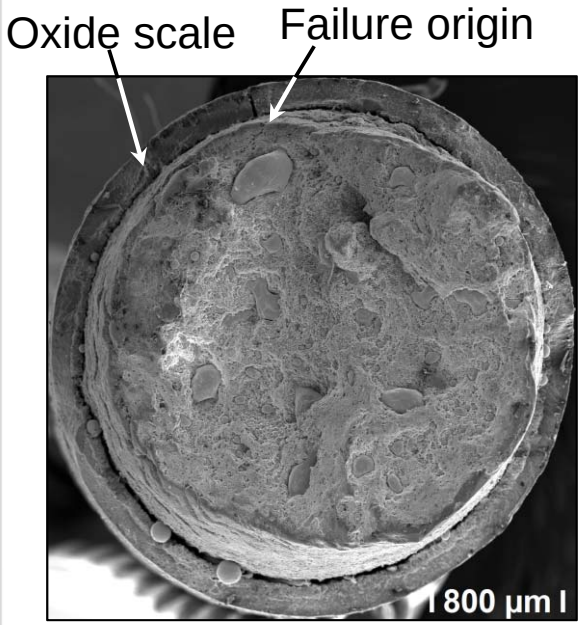


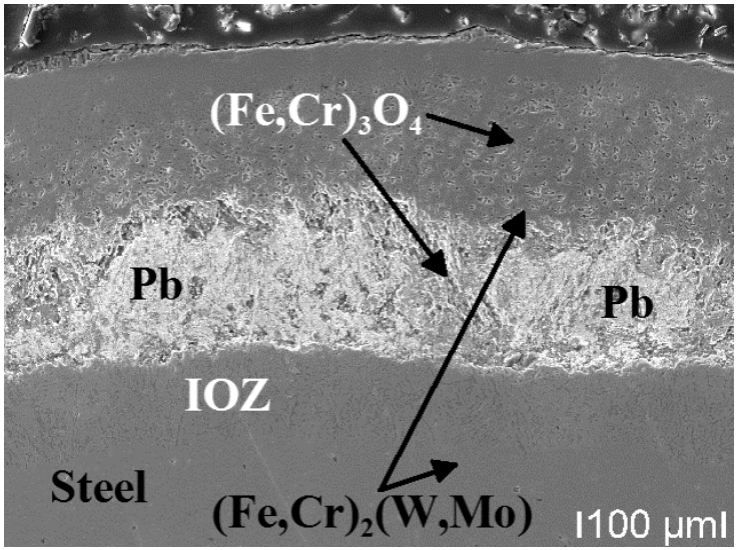


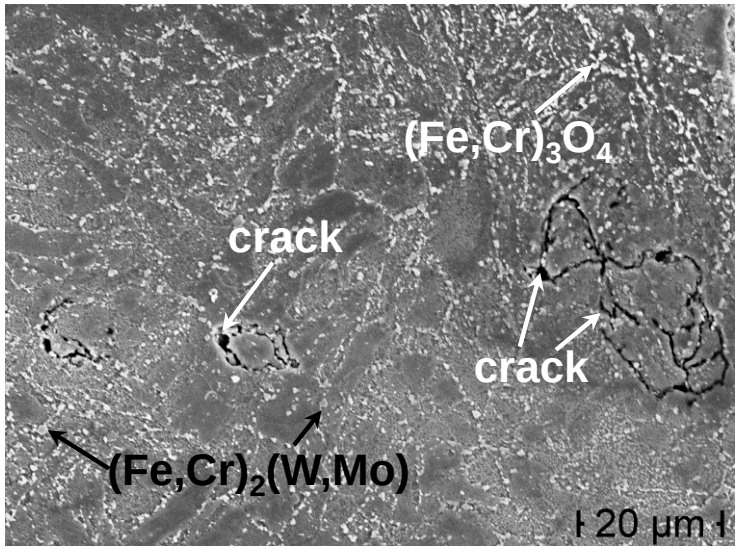


Results for P92

P92 at 75MPa and 13,090h

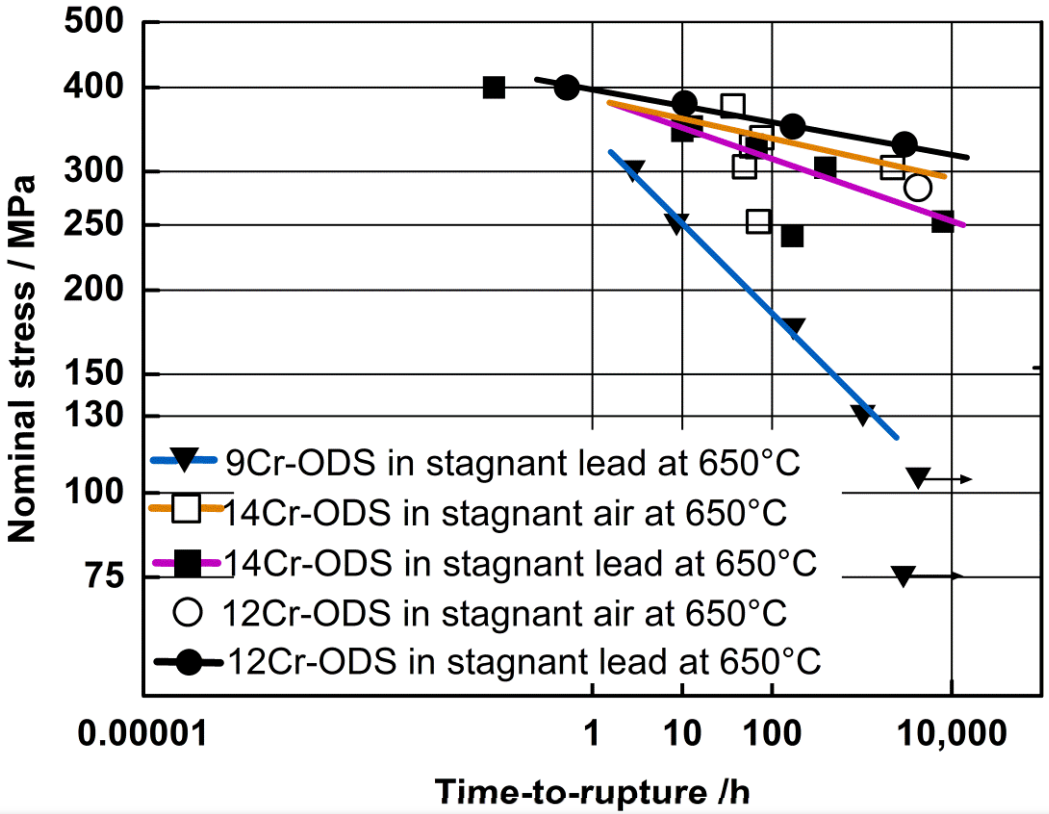






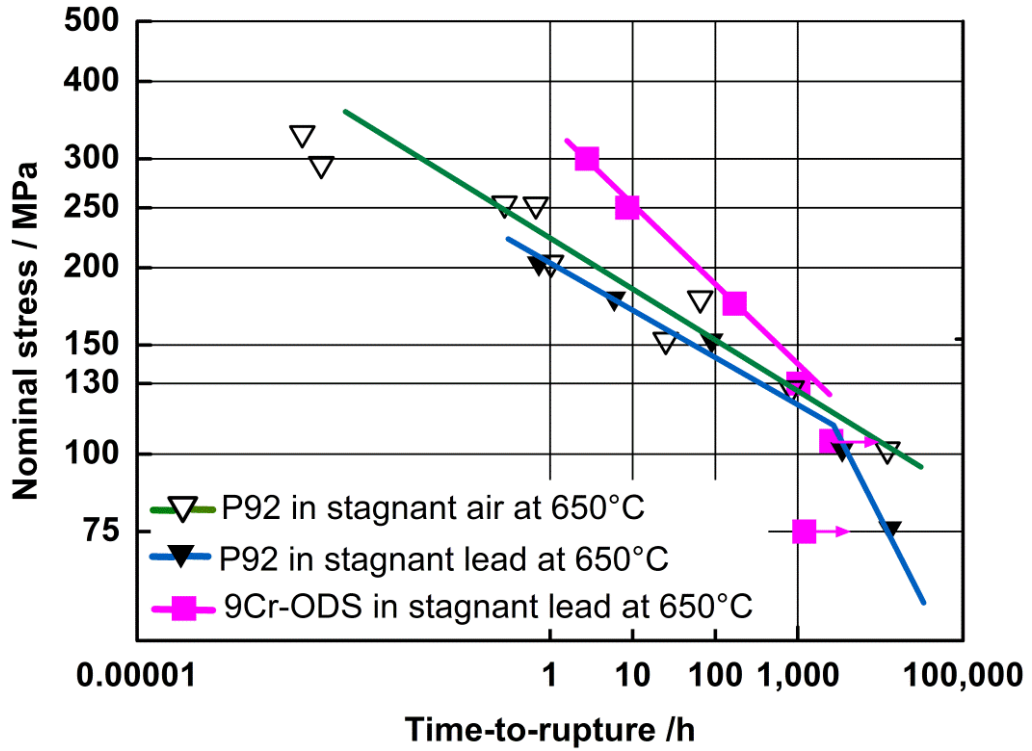
- ✓ Indications for LME: Failure origin at surface. Pb at oxide scale/steel interface.
- ✓ Indications for thermal aging: Increase in size and number of precipitates.
- ✓ Difficult to separate the influence of these two effects in the creep-rupture tests.

Creep strength of 9-14 Cr ODS steels in Pb and air at 650°C



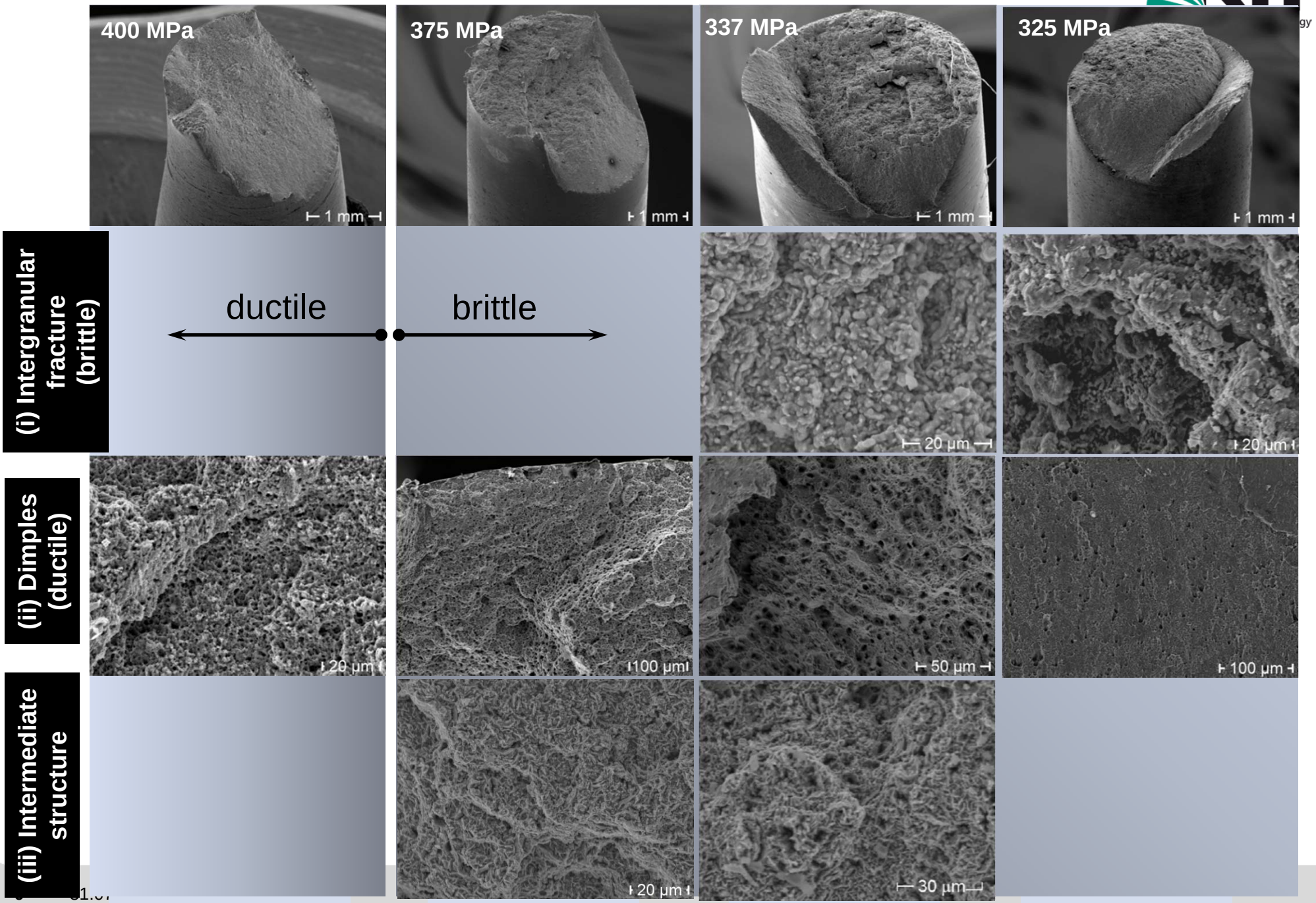
- ✓ 12Cr- and 14Cr-ODS: insignificant difference in strength in oxygen-controlled Pb and air at 650°C.
- ✓ The lower the stress, the bigger the difference in strength between 12/14Cr-ODS and 9Cr-ODS in Pb (and air).

Creep strength of 9Cr-ODS in comparison to conventional P92



✓ The lower the stress, the smaller the difference in strength between 9Cr-ODS and P92 (T91) in Pb (and air).

Fracture analysis of 14Cr-ODS



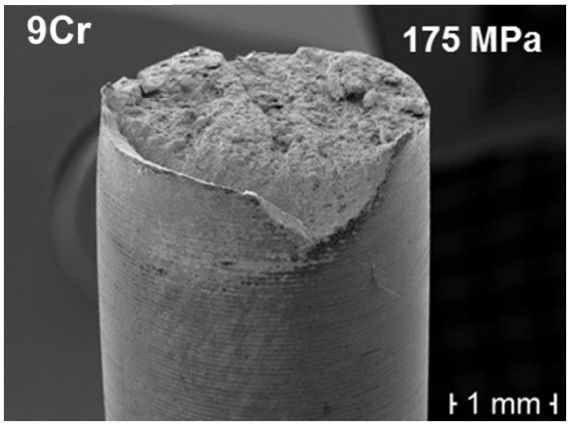
Z=62 %; ε_R=18 %

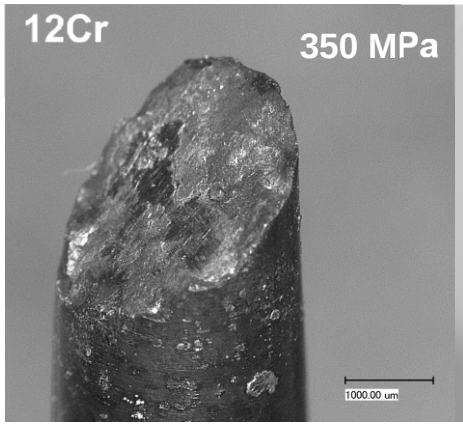
Z=4 %; ε_R=7 %

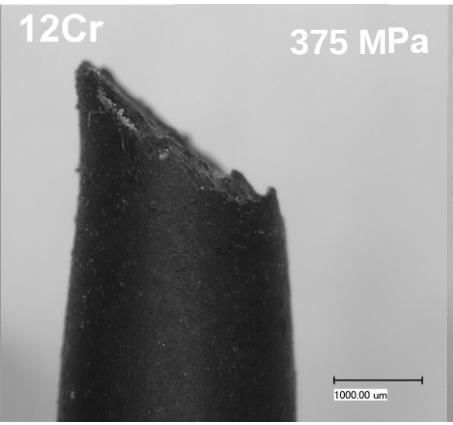
Z=5 %; ε_R=7 %

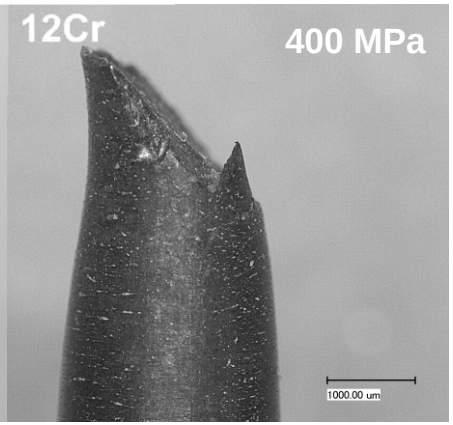
Z=6 %; ε_R=6 %

Secondary creep vs. Fracture mode of ODS



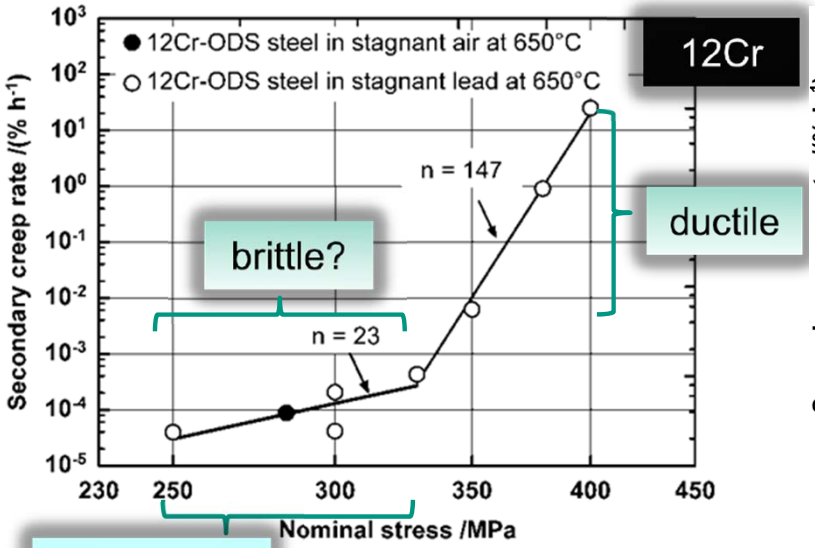


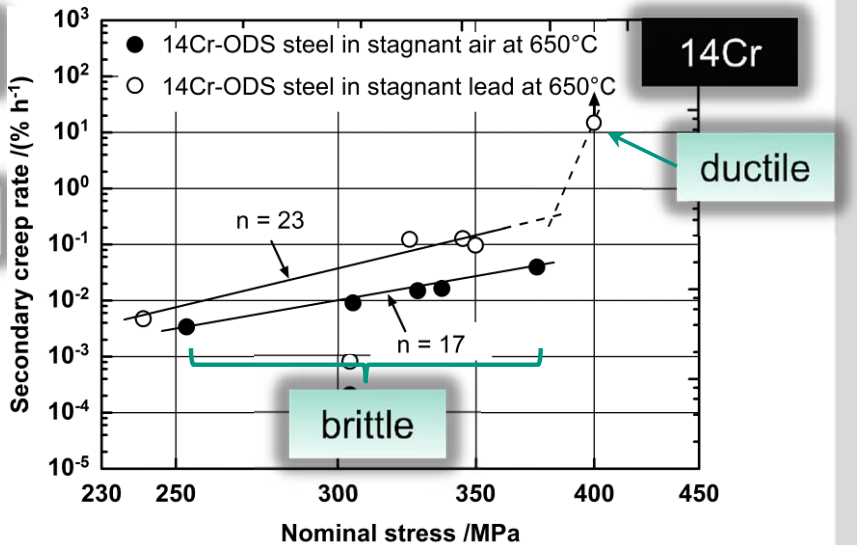




9Cr

brittle at ≤300 MPa





Summary: Creep and fracture

	F/m T91/P92	F/m 9Cr-ODS	Ferr 12Cr/14Cr-ODS
High load (high stress exponent)	Ductile	?	Ductile
Creep mechanism	Diffusion & agglomeration of vacancies at precipitates along grain boundaries	Intragranular dislocation climb and glide mechanism [H.Sakasegawa, 2008]	Dislocation glide from one side to the other at high stresses ⇩ Orowan loops creation at intermediate stresses ⇩ Gliding dislocation on spherical obstacles at low stresses [E. Nembach, 1997]
Low load (low stress exponent)	Ductile, except for P92 at 75 MPa in Pb	Brittle	Brittle

Conclusion

- ✓ Creep-rupture in static Pb (650°C/10^{-6} mass%) generally similar to tests in air.
- ✓ Change in rupture mode for f/m P92 at 75 MPa in Pb.
- ✓ Influence of Pb and thermal aging not yet possible to separate.
- ✓ 12-14Cr (ferritic) ODSs generally stronger than 9Cr-ODS (ferritic/martensitic).
- ✓ Brittle fracture at low load, ductile fracture at high load (<330/350 MPa)
- ✓ Influence of deformation rate (secondary creep)?

Acknowledgment

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