Qualification of New, Commercial Oxide Dispersion Strengthened (ODS) Alloys

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ODS Alloys for Fossil Energy Application

- Increase efficiencies of fossil fuel systems require materials that can reliably operate at higher temperatures and pressures

- ODS steels out perform Ni-based superalloys in terms of creep and oxidation resistance at temperature above 900ºC and could be used up to 1200ºC

- Need to take advantage of the full potential of ODS alloys to balance the cost of alloy fabrication

- Potential applications: HT heat exchanger, fuel nozzles & combustors can for turbines fired with H_2

ODS Alloys Process

-Mechanically Alloyed powder: metallic powder with 5-10 nm Y_2O_3 particles: nano-precipitates stable at high TºC

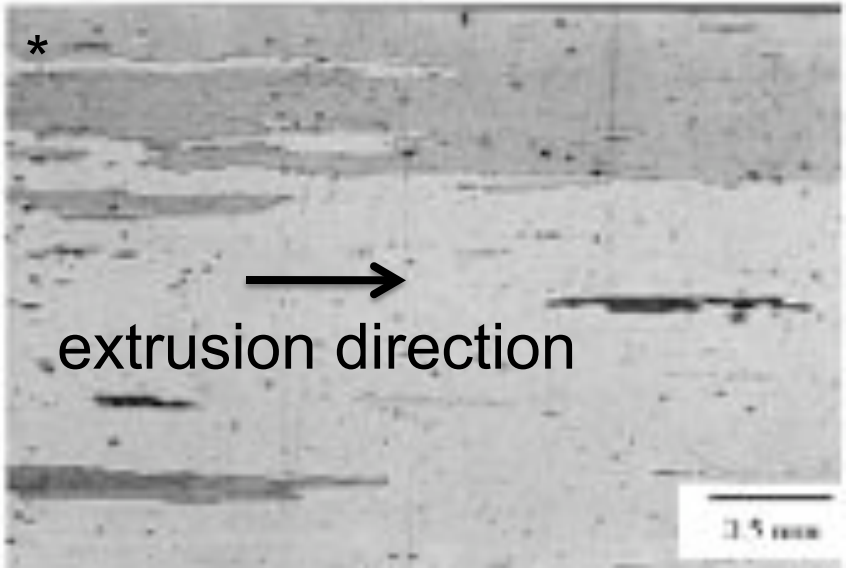
-Alloys composition:

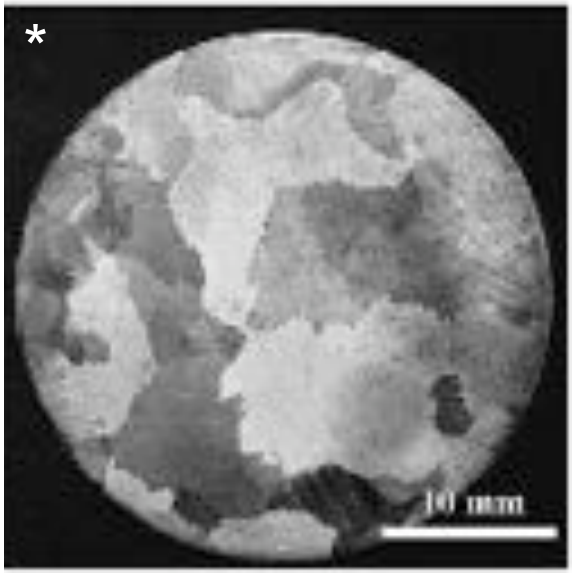
	Fe	Cr	Al	Ti	Y_2O_3	Other
ODM751	bal.	16.5	4.5	0.6	0.5	1.5 Mo
MA956	bal.	20	4.5	0.5	0.5	0.5 Ni max
MA956HT	bal.	21.6	5.9	0.4	1	
PM2000	bal.	20	5	0.5	0.5	

- Extrusion process to form tubes, bars and sheets:

- Re-crystallization annealing at very high TºC (up to 1380ºC) to suppress grain boundaries

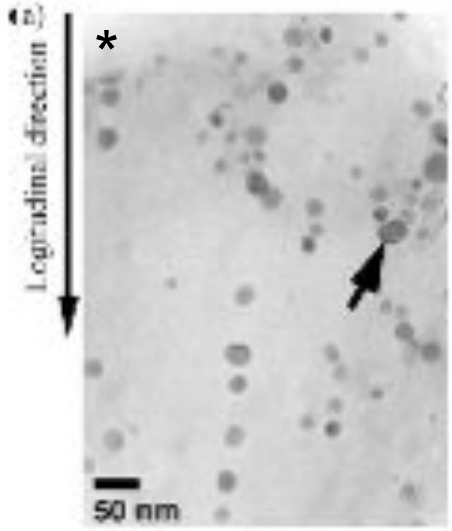
ODS Alloys Microstructure





Longitudinal

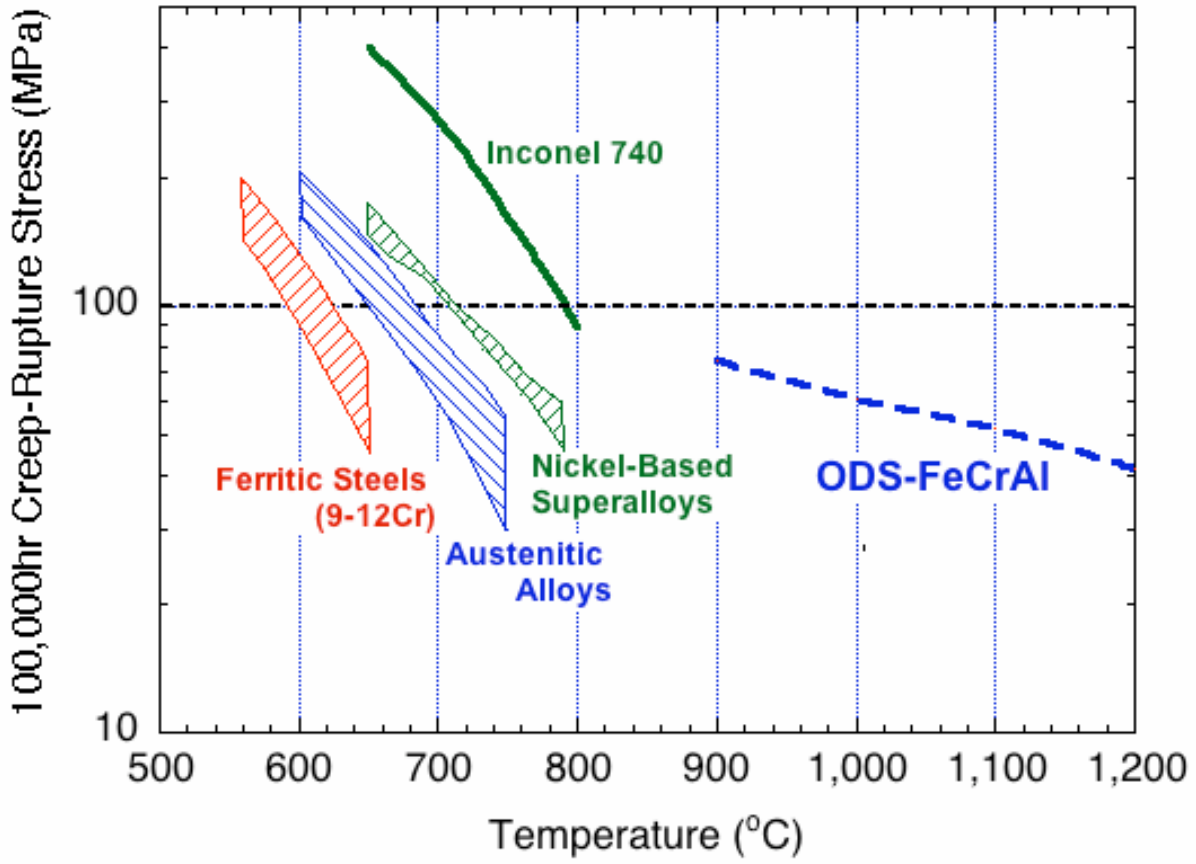
Transverse



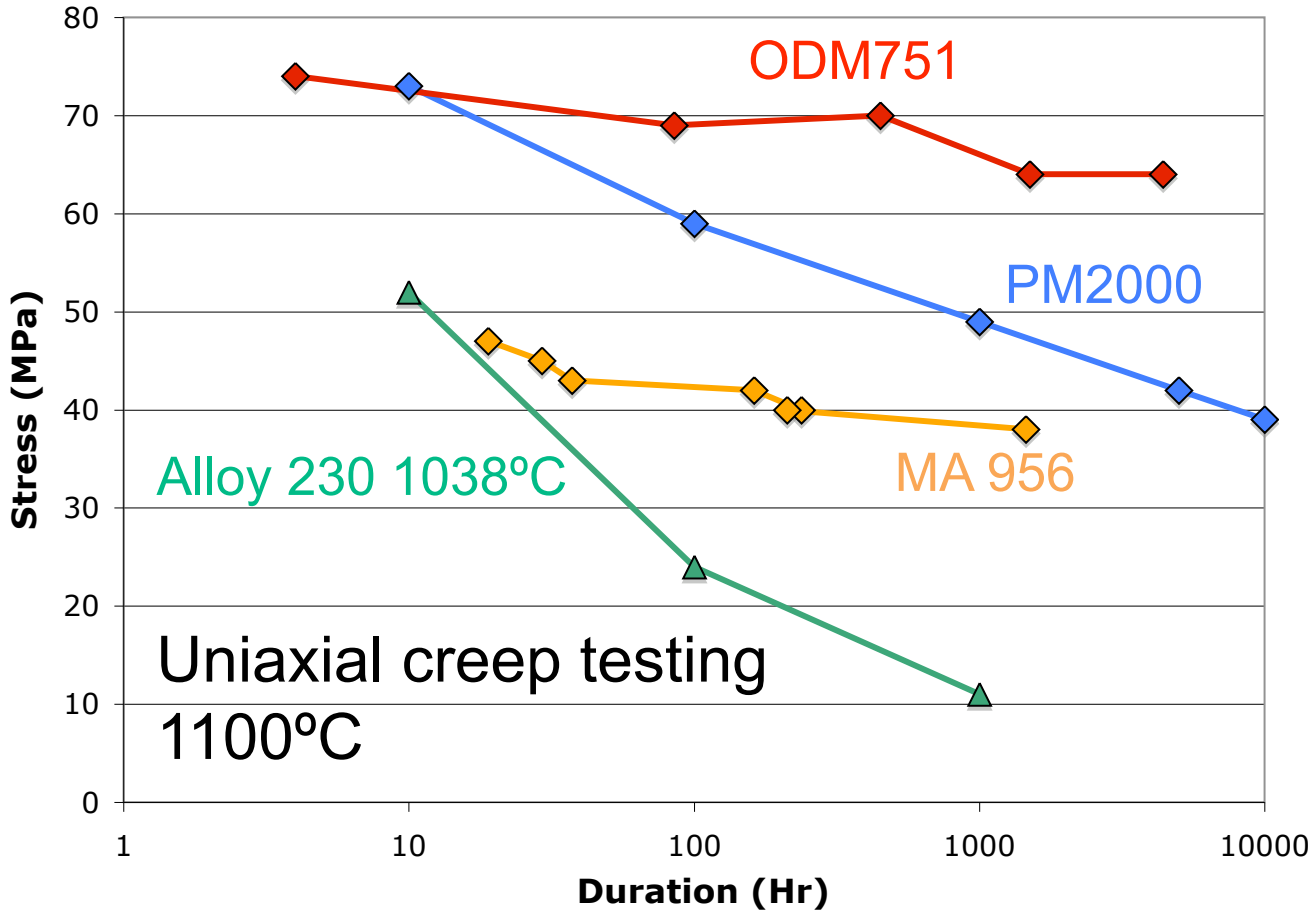
- Elongated grains
- nano Y_2O_3 precipitates

*Capdevila & Al., Mat. Sci. and Eng. A, 490, 277 (2008)

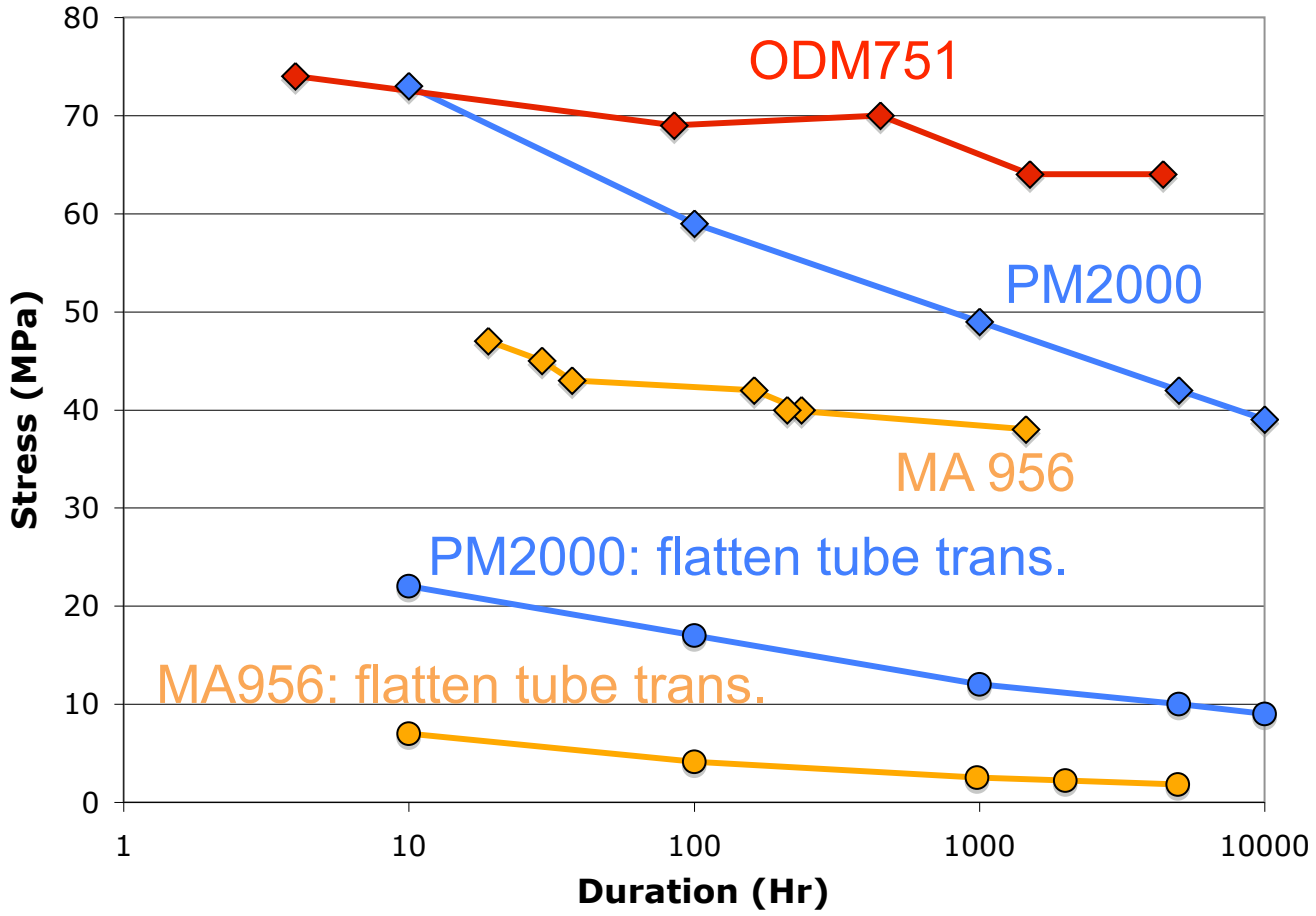
ODS-Alloys Out Perform Ni-based Superalloys at High Temperature



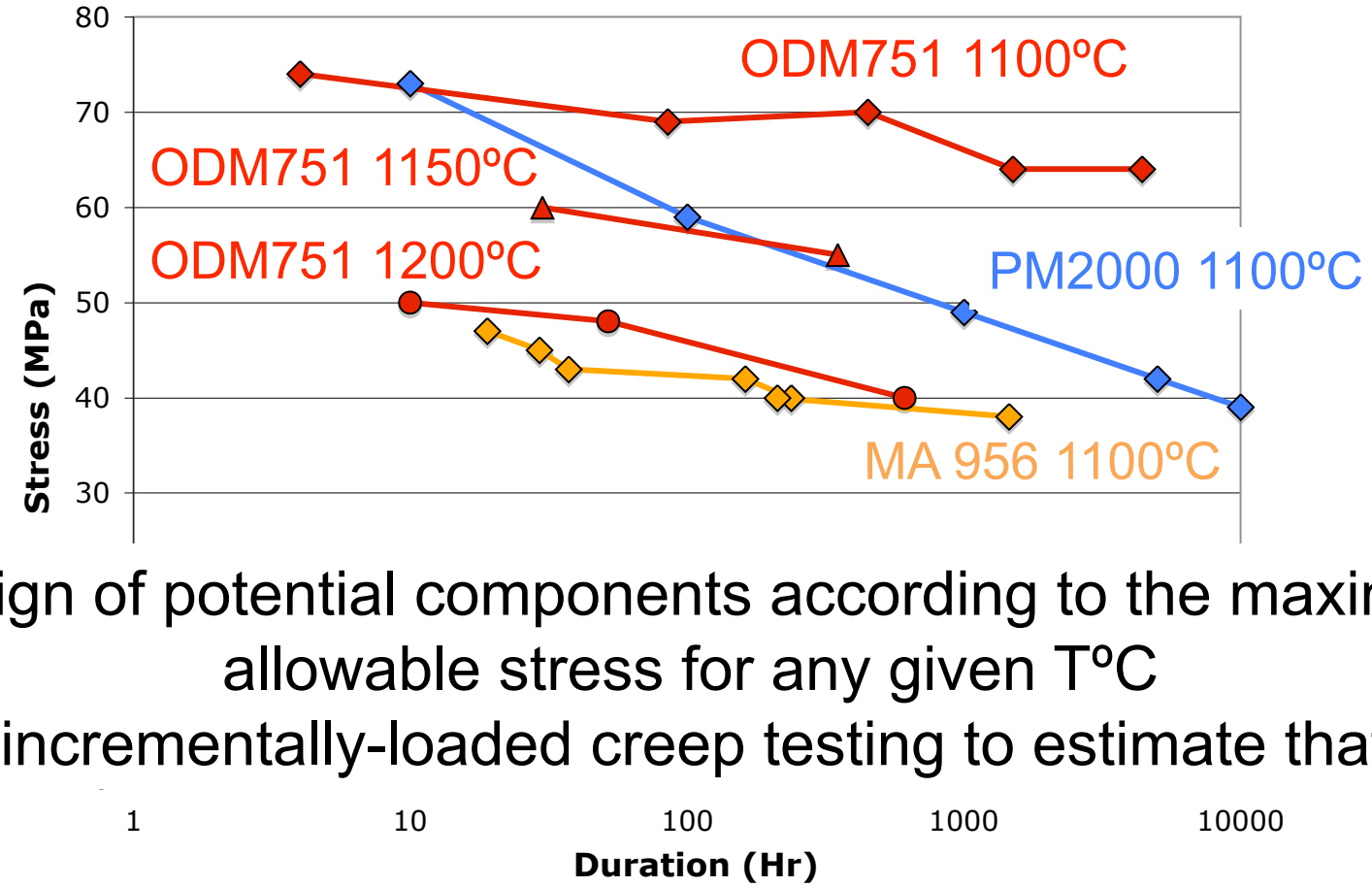
Excellent Creep resistance of ODS Steels at 1100ºC



Lower hoop creep strength resistance



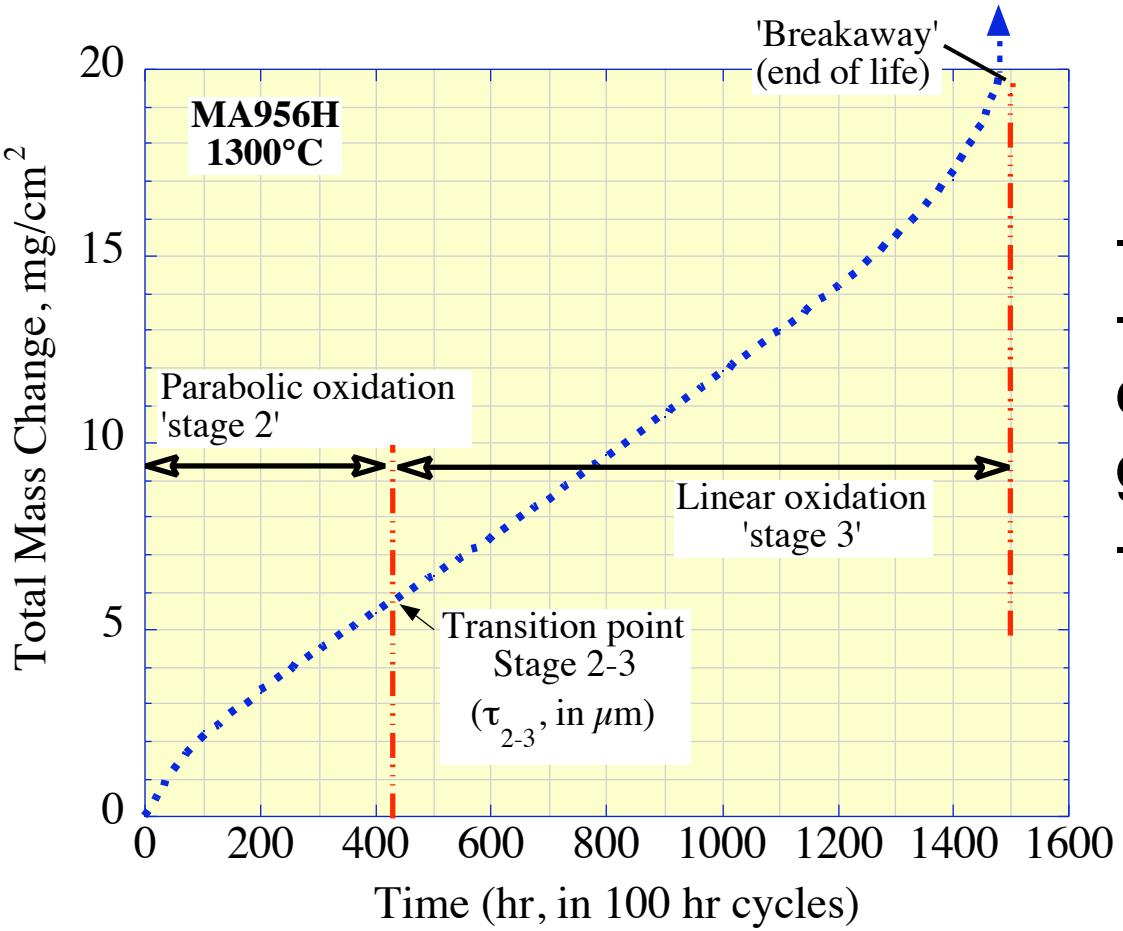
Existence of a stress to rupture threshold for a given T°C



Design of potential components according to the maximum allowable stress for any given T°C

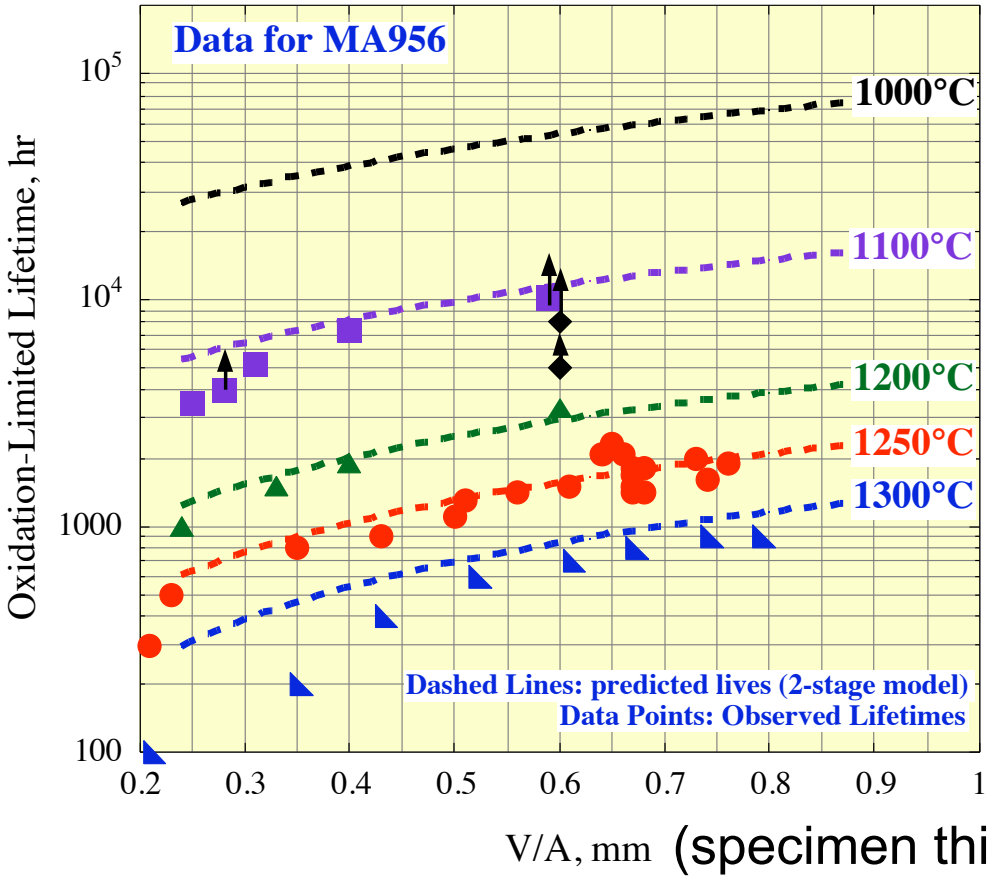
Use of incrementally-loaded creep testing to estimate that max σ

3 oxidation stages have been identified during cyclic exposure



-1) short transient stage
-2) parabolic stage: dominated by oxide scale growth
-3) linear stage: scale growth + spallation

Development of lifetime models based on oxidation rate

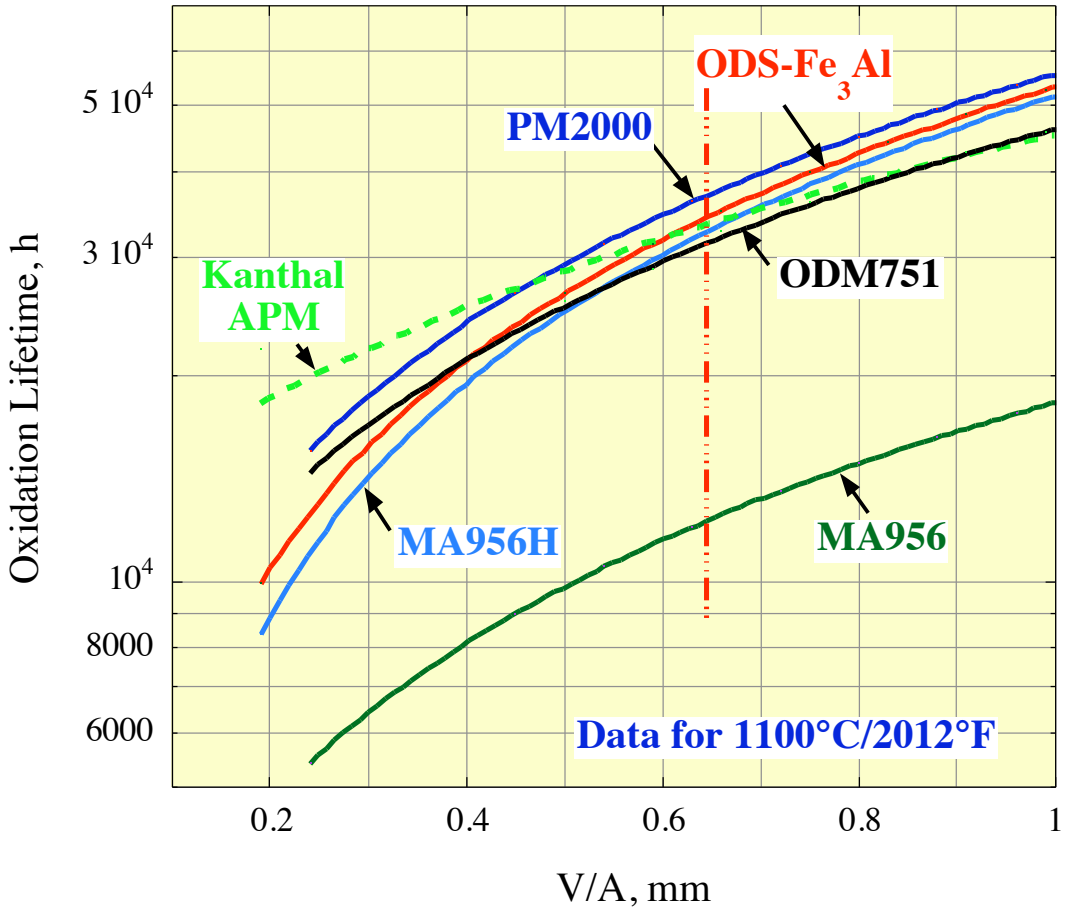


Main Parameters:

- All the constant from the parabolic and linear oxidation stages
-V: Volume of alloy being oxidized
-A: Area exposed to environment
-Cb_0: Initial mass fraction of Al
-Cb_b: Mass fraction of Al at which Al_2O_3 can no longer form

Good agreement between experimental data and models

Quite similar lifetime for many ODS alloys



Development of Non-Fusion Joining Techniques for ODS Alloys

1. Inertia Welding – readily available industrial technique, produces robust joints with acceptable high temperature creep performance.

2. Pulse Plasma Assisted Diffusion produced joints with performance 75% of the base material in incremental load tests

3. Friction stir welding

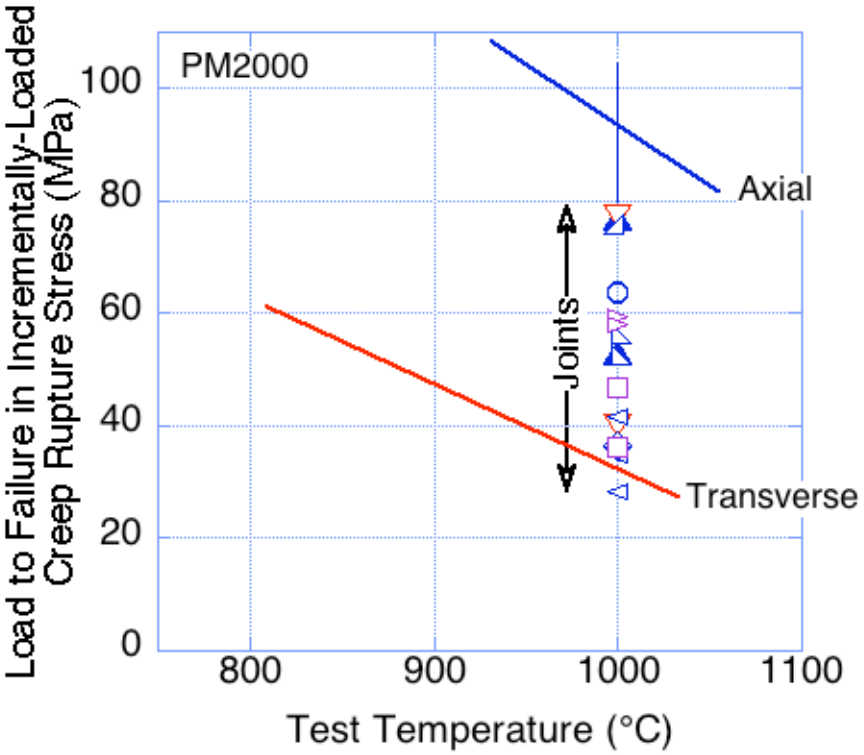
4. Transient Liquid Phase – failure to propagate recrystallization limits application scope

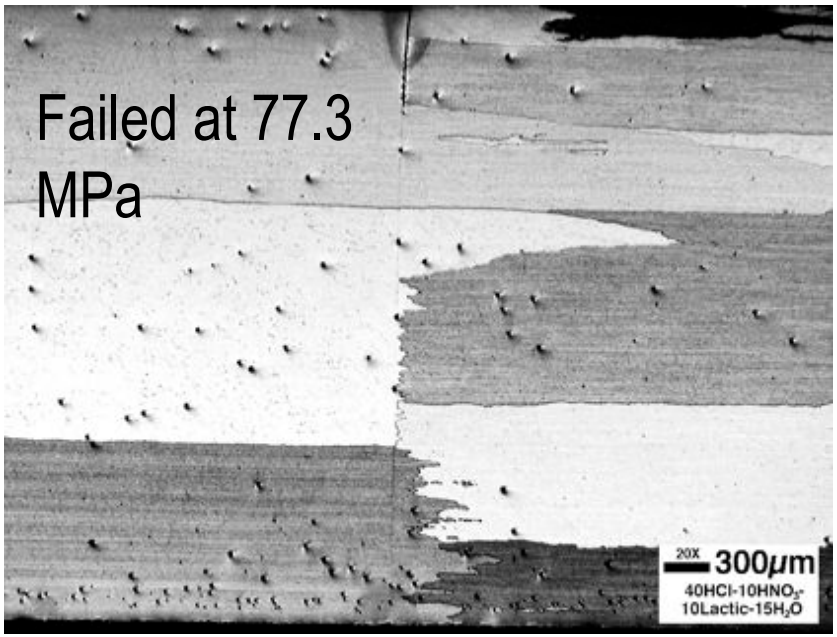
5. Magnetic Pulse joining successful in providing hermetical seals and Joints. Technique applicable only to thin sections. Limited Scope

6. Explosive bonding

SUMMARY OF PRIOR WORK ON JOINING OF OXIDE DISPERSION-STRENGTHENED ALLOYS, Wright and Al. ORNL/TM-2009/138

Pulsed plasma-assisted diffusion bonding gives excellent results



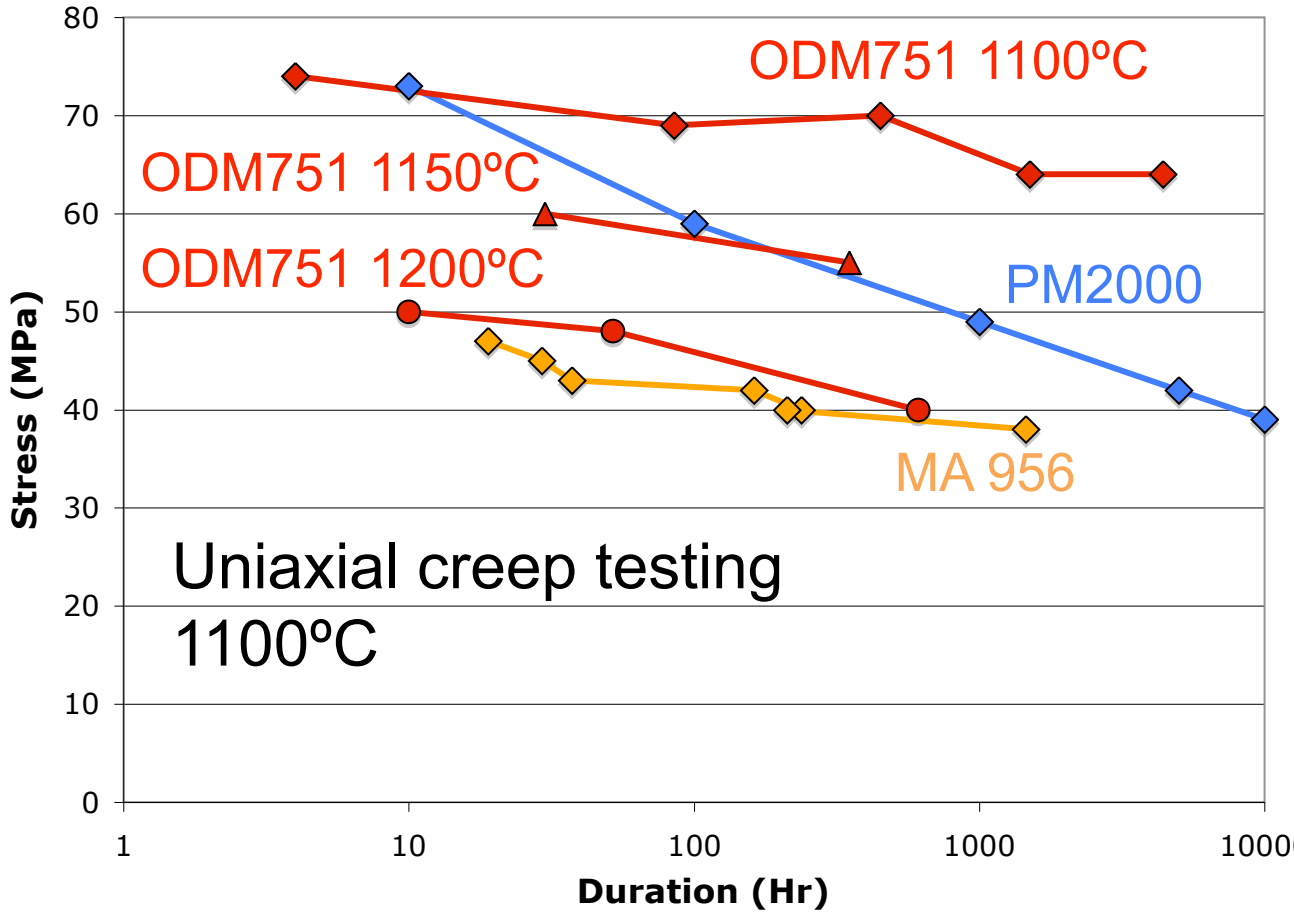


- Miniature specimens/butt joints
- Joint strength highly-dependent in microstructure
- Best: >81% of load to fail monolithic

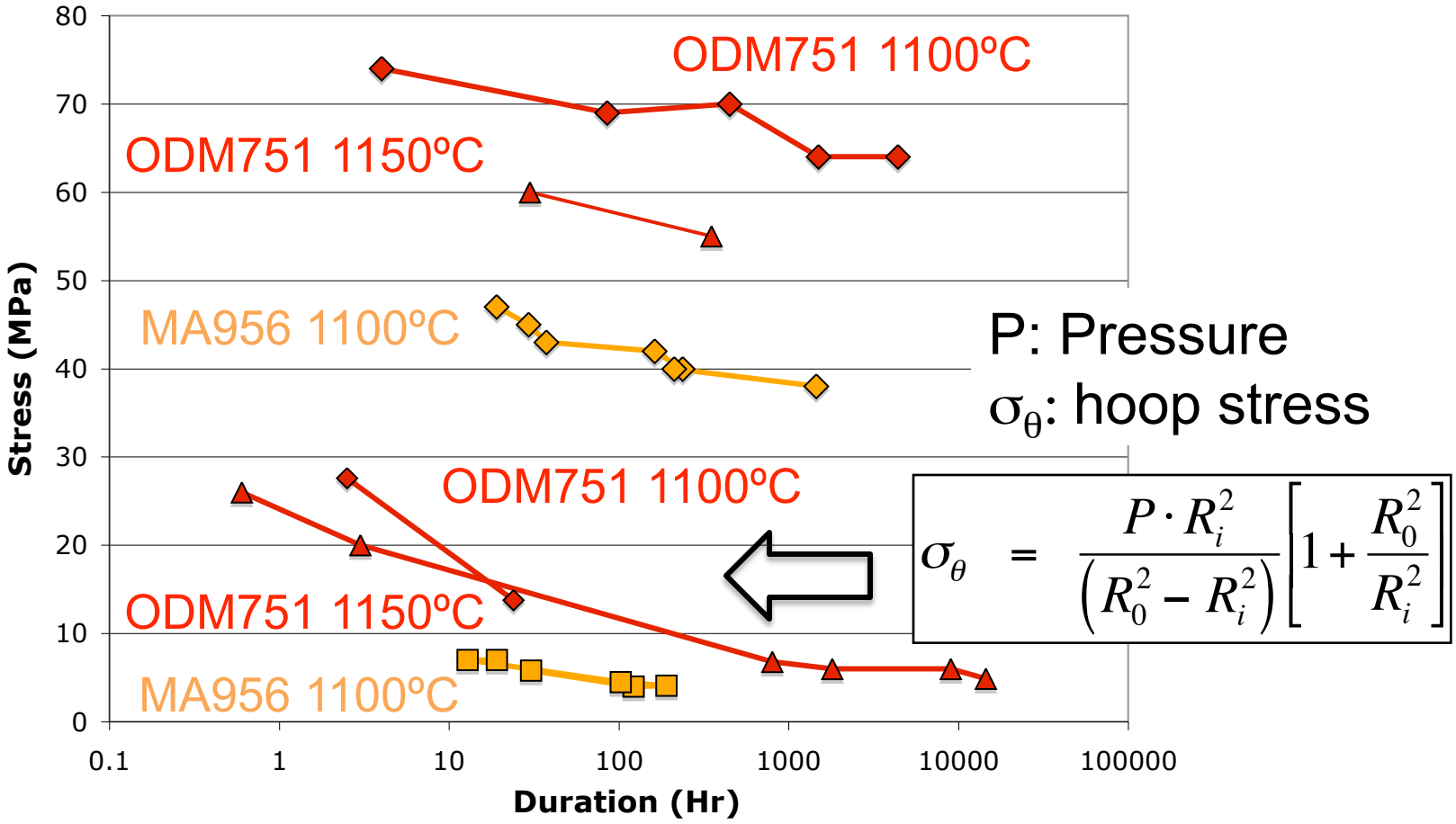
ODS Program FY 2010 Milestones Evaluation of New ODM751R Alloy

- Obtain sample lengths of ODM 751R extruded rods and tubing for initial structure and properties characterization
- Perform and report on initial characterization work on ODM 751 samples
- Status
  - Dour Metal Sro recently established by a former employee of Dour Metals, Belgium to produce ODS alloys
  - ORNL has contracted Dour to produce sample quantities of ODM 751R rod and tube for material characterization studies
  - Samples of mechanically alloyed ODM751R powder have been obtained by ORNL and initial characterization work started.

Superior creep properties for the ODM 751 alloy



ODS Alloy Tube testing up to creep failure

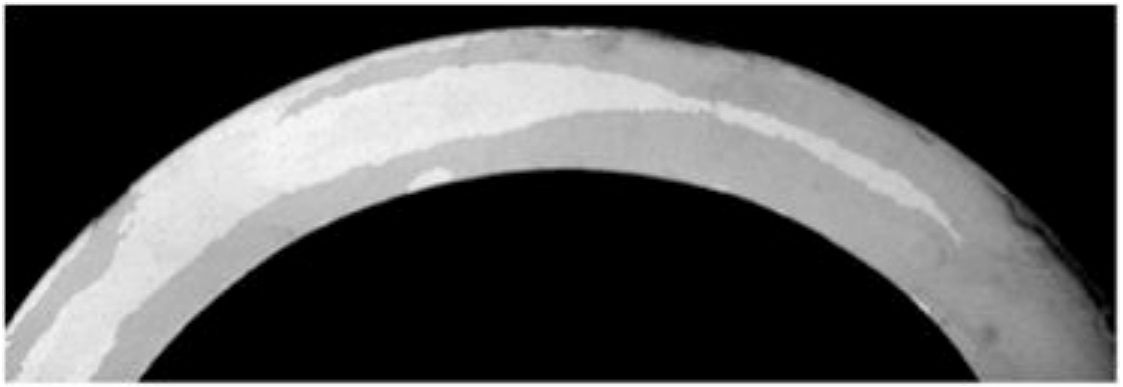


P: Pressure

σ_θ: hoop stress

$$\sigma_\theta = \frac{P \cdot R_i^2}{\left(R_0^2 - R_i^2\right)}\left[1 + \frac{R_0^2}{R_i^2}\right]$$

Better Hoop Creep Strength due to overlapping circumferential grains



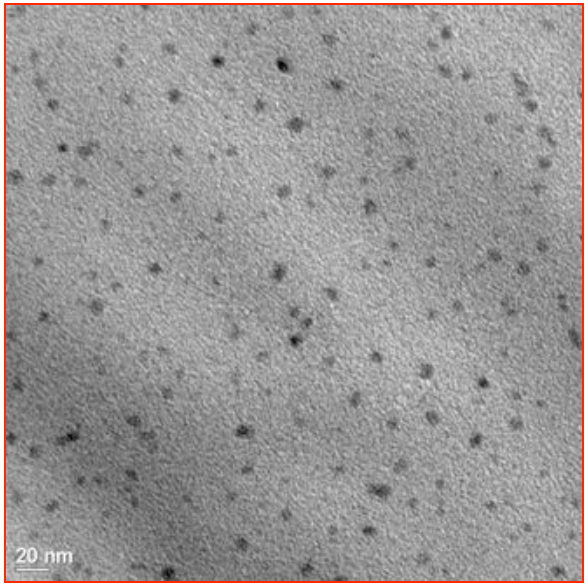
"onion skin grain shape"

British Gas High TºC Heat Exchanger
made of ODM751 (36 tubes 3.6m)
up to 1150ºC, 3.5 Bar

New ODM 751R alloy

-ODM751R mechanically alloyed powder has been produced

-by Dour metal and characterized by TEM at ORNL



5-10 nm particles

-1kg of powder was sent at ORNL for extrusion

-Extrusion parameters will be discussed next week at ORNL

2010 other milestone: ODS alloy awareness workshop

A technical and engineering information exchange workshop between potential users, previous and current suppliers, and R&D leaders

Main Goals:

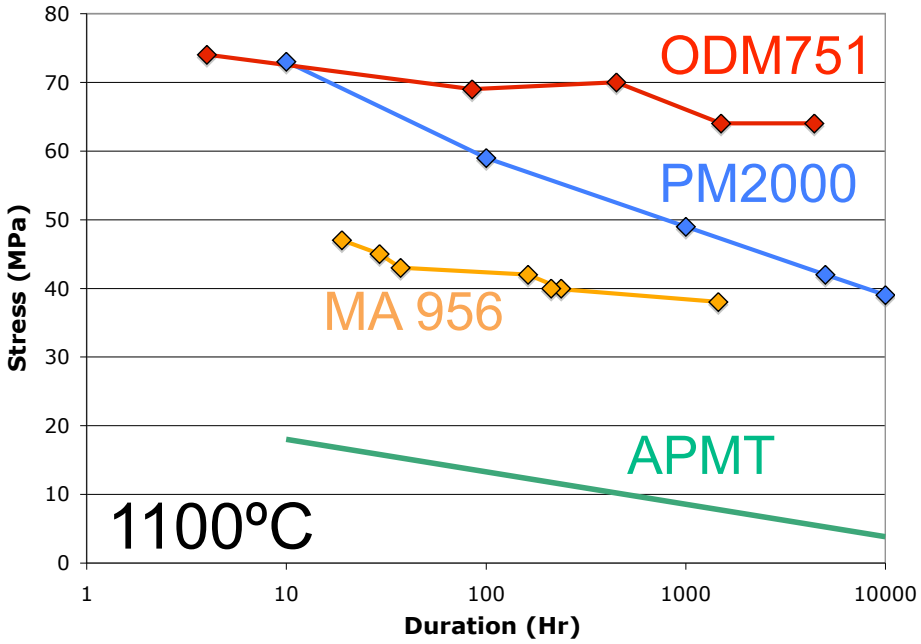
- to promote commercial and user interest in ODS alloys within the fossil energy arena

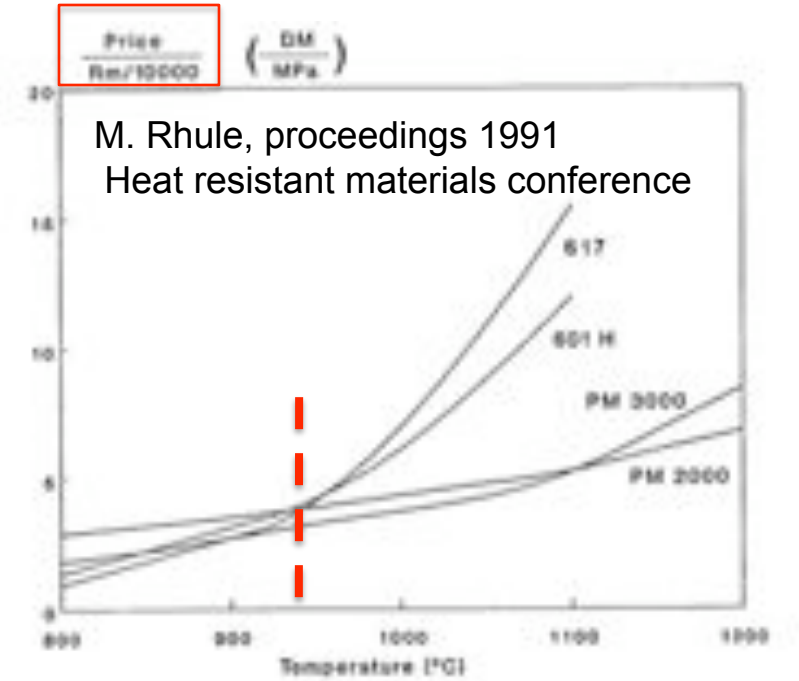
- to identify barriers for future use and propose solution path

- to identify common goals with the nuclear industry and initiate collaborations: production, joining, characterization…

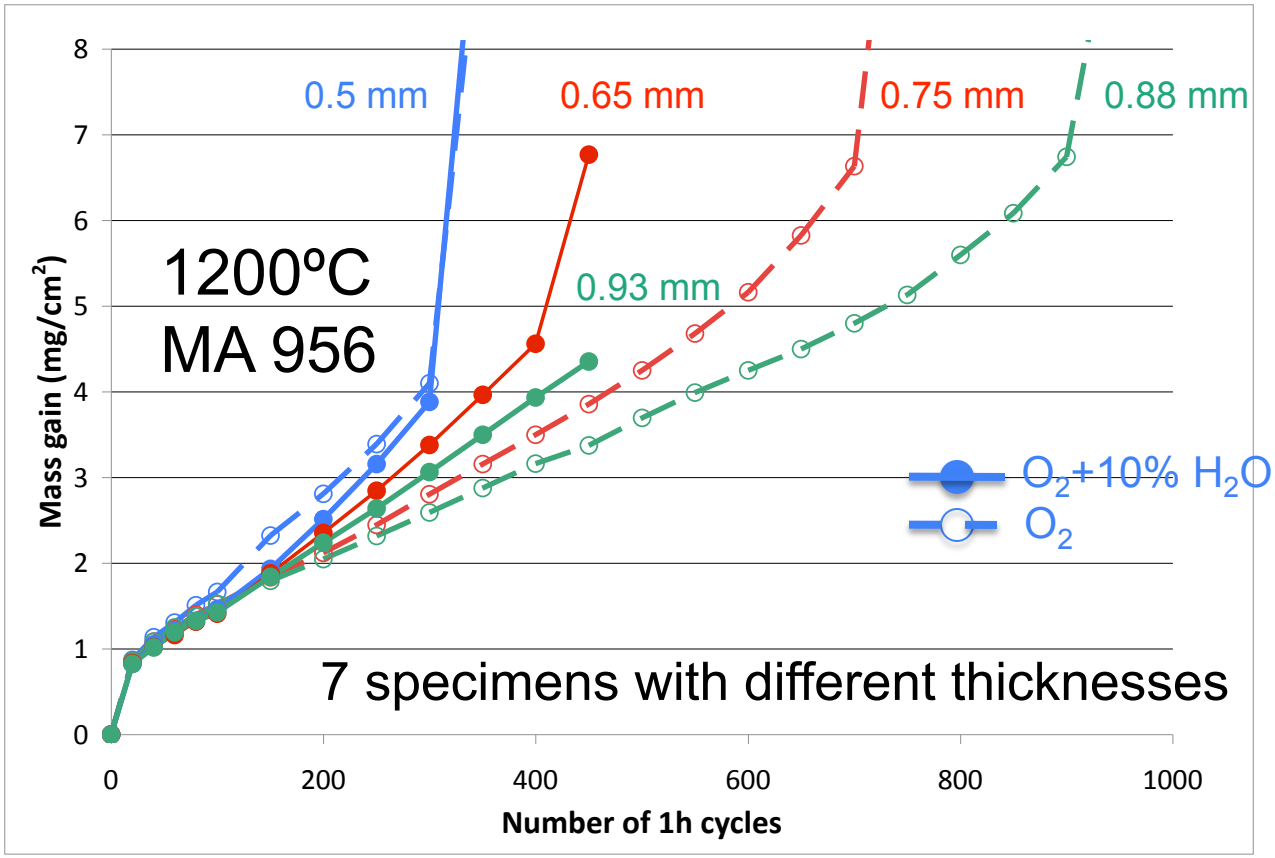
2009/10 subtask: to produce ODS alloy without mechanical alloying

- to determine the reactive gas atomization processing parameters to approximate MA957 / ODM751R microstructure
- to tailor the cost/properties ratio according to the potential application (ex: Kanthal APMT)



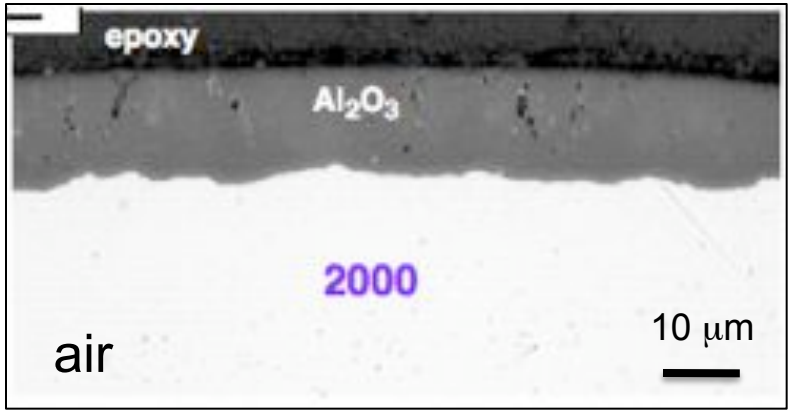


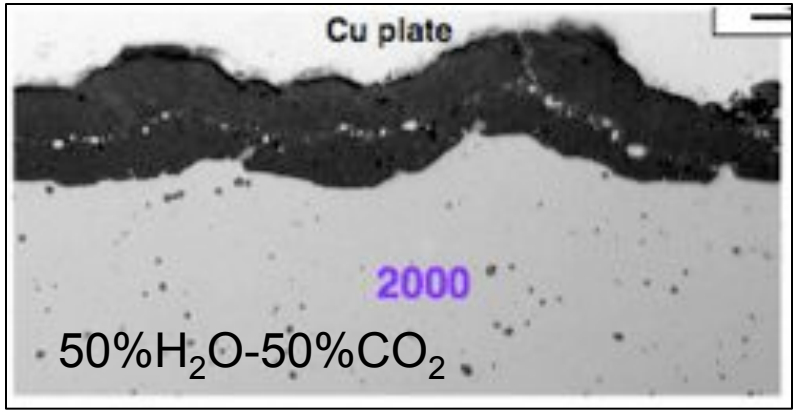
Improvement of oxidation-based lifetime models: effect of H_20



- Decrease of the lifetime due to the presence of H_2O

Improvement of oxidation-based lifetime models: effect of CO_2 & H_20

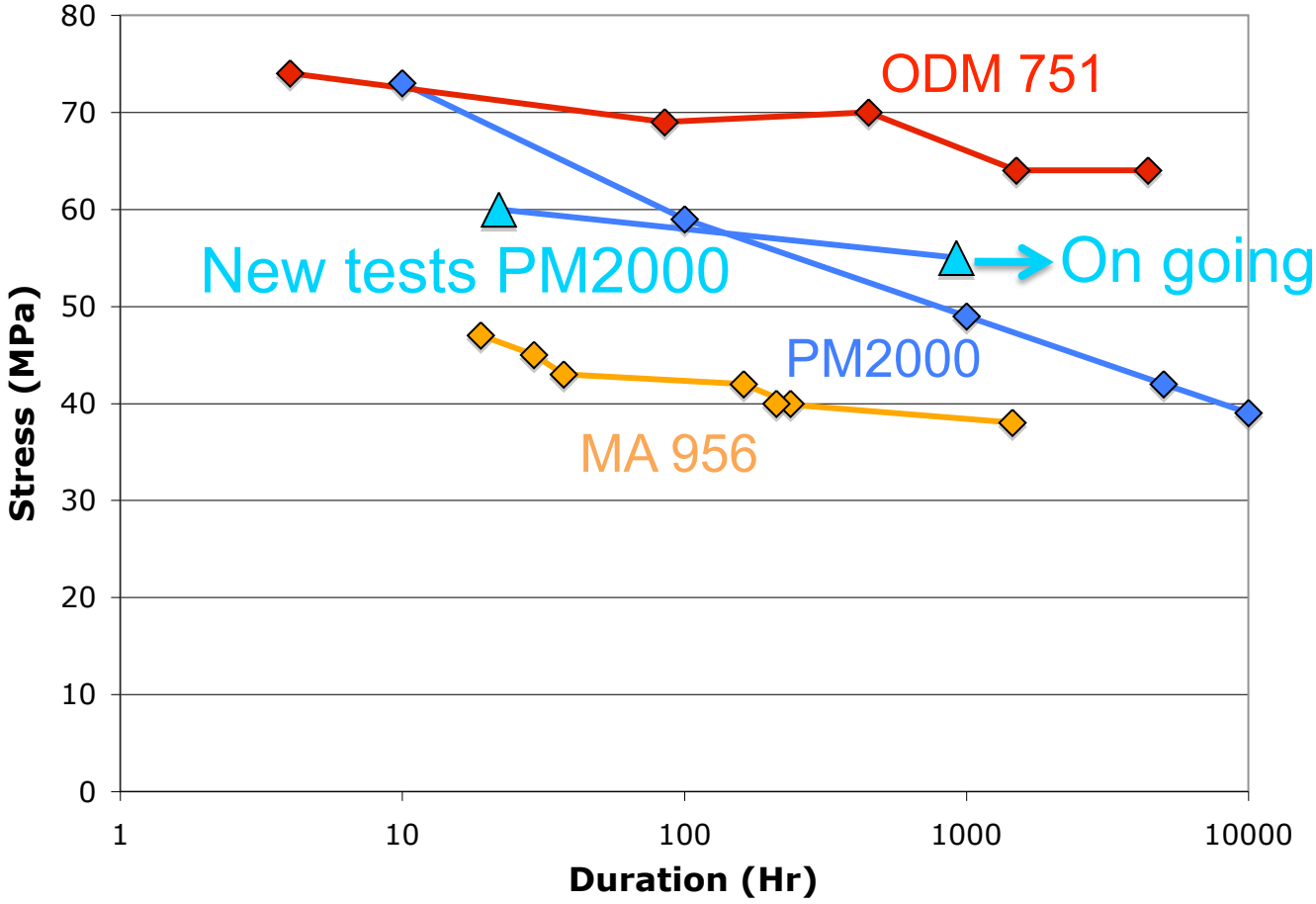




2kh 1100ºC = rougher scale with CO_2

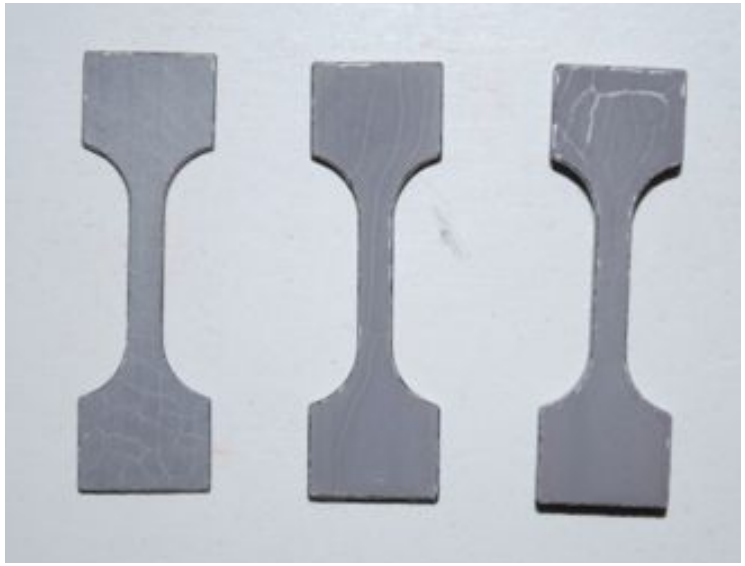
New environmental rig to test the effect of mixture gas

Creep baseline for PM2000 and "old" ODM751

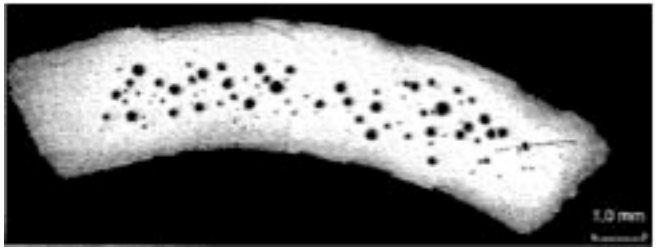


Effect of annealing/oxidation on the creep resistance

PM2000 dog bone creep specimens pre-oxidized in air
3 different thicknesses, 2 TºC: 1100ºC and 1250ºC



24.5 mm long specimen
1000 hr 1250ºC



7300h, 1300ºC
large formation of porosity

On Going/Potential Research relative to ODS alloys

Improvement of ODS alloys hoop creep strength:

- change in fabrication process
- flow forming process to change grains orientation

Improvement of ODS joining techniques

- work on welding parameters
- post welding process such as flow forming

Upgrade of testing equipment

- tube pressurization

Conclusion

- ODS FeCrAl alloys have demonstrated unique properties at temperature up to 1200ºC

- ODM751R powder will soon be extruded for extensive alloy characterization

- Collaboration with potential users, suppliers, technical experts and researchers will be intensified to widen ODS alloys use

- On-going research to improve ODS properties, weldability…will evolve to respond to potential users need