Durability and lifetime predictions of FeCrAl-ODS components

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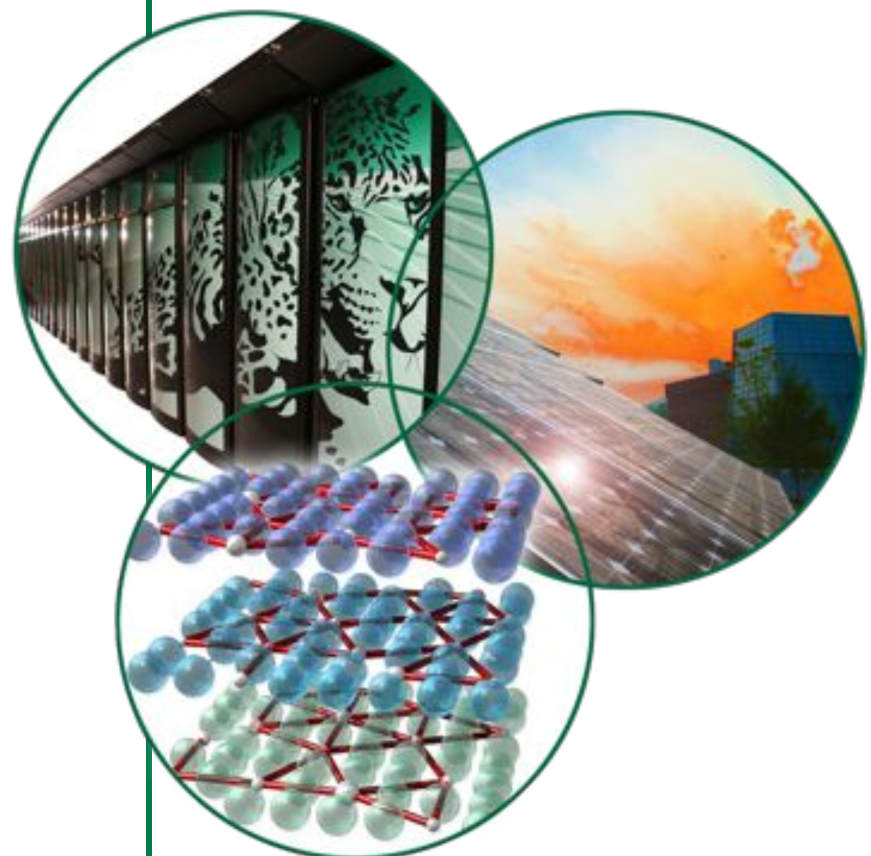

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U.S. DEPARTMENT OF ENERGY

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Durability of ODS alloys

- Depends on the service conditions: temperature, stress, cycles…

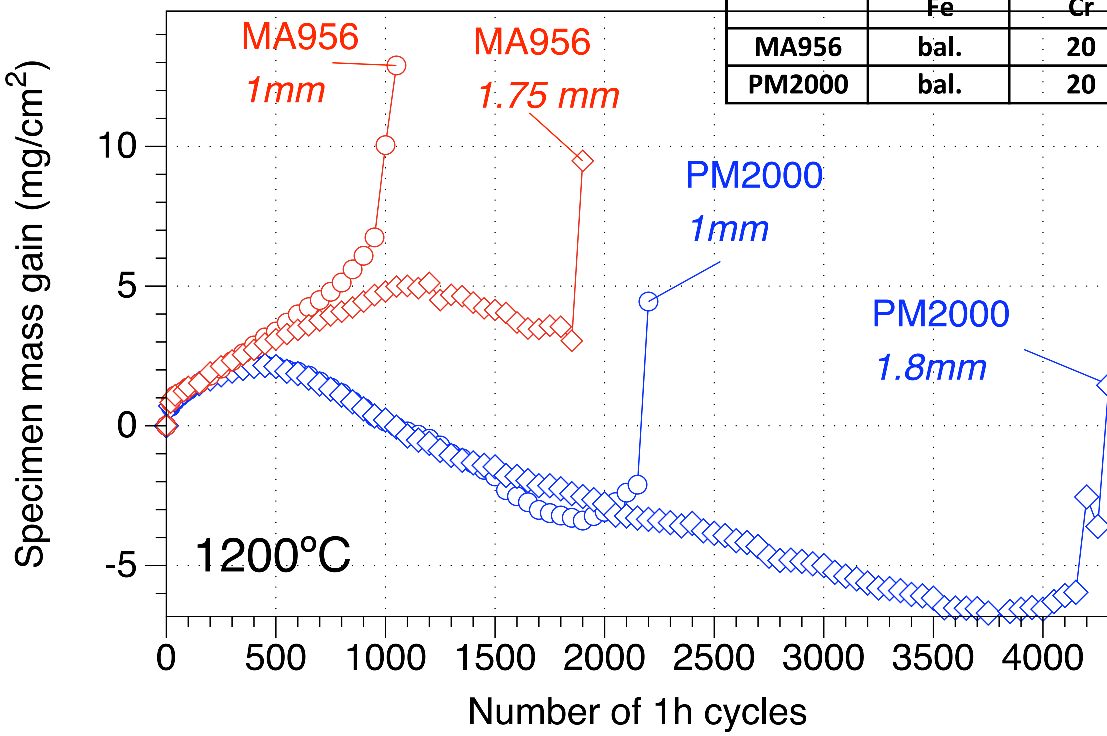
- High temperature creep and oxidation are expected to be the main mode of degradation

- Existence of a stress threshold at a given temperature below which deformation is minimum

- For a mechanically sound component, oxidation will determine the components durability

Durability depends on the time to break away oxidation

	Fe	Cr	Al	Ti	Y_2O_3	Other
MA956	bal.	20	4.5	0.5	0.5	0.5 Ni max
PM2000	bal.	20	5	0.5	0.5	



Low mass change = growth and spallation of Al_2O_3

Breakaway oxidation = fast formation of Fe rich oxides

Breakaway oxidation is due to Al consumption to form Al_2O_3

- Existence of a critical Al content C_b below which Al_2O_3 cannot form anymore
- Basis of FeCrAl lifetime models : time requires to drop from C_o, initial Al concentration, to C_b

Al to form Al_2O_3 = Al consumed in the alloy

Al_2O_3

$$S \cdot 1.125 \cdot k \cdot t^n$$

k, n: oxidation parameter

S: surface

FeCrAl

$$V \cdot \Delta C$$

$\Delta C = C_b - C_0$

V: volume

Quaddakers et al.

$$1.125 \cdot k \cdot t_b^n = \frac{\Delta C}{100} \cdot \rho \cdot \frac{d}{2}$$

d thickness

ρ density

Determination of oxidation kinetics

- Quaddakers et al. Model including scale spallation

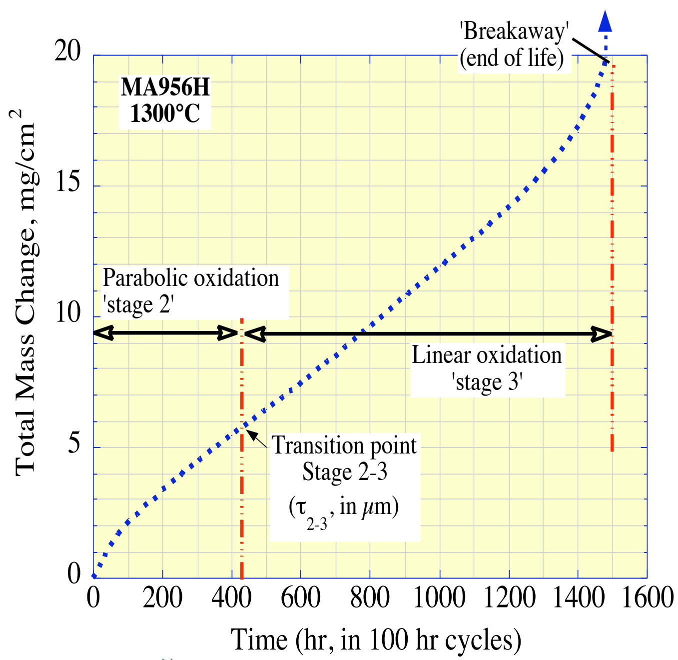
$$\frac{t_b}{t^*}\left(1.125\cdot\Delta m^*\right) = \frac{\Delta C}{100}\cdot\rho\cdot\frac{d}{2}$$

$\Delta m^* = \cdot k \cdot t_m^{*n}$ mass loss

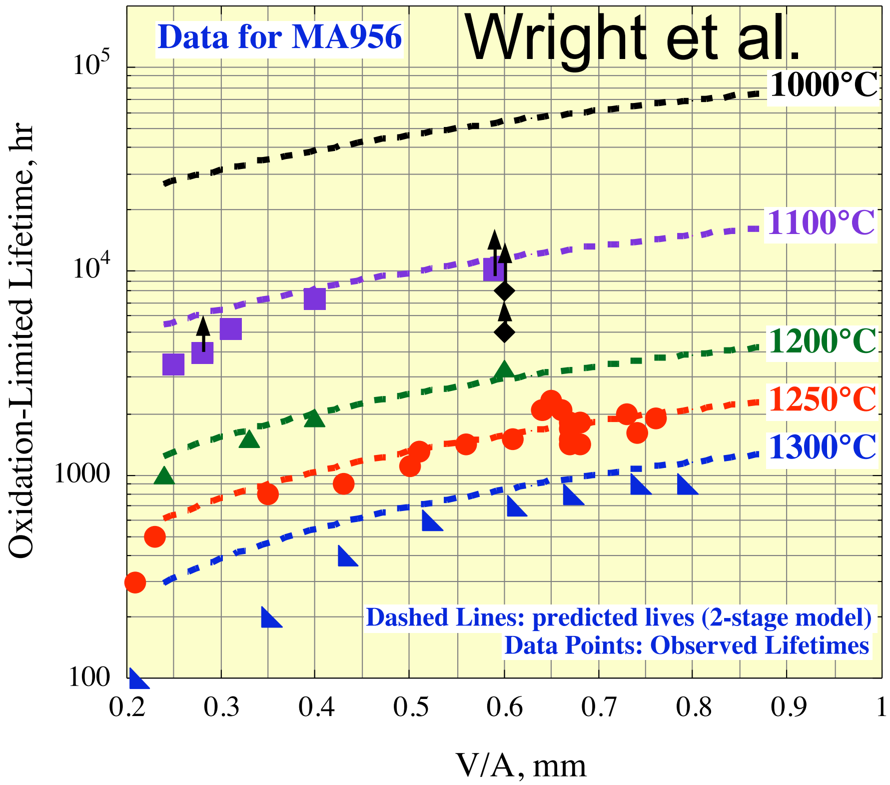
$$\beta\cdot e^{-\lambda S_m}\cdot\frac{k\cdot t_b}{(\Delta m)^{(n-1)}} + (1-\beta)\cdot e^{-\lambda S_t}\cdot\left(k\cdot t_b\right)^{1/n} = 0.89\cdot\frac{\rho_m}{\rho_{ox}}\cdot\frac{\left(C_0 - C_b\right)}{\left(1-C_b\right)}\frac{V}{A}$$

- Nicholls et al.
* Intrinsic chemical failure
* Mech. induced chemical failure
* Partial spallation of Al_2O_3

- Wright and al.: 3 stages oxidation kinetics



Good correlation between experimental data and models



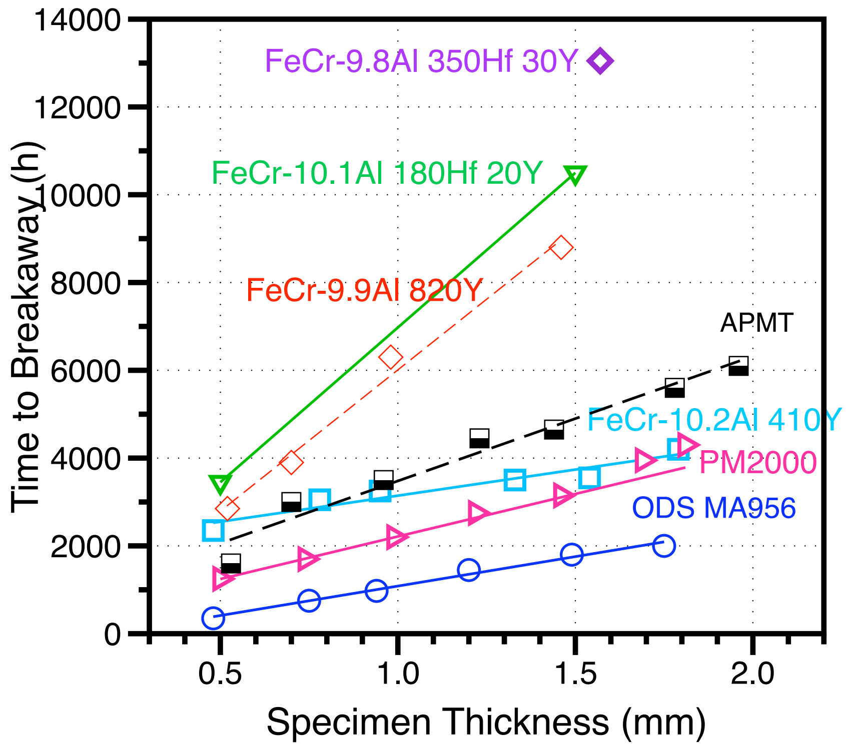
Complex models require lots of experimental data

Extrapolation to very long duration?

Need total mass gain and not specimen mass gain

New approach based on mass gain curves, time to breakaway oxidation and microstructure/elemental characterization

Extrapolation based on the linear relation between lifetime and thickness



1h cycle 1200ºC
Cast and ODS
FeCrAlY + RE

Linear lifetime/thickness relationship for many Al_2O_3 forming alloys

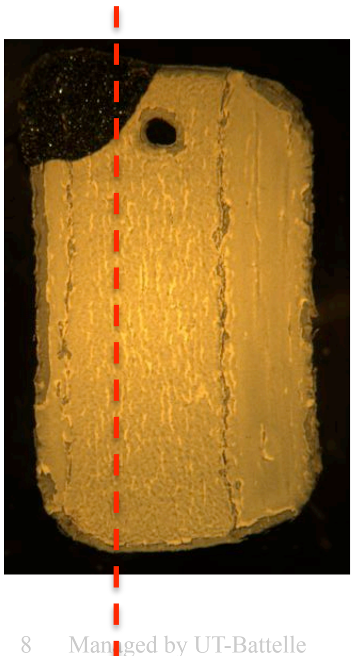
Convenient way to compare alloys or exposure conditions

Focus on Al consumption in the alloy

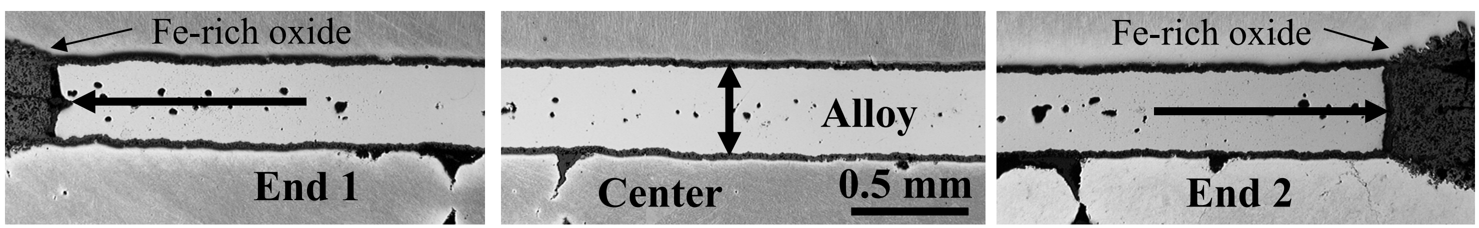
$$1.125 \cdot k \cdot t_b^n = \boxed{\frac{C_b - C_0}{100} \cdot \rho \cdot \frac{d}{2}}$$

What is C_b? Uniform consumption of Al?

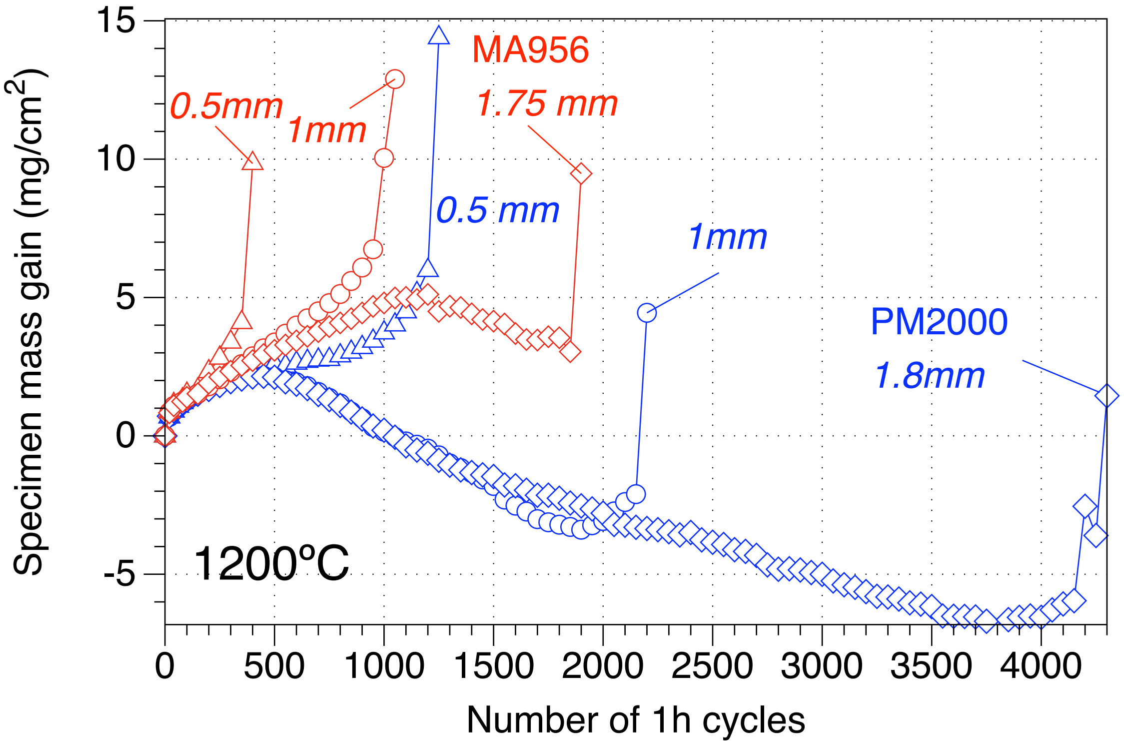
What about Al gradients from the specimen center to the surface? How does C_b change with T, cycles…



Microprobe profile to determine Al remaining after the onset of breakaway oxidation



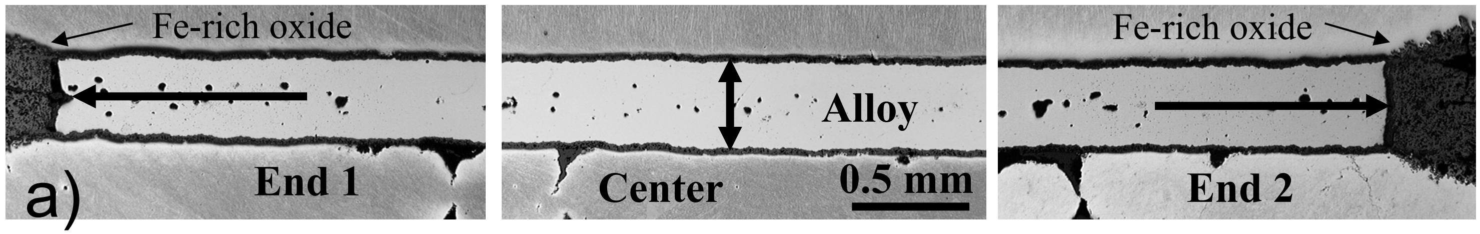
Mass gain curves 1h cycles 1200ºC MA956 & PM2000

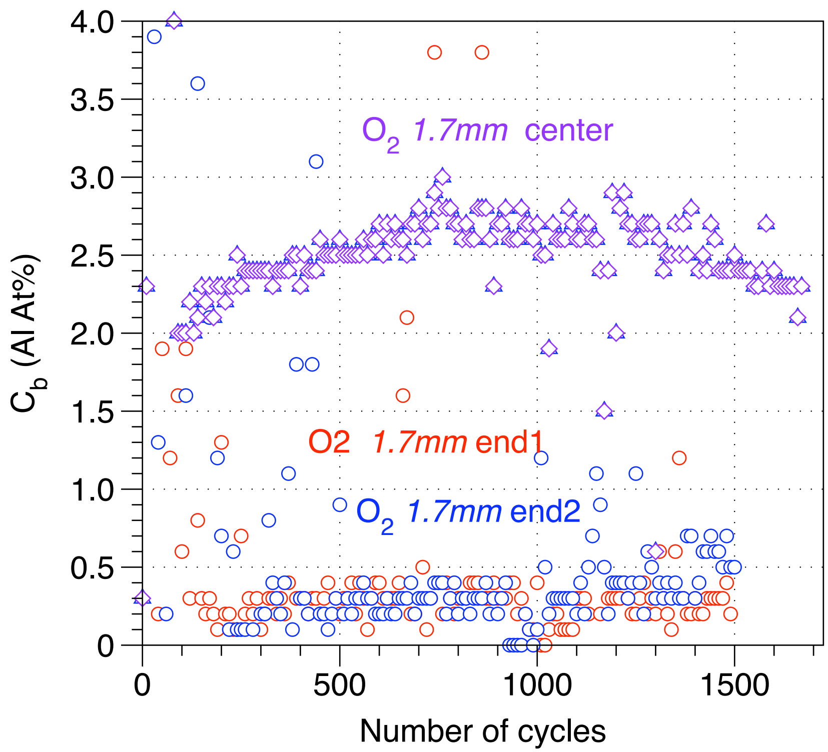


1h cycle
O_2

Manifest difference regarding oxidation kinetics and lifetime between MA956 and PM2000

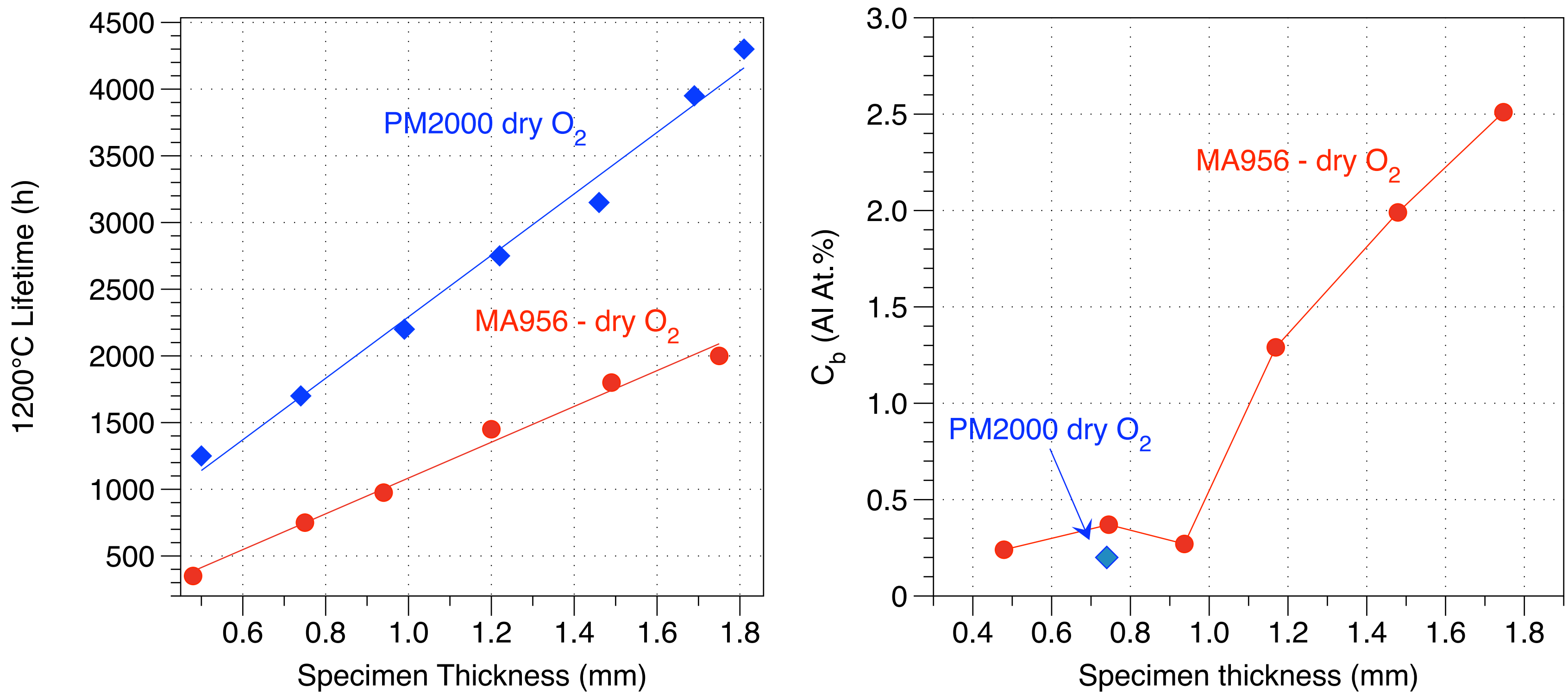
Al remaining content measurement





- Significant difference in Al content at the ends and in the center of the specimen
- C_b = concentration at the center?

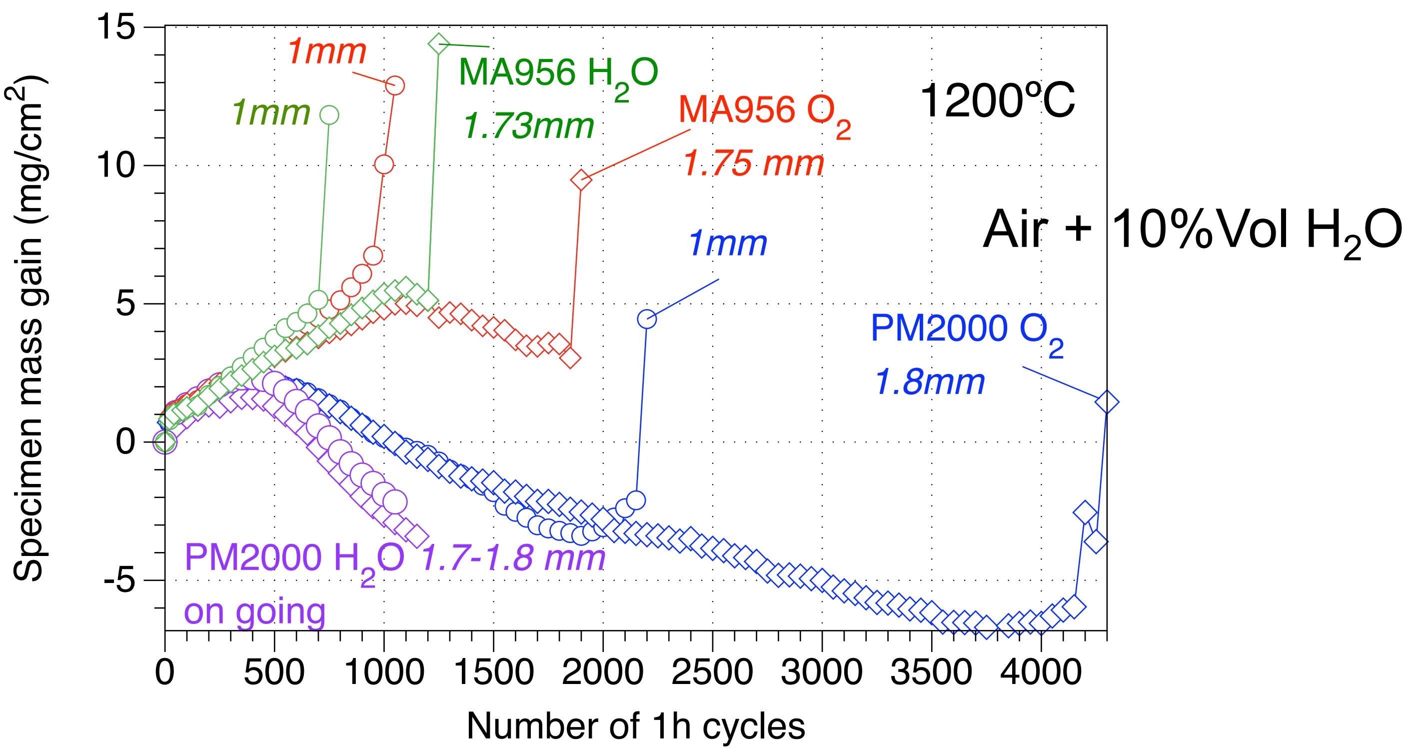
C_b depends on the specimen thickness



Linear relationship between lifetime and thickness

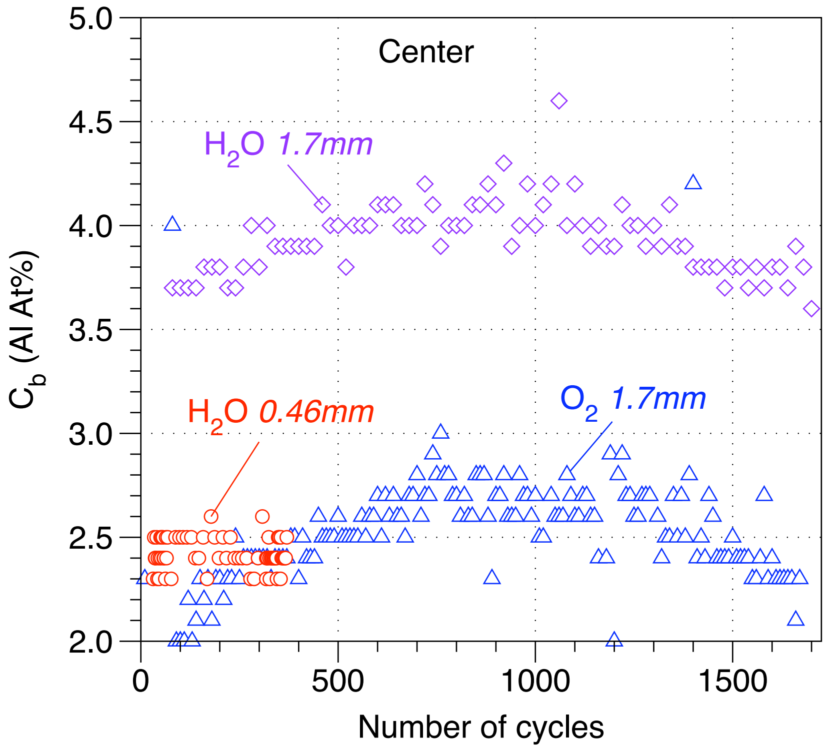
C_b constant up to 1mm and then linear increase

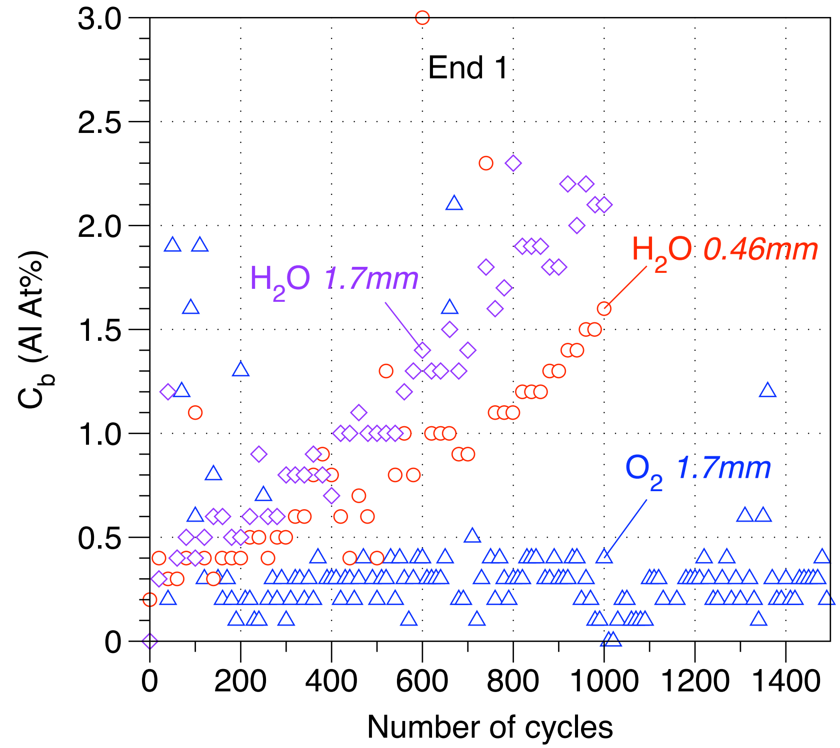
Significant effect of H_2O on mass gain curves



- Decrease of time to rupture for MA956
- Change in oxidation kinetics for PM2000

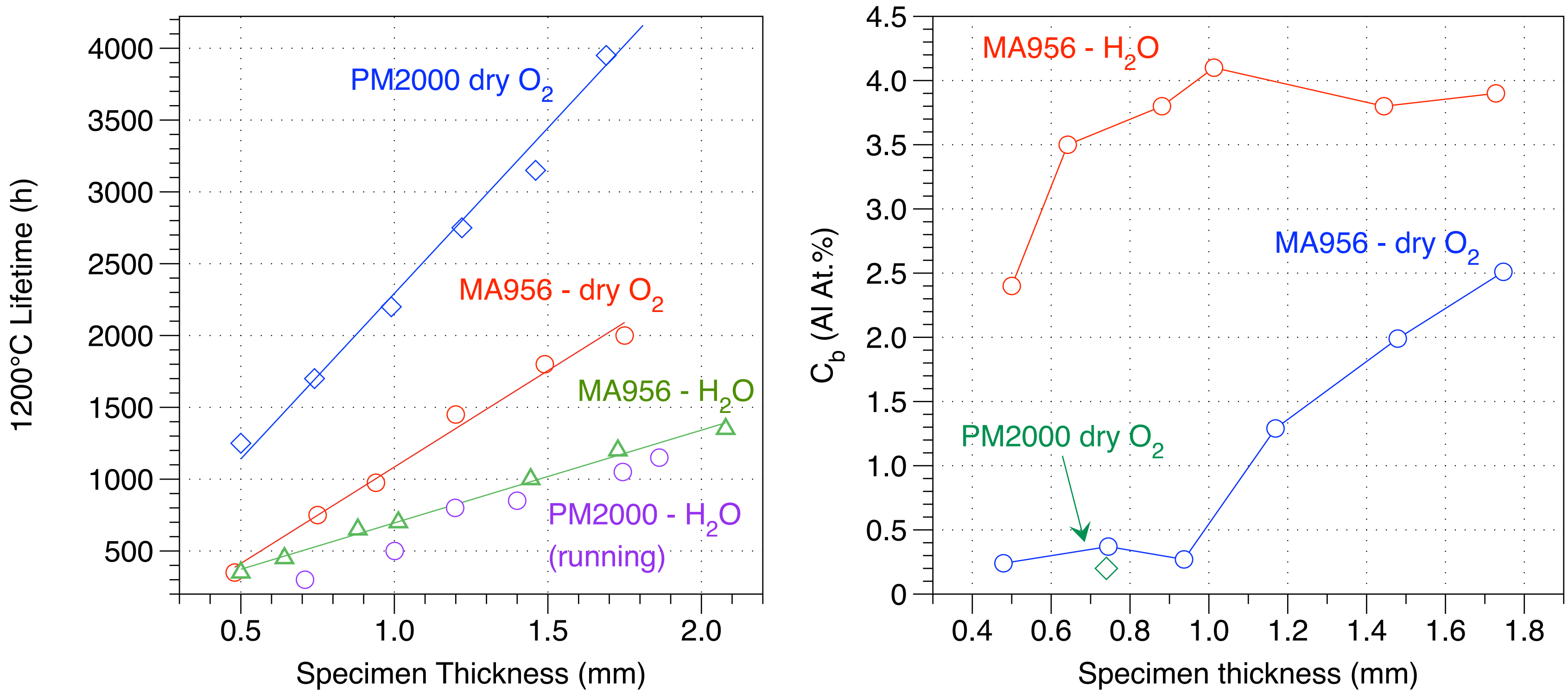
Significant effect of H_2O on remaining Al content in MA956





- Effect of H_2O on the total Al concentration
- Effect of H_2O on the Al gradient

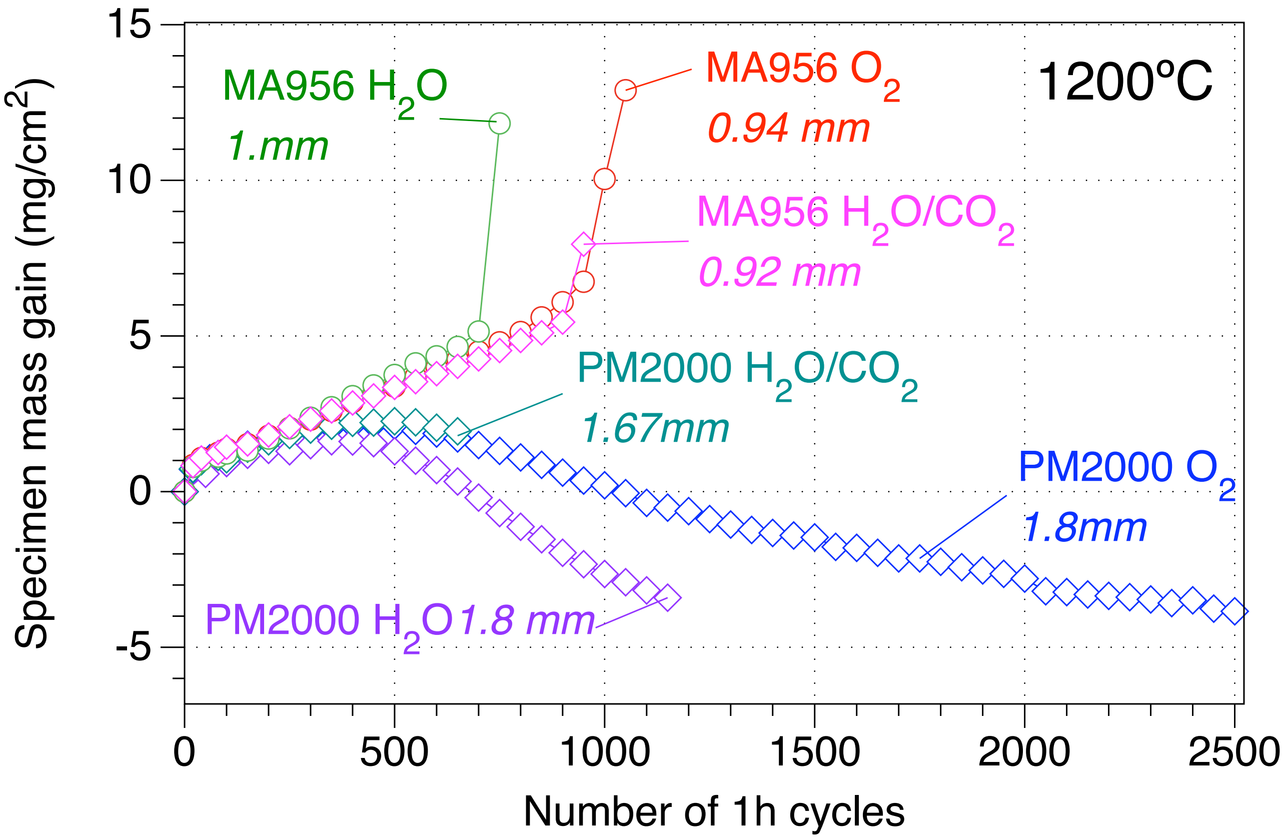
Significant effect of H_2O on lifetime and remaining Al content



Linear relationship between lifetime and thickness in H_2O but significant decrease in lifetime

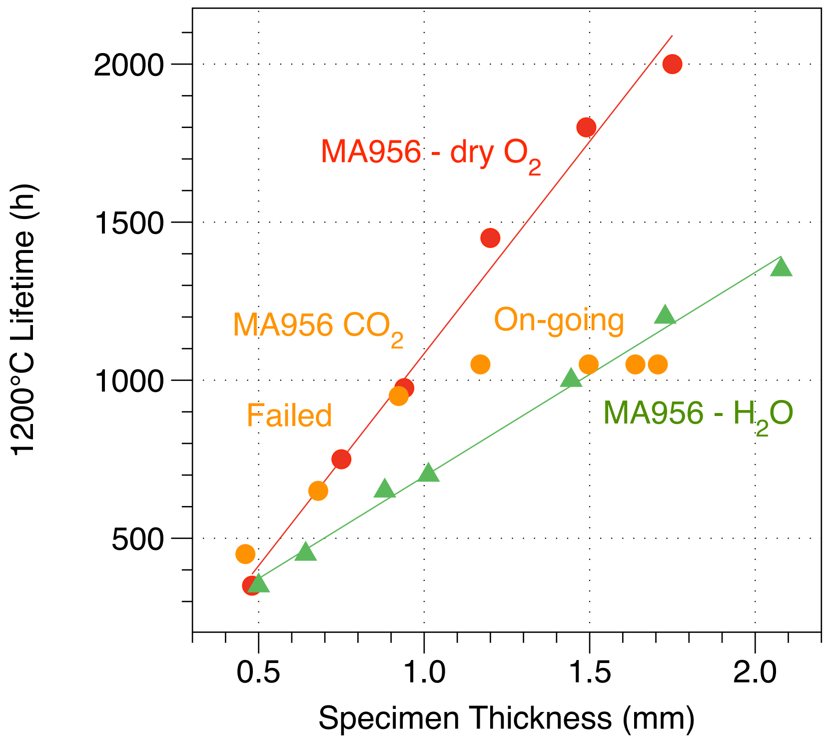
Higher C_b value + higher Al gradient

No effect of 50%H_2O-50%CO_2 on oxidation kinetics



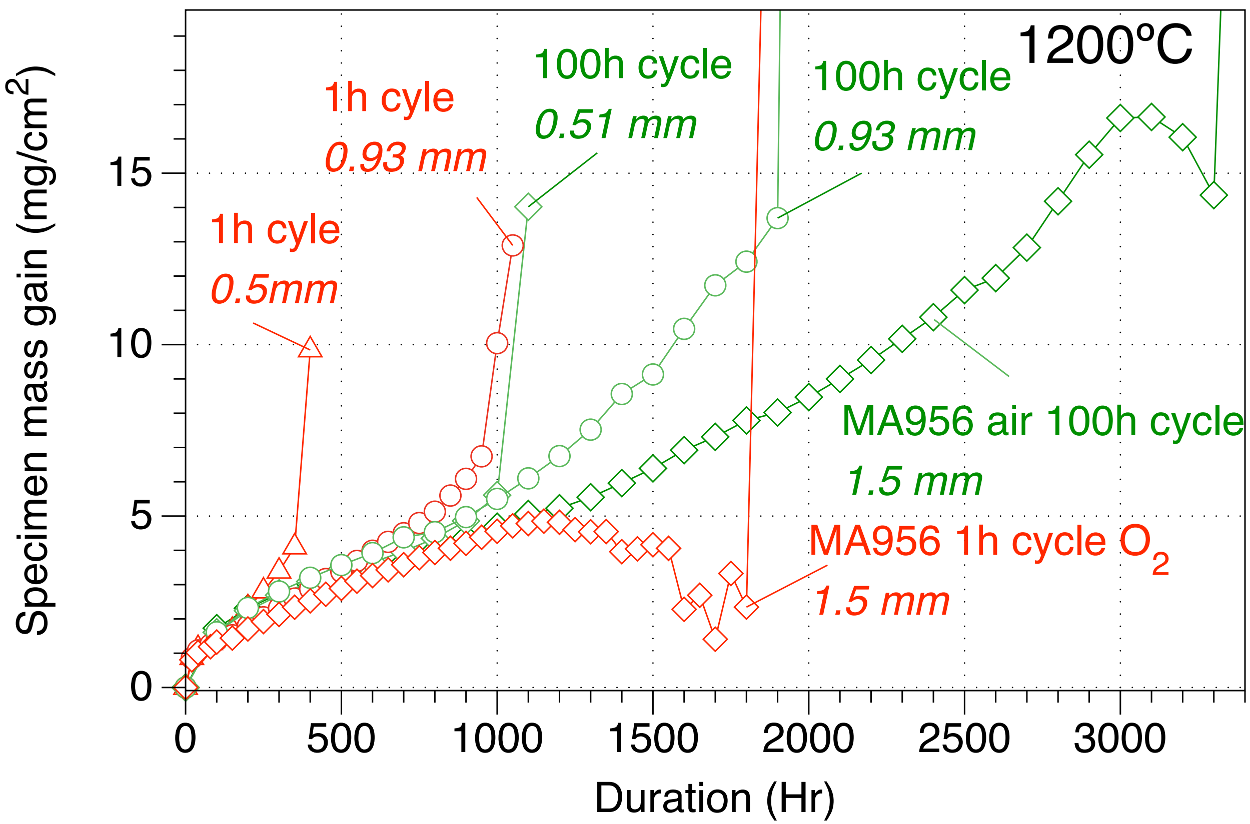
On going tests but no difference with O_2 thus far

No effect of 50%H_2O-50%CO_2 on MA956 specimen lifetime



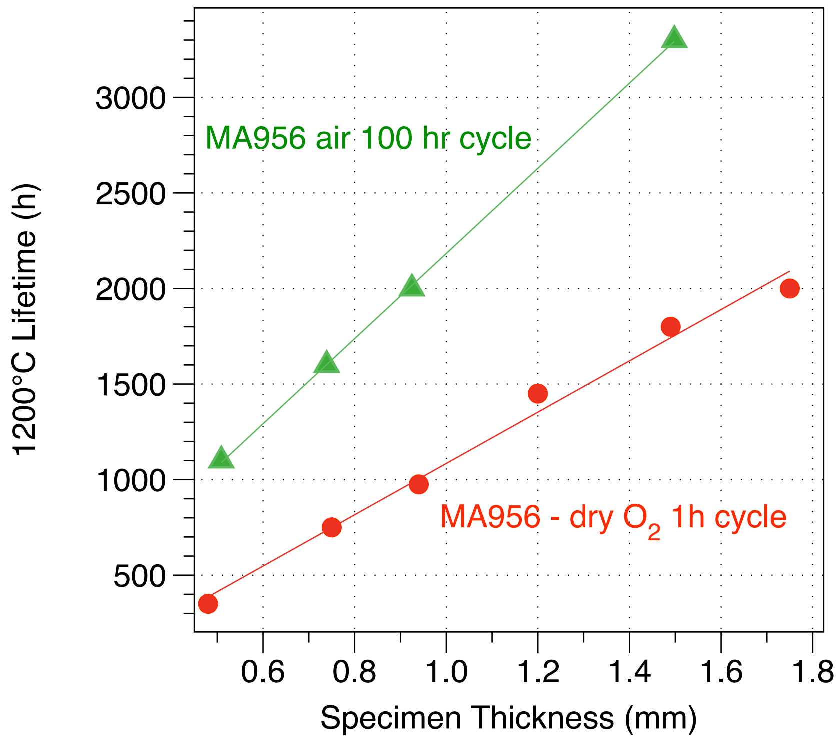
Lifetime in H_2O/CO_2 similar to O_2 lifetime

Effect of cycle frequency on MA956 oxidation kinetics: 1h versus 100h



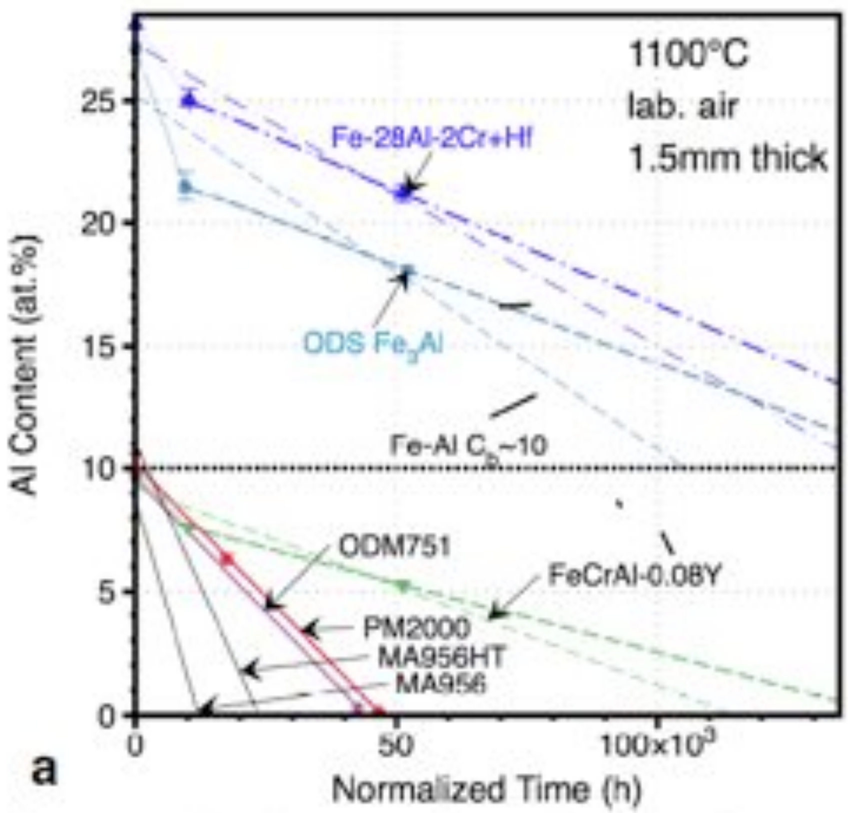
- Oxidation kinetics similar only at the beginning but deviate due most likely to different spallation rate

Longer lifetime with 100h cycle compared to 1h cycle



Linear relationship for both cycle frequencies

Al profile before breakaway oxidation to predict lifetime



Pint et al. 2010

Al profile after 10 and 50000kh to assess the evolution of C with exposure time

Conclusion

- Oxidation lifetime models based on oxidation kinetics are in good agreement with experimental data
- Al concentration profiles could improve existing models and be the basis of models relying on Al consumption
- Integration of environment effects, cycling frequency… in models
- Use models to improve ODS oxidation performance
- Interaction between oxidation/ mechanical properties or/and microstructure evolution//mechanical properties need to be assessed.

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