Oxidation of Alumina-forming ODS Alloys

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Outline of the Presentation

- Introduction – factors affecting the oxidation of ferritic stainless steels
- Scale growth
- Scale adhesion
- Breakaway effects
- Improvements that can be made to mitigate degradation due to oxidation

Major constituents of some commercial FeCrAl alloys

Alloy	Wt%		Ppm					balance Fe
	Al	Cr	Y	Hf	Zr	Ti	Si	Y_2O_3
Aluchrom YHf	5.5	20.0	480	405	320	99	2900	0
Kanthal AF	5.2	21.0	340	3	580	940	1900	0
Kanthal APM	5.9	21.0	200	200	1000	200	-	0
MA956 (ODS)	4.6	20.0	0	-	-	5000	-	5000
PM2000 (ODS)	5.9	21.0	0	-	-	4100	-	5000

Scale Growth

- Want to form protective, stable α- alumina scale as soon as possible
- Subsequent oxide growth should be as slow as possible to conserve aluminium supply
  - Pre treatment of alloy to ensure formation of α-alumina scale
  - Use reactive element additions to control scale growth rate
  - Add a non-ODS layer to minimize lack of compliance between oxide and substrate
  - Start with more aluminium in base alloy

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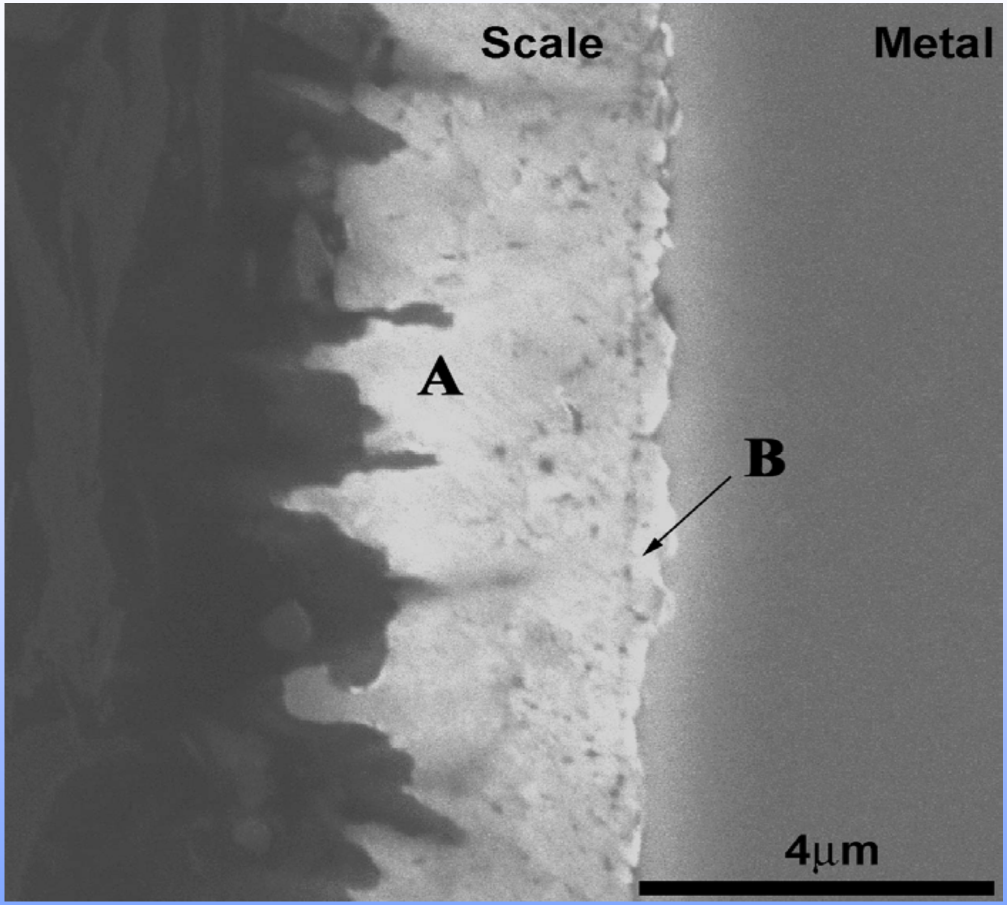
Scale cross-section



50μm foil Aluchrom YHf 3000h at 900°C
A – initially formed outward growing transient alumina
B – inward growing α-alumina

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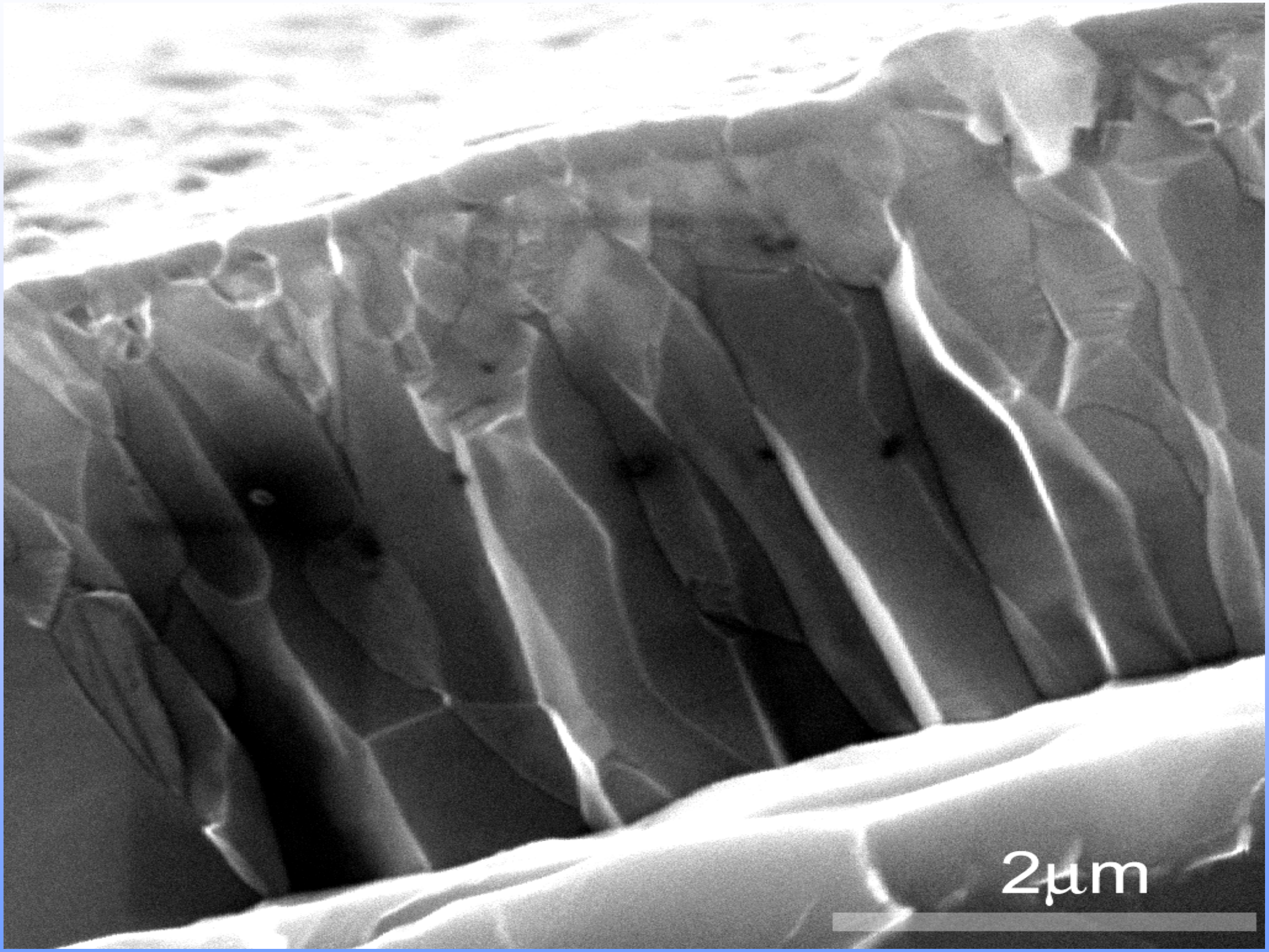
Columnar growth of alumina



Model FeCrAlY alloy oxidised for 500 h at 1200°C

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Scale Growth

- Can preoxidise alloys at T> 1000°C to ensure that α-alumina results – but 'waste' aluminium
- Work by Quadakkers et al has shown that gas annealing at 1200°C in an Ar + 4%H_2 + 2%H_2O mixture quickly gives an excellent protective scale for many alloys
- Although alloys with more than 6% Al have low ductility, extra Al can be incorporated into the finished components by a gas phase reaction followed by a diffusion treatment.
- Can modify the surface layer of the alloy by mechanical treatment or add an overlayer
- Additions of a 'soft' FeCrAl layer to ODS alloys appears to have a beneficial effect.

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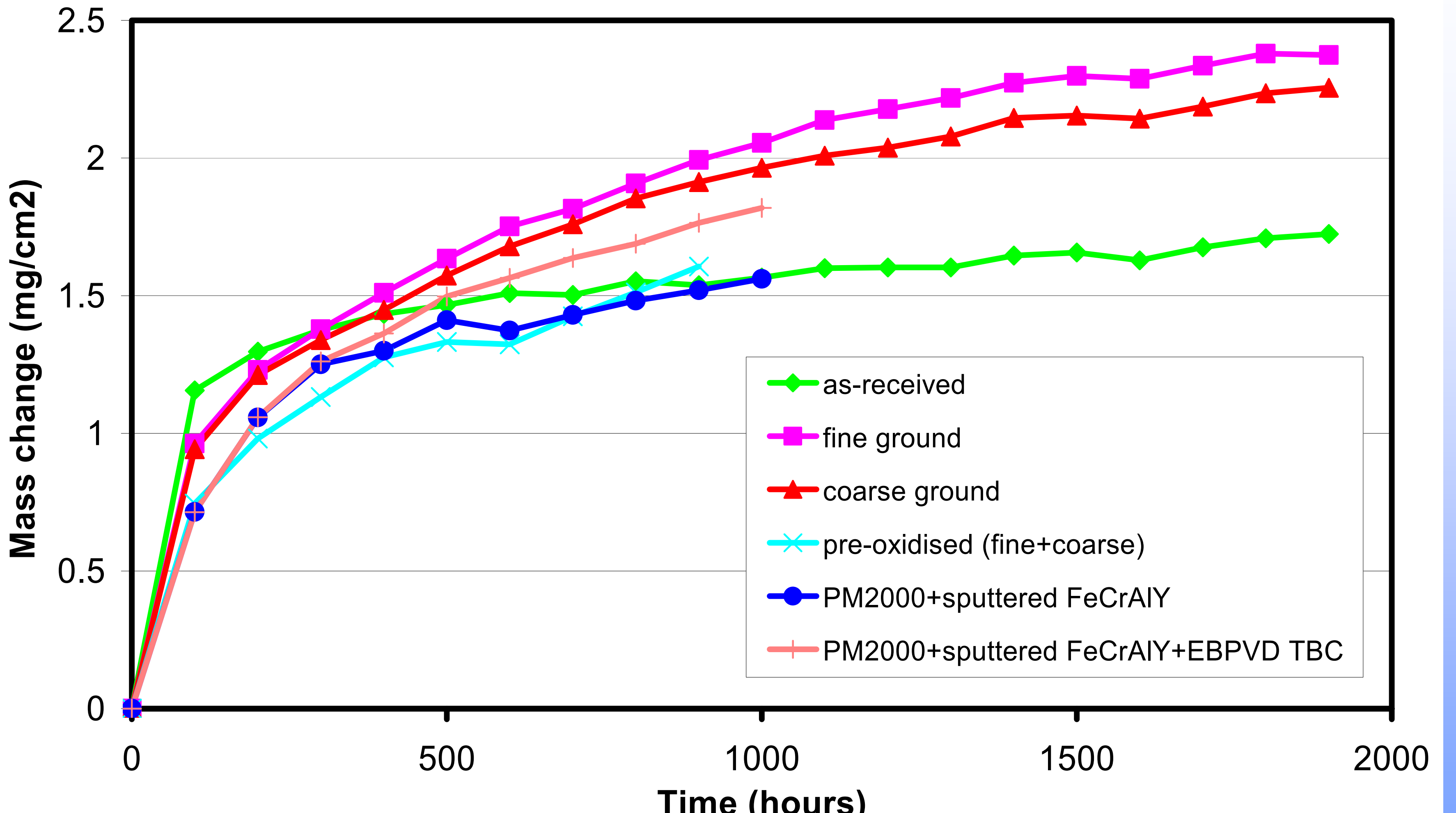

Mass change data from PM2000 slow cycle / 'isothermal' exposures in combustion gas at 1200°C

PM2000
+ sputtered FeCrAlY
+ EBPVD TBC

500 hours at 1200°C in combustion gas
(N_2+14%O_2+3.2%CO_2+1%Ar+5%H_2O)

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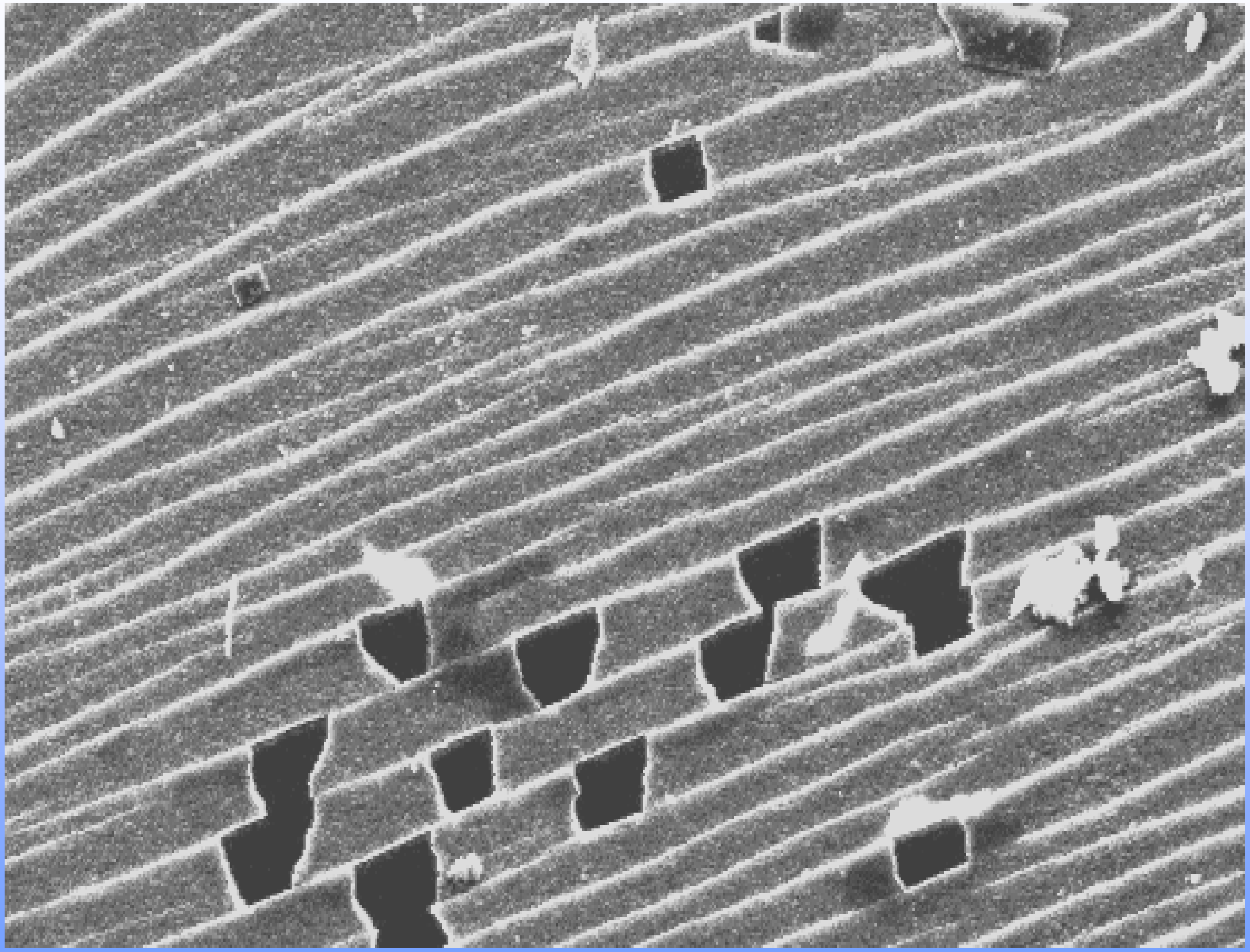
Scale Adhesion

- Presence of reactive elements such as yttrium, hafnium and titanium help scale adhesion
- Reactive elements also act as scavengers for tramp elements such as sulphur, which otherwise segregate to metal - oxide interface and affect adhesion
- Even carbon can form chromium carbides at the scale metal interface, although may be tied up with titanium, for example
- The build up of oxide growth stresses or accumulation of point defects at the scale metal interface can also affect adhesion

Fe-20Cr-5Al with S<5ppm, oxidised at 1060°C for 4.5h



10μm

In-situ bending experiment

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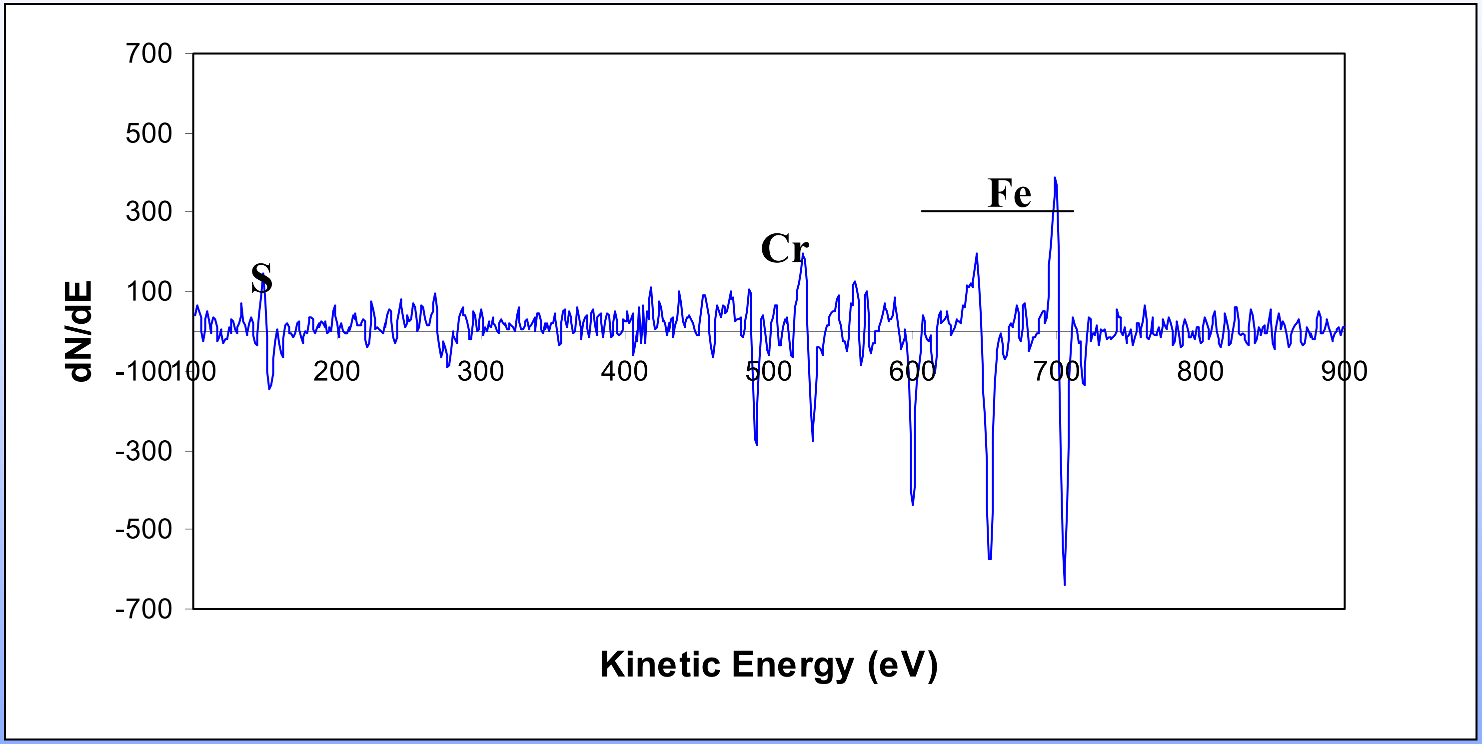
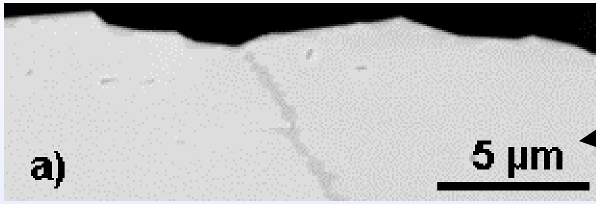


Auger spectrum, Fe-20Cr-5Al with S<5ppm, oxidised at 1060°C for 4.5h (in-situ bending experiment)

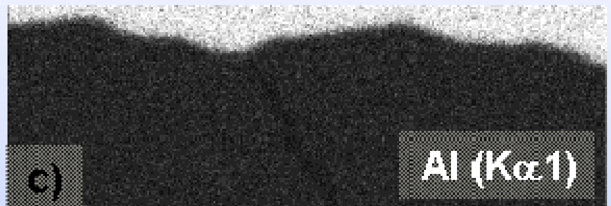
Oxidation of an FeCrAlY alloy with 530ppm carbon at 1200°C



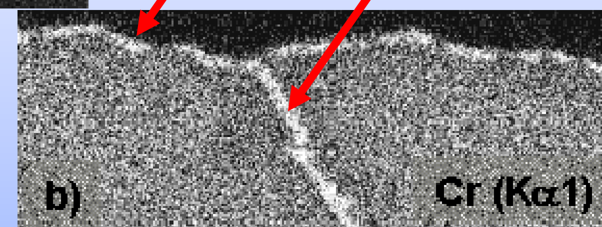
Alumina scale

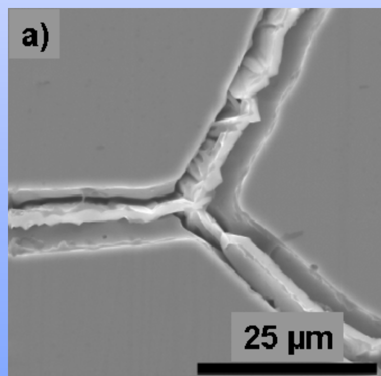
Substrate

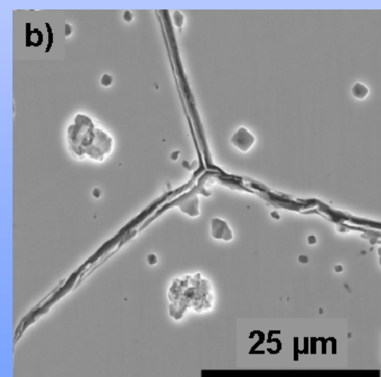
Kochubey, Naumenko et al (2006)

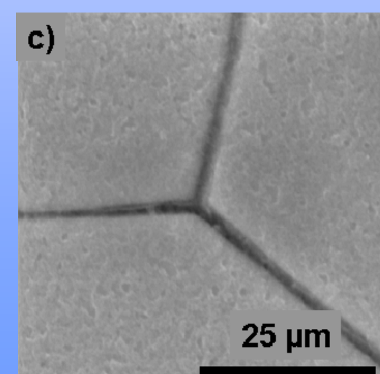


Cr present at the metal - oxide interface as well as the grain boundary



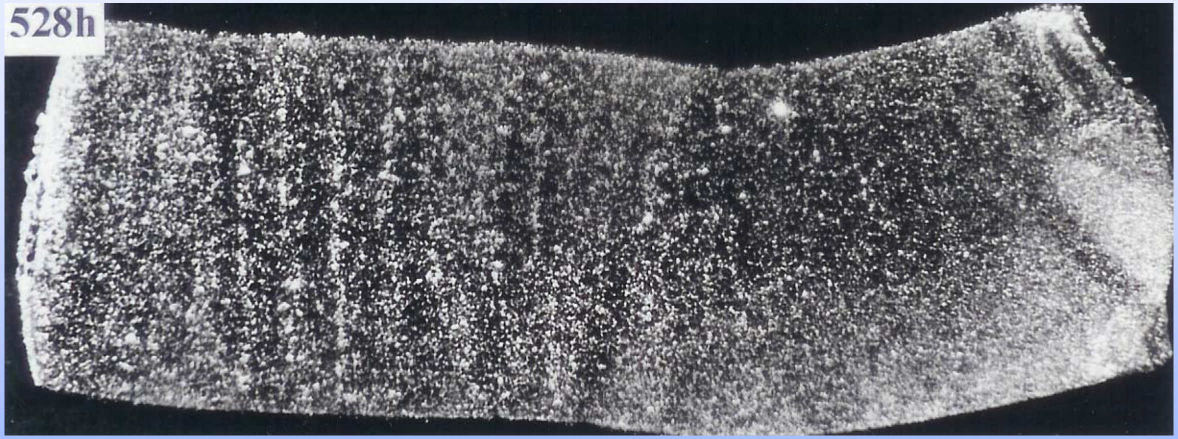






Carbide growth at different cooling rates:
(a) furnace cooled, (b) air cooled, (c) liquid N_2 quenched

Distortion of parallel sided coupon of Fe-20Cr-5Al alloy after oxidation for 528 h at 1050°C



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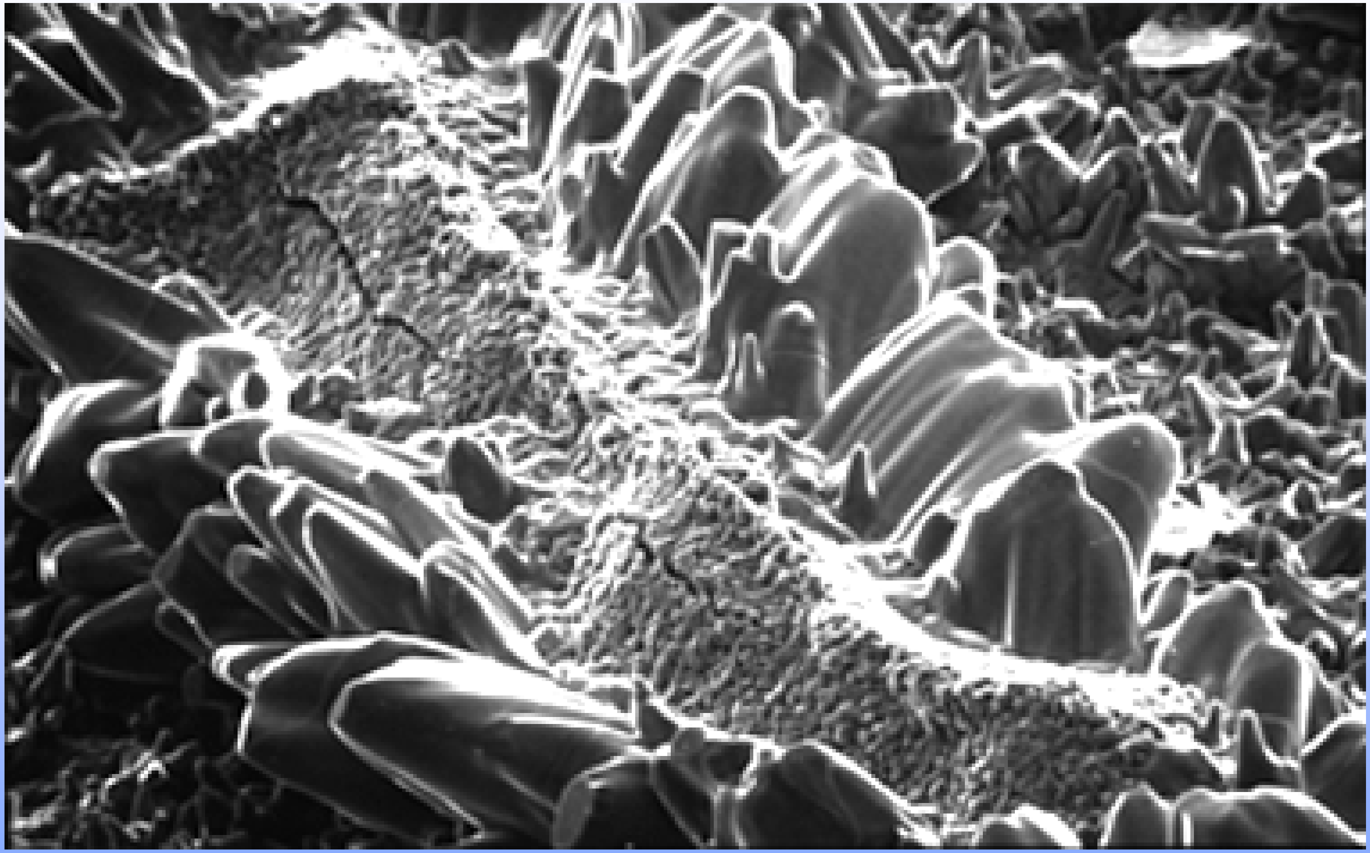
Breakaway Effects

- Lack of aluminium in sufficient quantities to reheal protective alumina scale that has fractured can lead to growth of voluminous iron and chromium rich oxides
- Iron/chromium scale then formed offers little protection and sample quickly goes into “breakaway” oxidation
- Related to the amount of aluminium remaining in the sample and the size of the aluminium reservoir



100μm

SEM image of breakaway oxidation in PM2000, oxidised at 1300°C for 140h containing critical remnant aluminium concentration

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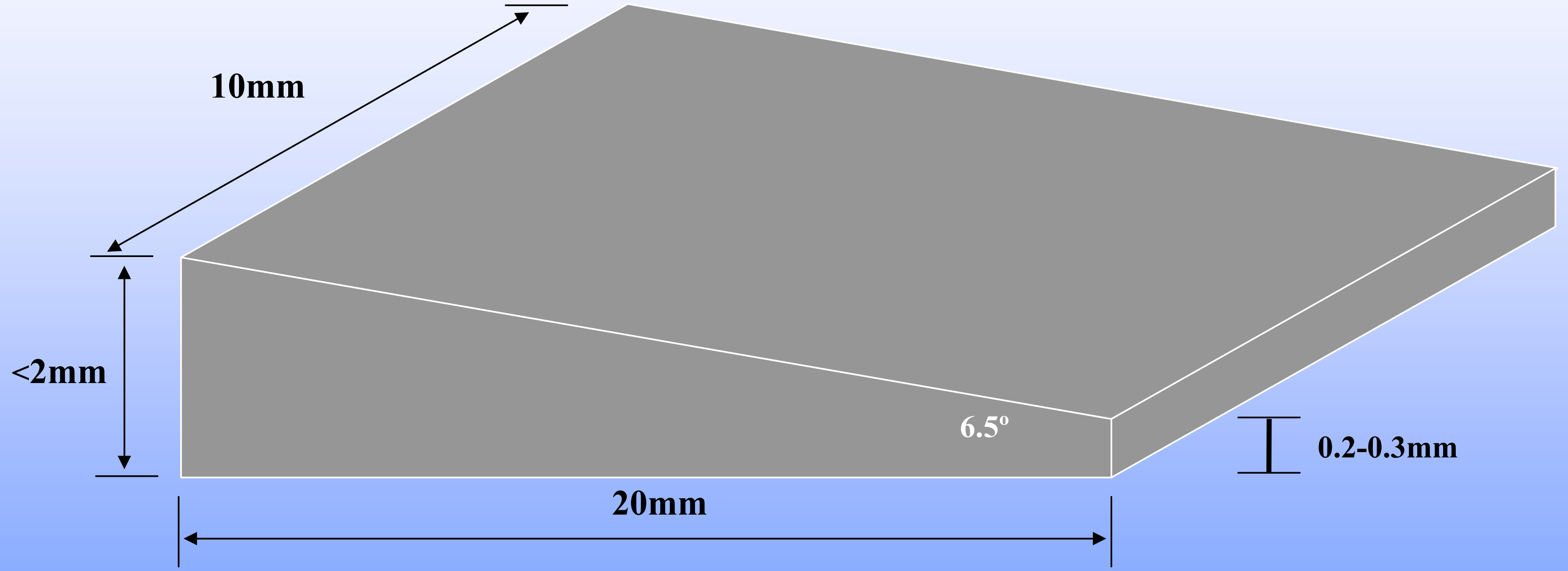

Taper section sample geometry

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MA956 oxidised at 1350°C for 24h.

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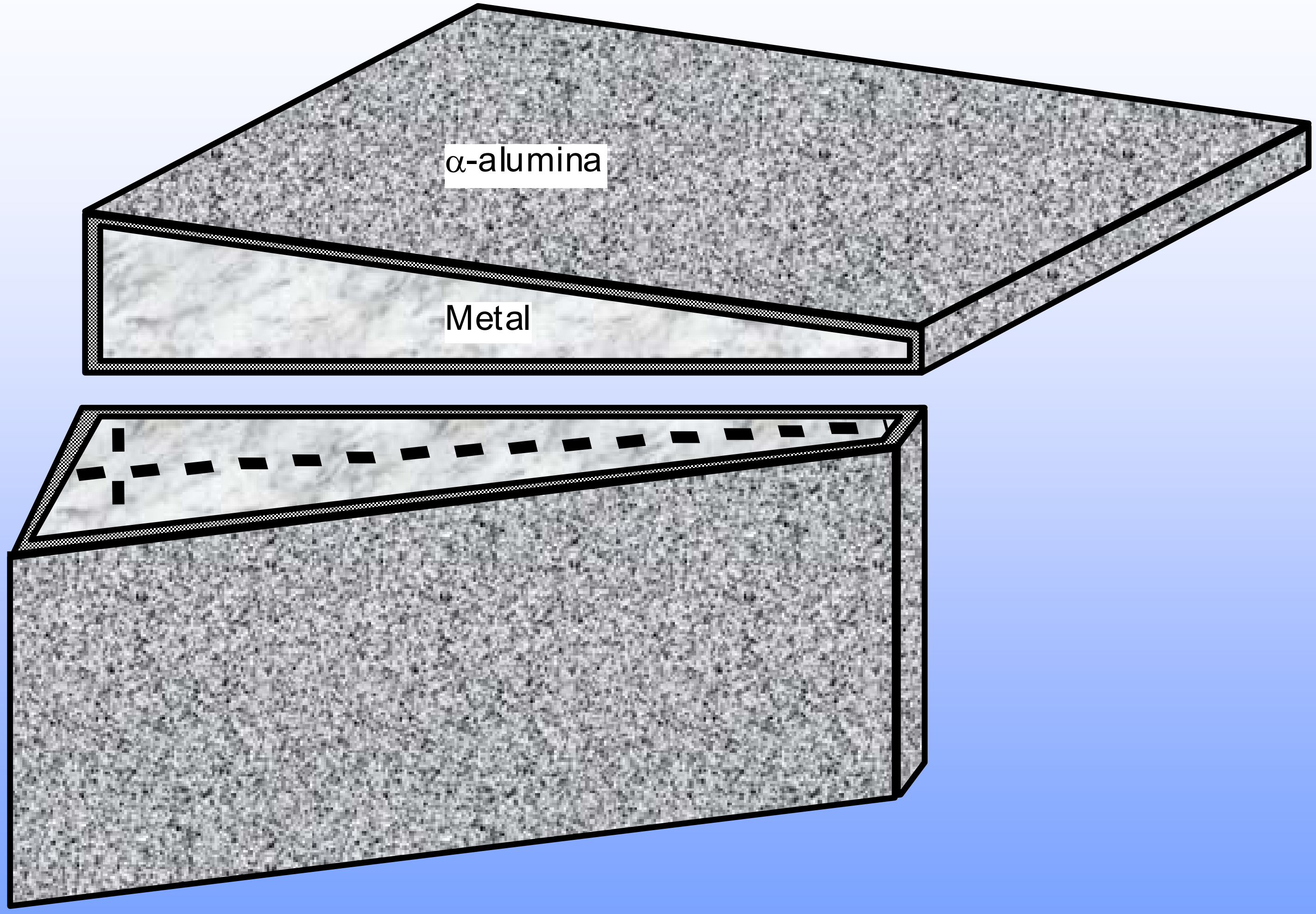
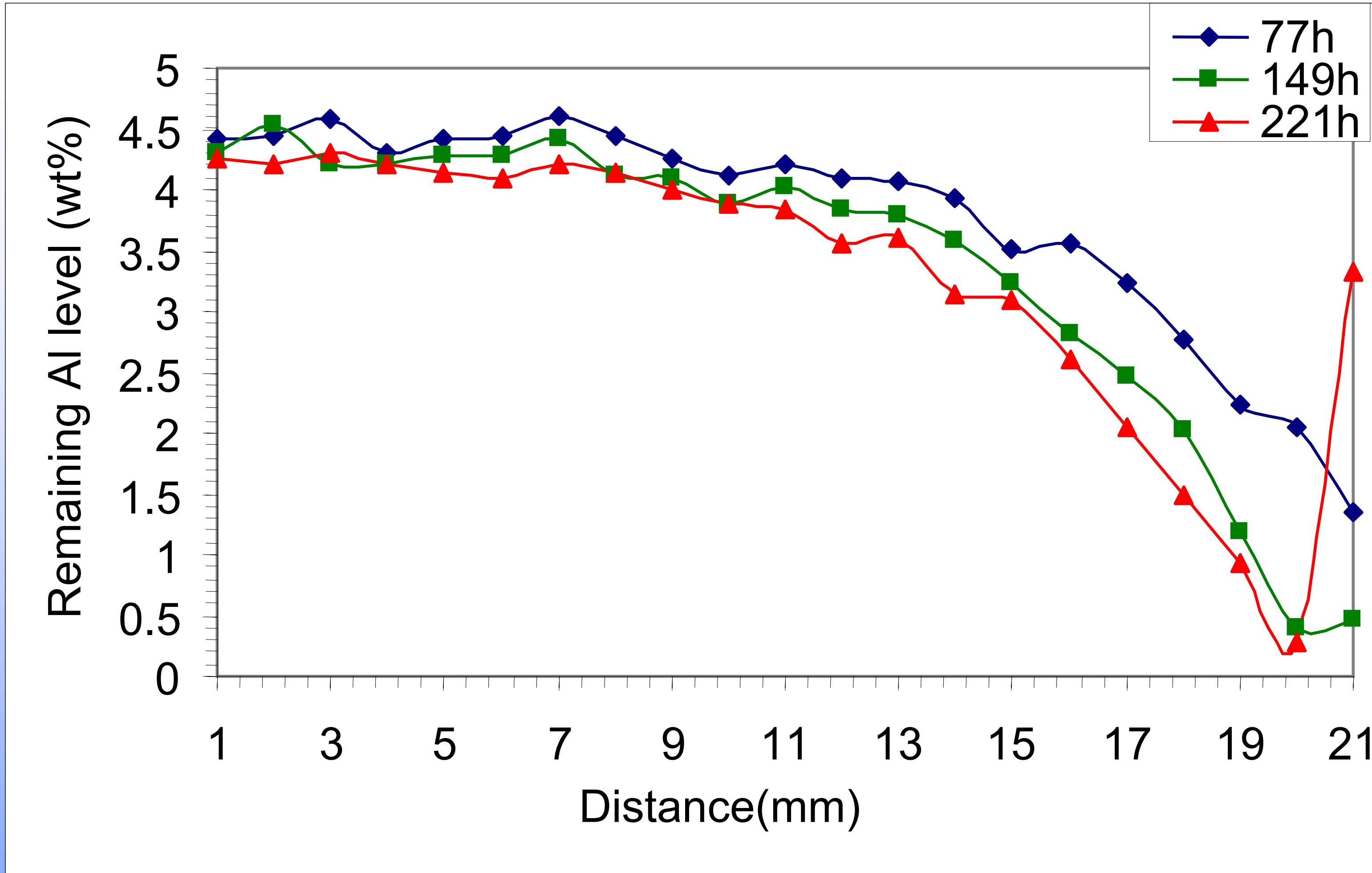
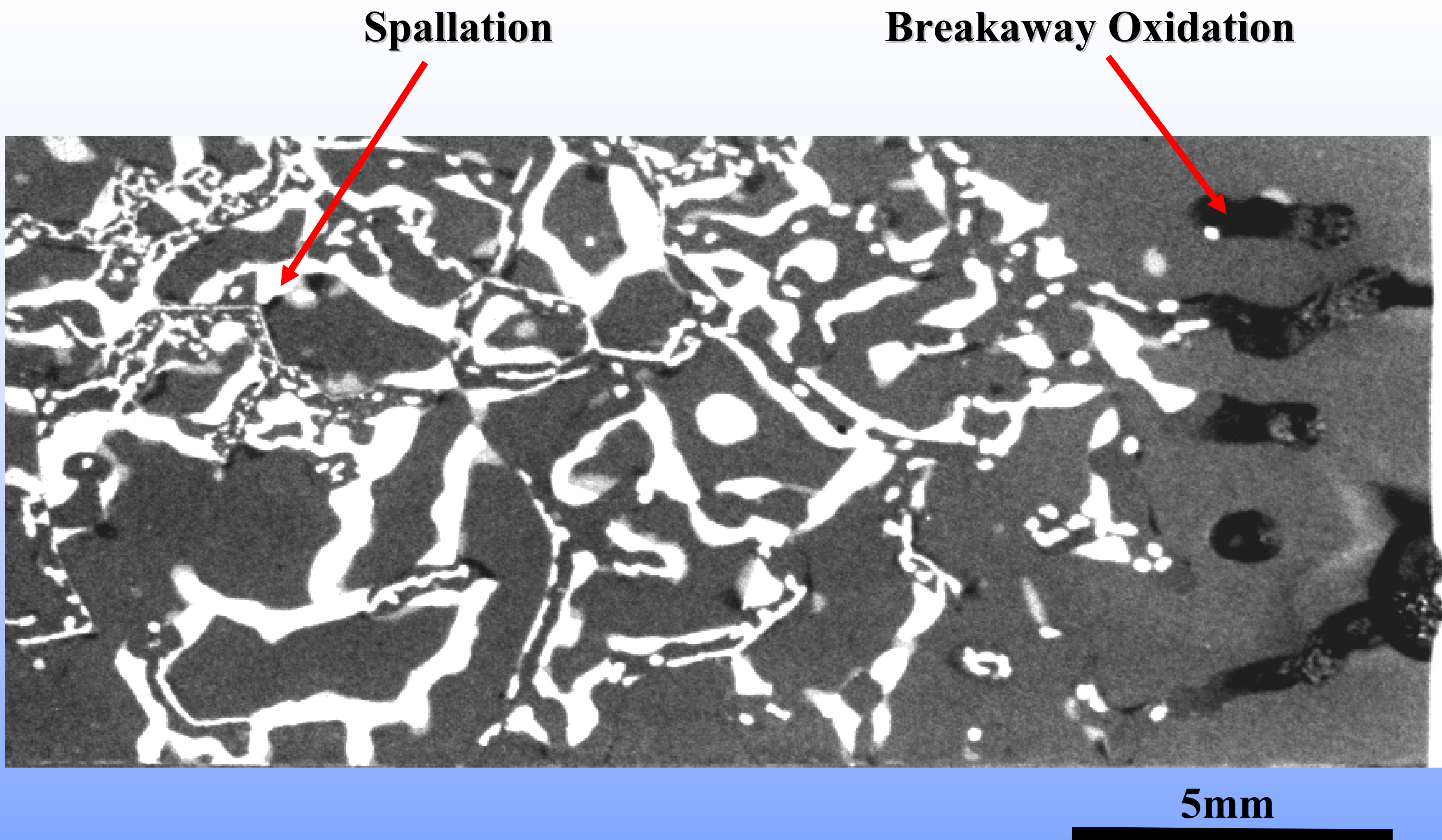


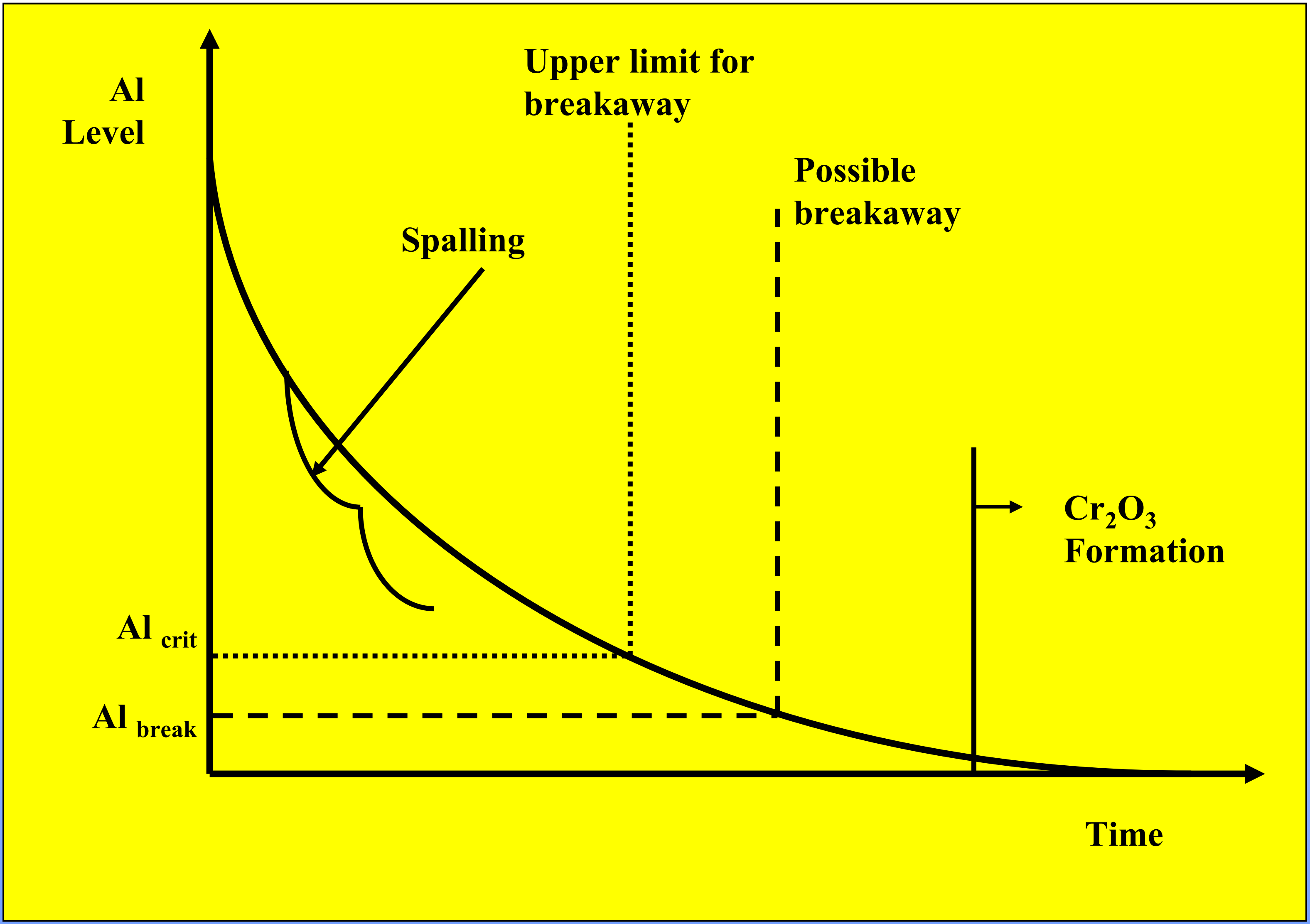
A schematic diagram showing the cut face from which elemental profiles were recorded during the microprobe analysis.



Al profiles along wedges of Kanthal APM alloy, oxidised at 1350°C for three different times.

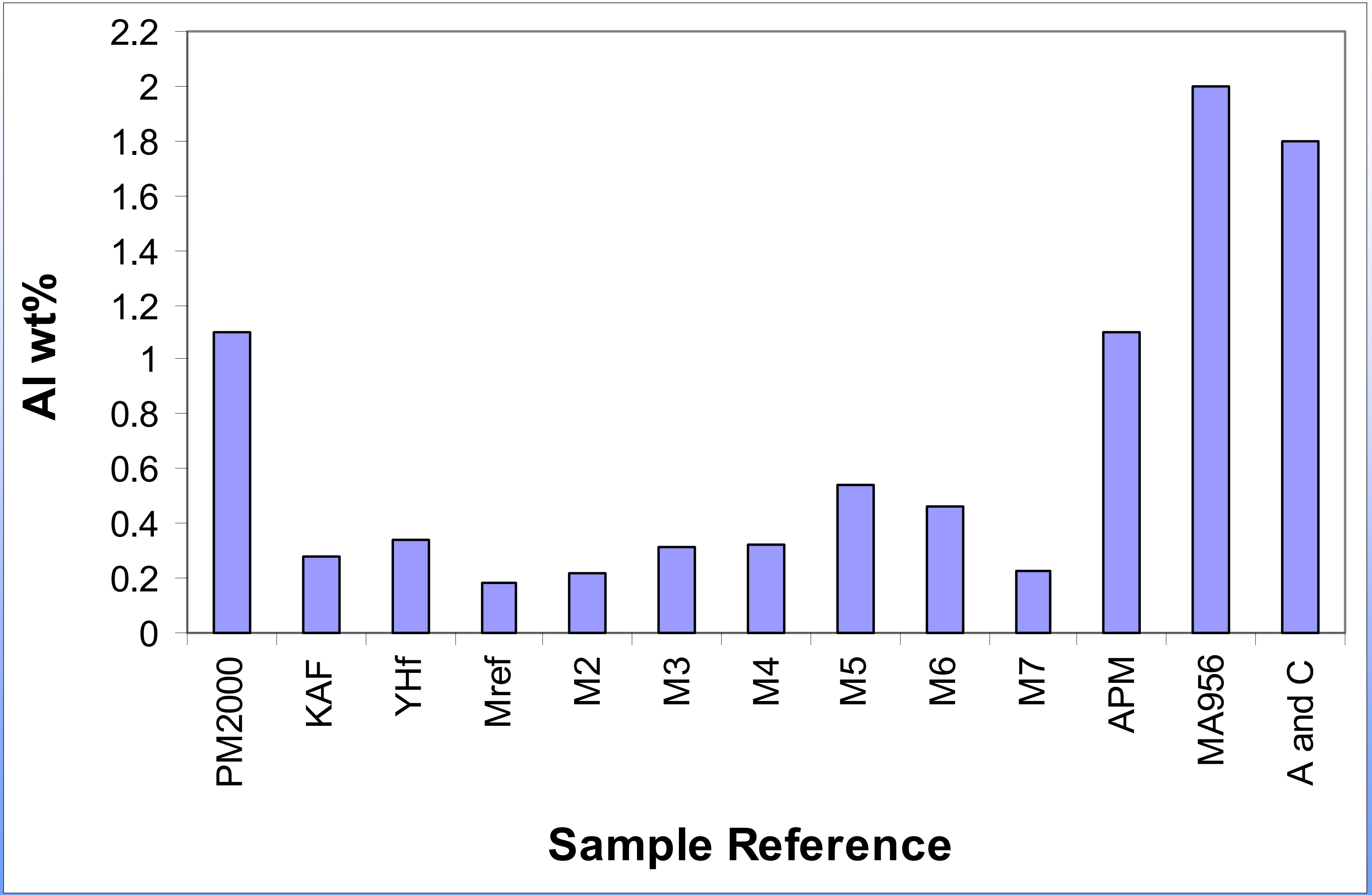


Wedge-shaped sample of an FeCrAl model alloy oxidised at 1300°C for 96h in laboratory air.



After H. E. Evans et al

Remnant Al content at onset of breakaway (1200°C)



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Control of Oxidation of ODS Alloys

- **Gas annealing at 1200°C in an Ar + 4%H_2 + 2%H_2O mixture quickly forms an excellent protective α-alumina scale for some alloys.**
- **Incorporate more than 6% Al into the finished components by a gas phase reaction followed by a diffusion treatment may prolong lifetime.**
- **Addition of a 'soft' FeCrAl layer to ODS alloys may have a beneficial effect on the control of scale spallation.**
- **Sufficient quantities of reactive elements and titanium are needed to control any tramp elements and excess carbon which may be present.**

Acknowledgements

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