Reduction in Defect Content in ODS Alloys

A.R.Jones, J.Ritherdon and D.J.Prior

University of Liverpool

1.'Graintwist' - **European BRITE project**

- Background – ODS tubed heat exchanger
- Flow forming
- Flow formed tubes
- Hoop creep properties

2. Microstructural evolution in warm flow formed tubes

3. Defect grain structures in ODS alloy variants

CEC BRITE Project (1998-2002)

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Development of Torsional Grain Structures to Improve Biaxial Creep Performance of Fe-based ODS Alloy Tubing for Biomass Power Plant (Graintwist)

Plansee GmbH / Lechbruck	**DE**
Metall Spezialrohr GmbH	**DE**
Mitsui Babcock Energy Ltd	**GB**
Sydkraft Konsult AB	**SE**
The University of Liverpool	**GB**
Risoe National Laboratory	**DK**
The University of Cambridge	**GB**

Heat transfer: *12.5 MW*

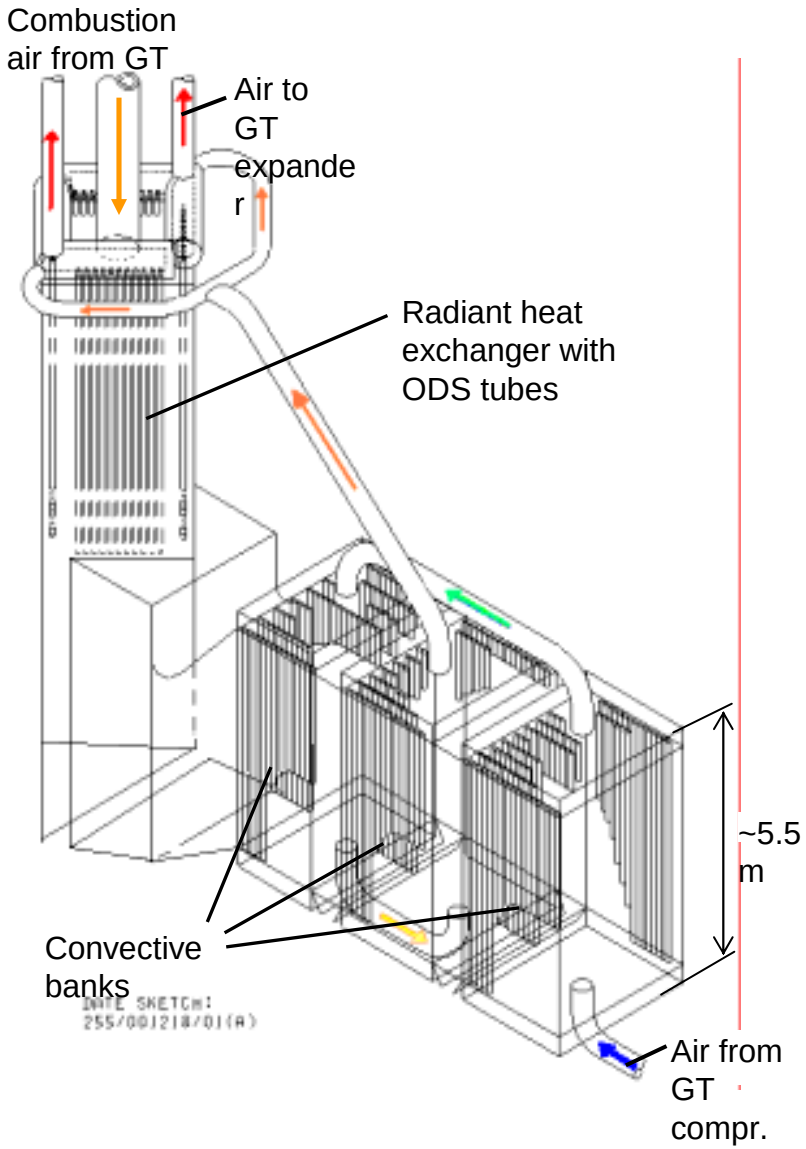
Air flow: *17.5 kg/s*

Pressure: *11.3 bar*

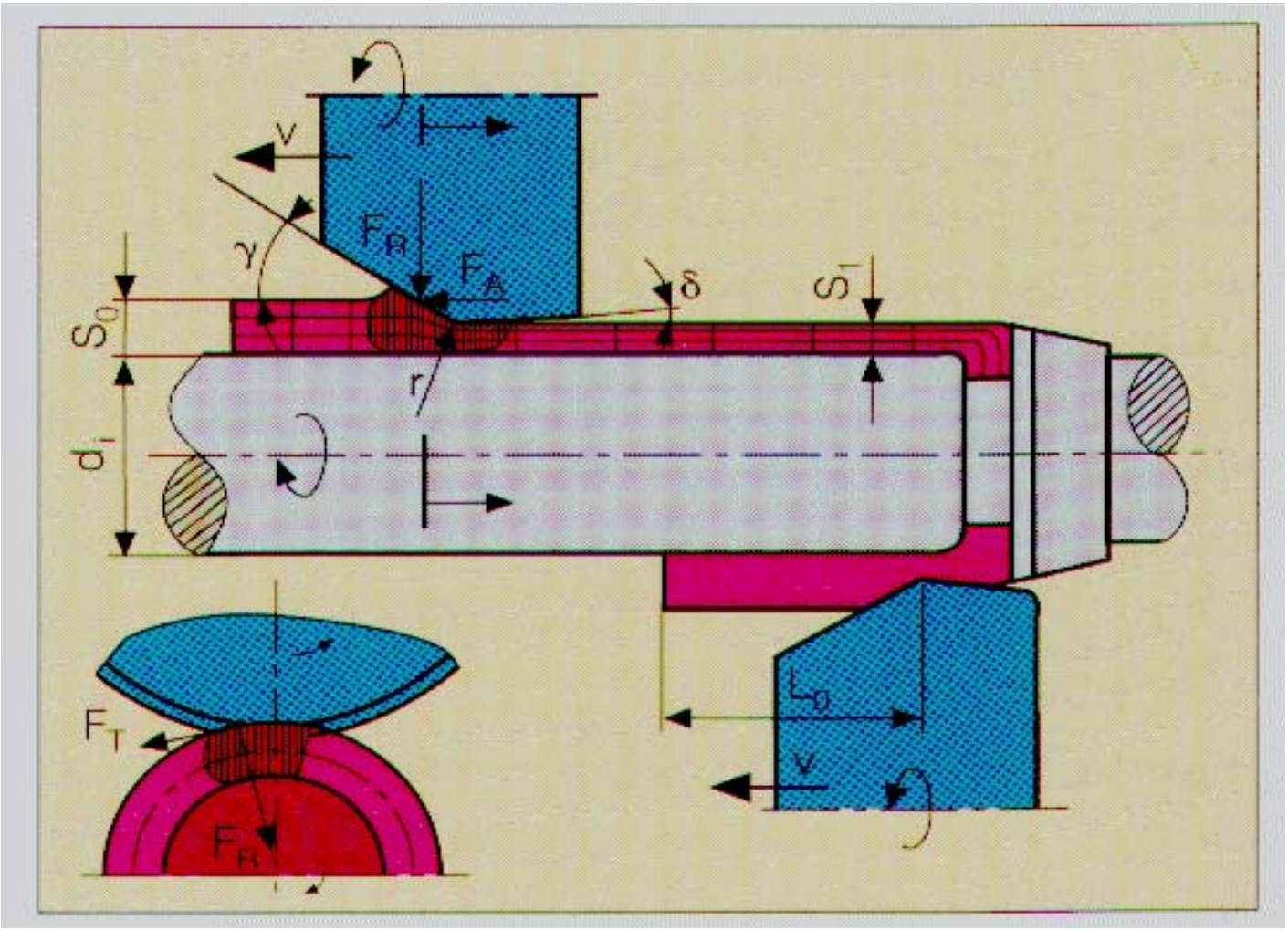
Air temp: *1013°C*

ODS temp: *1090°C*

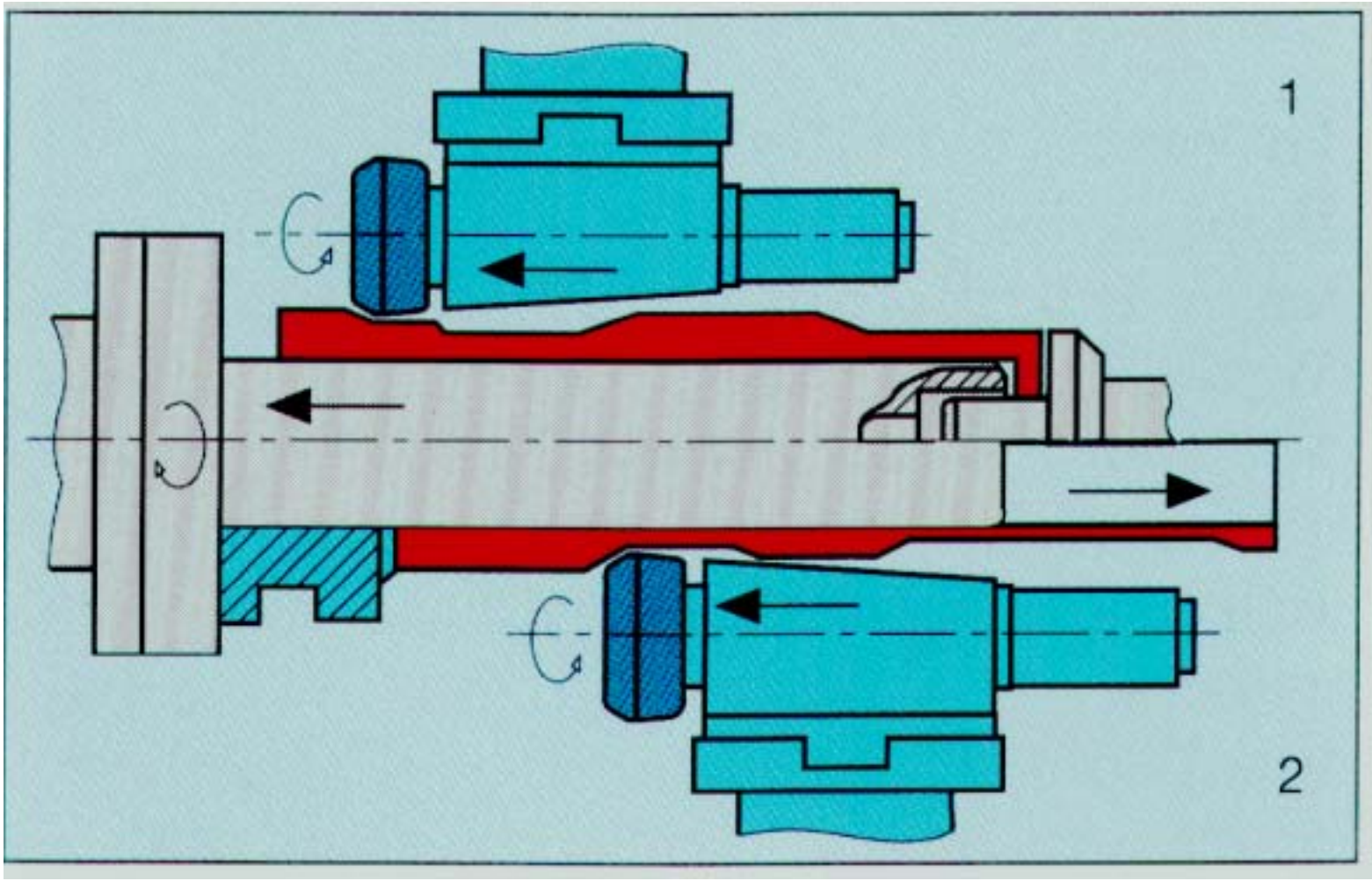
# of ODS tubes: *80*



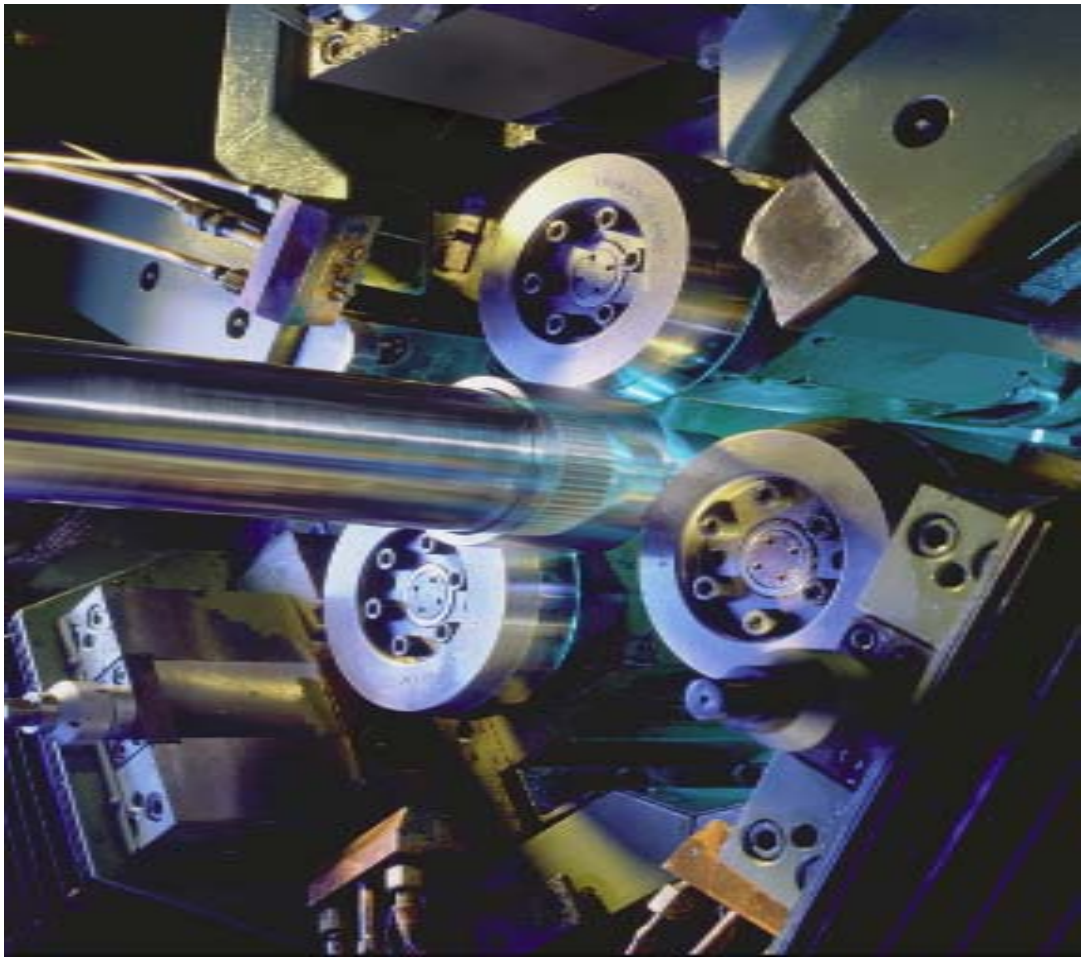
Flow Forming Principals



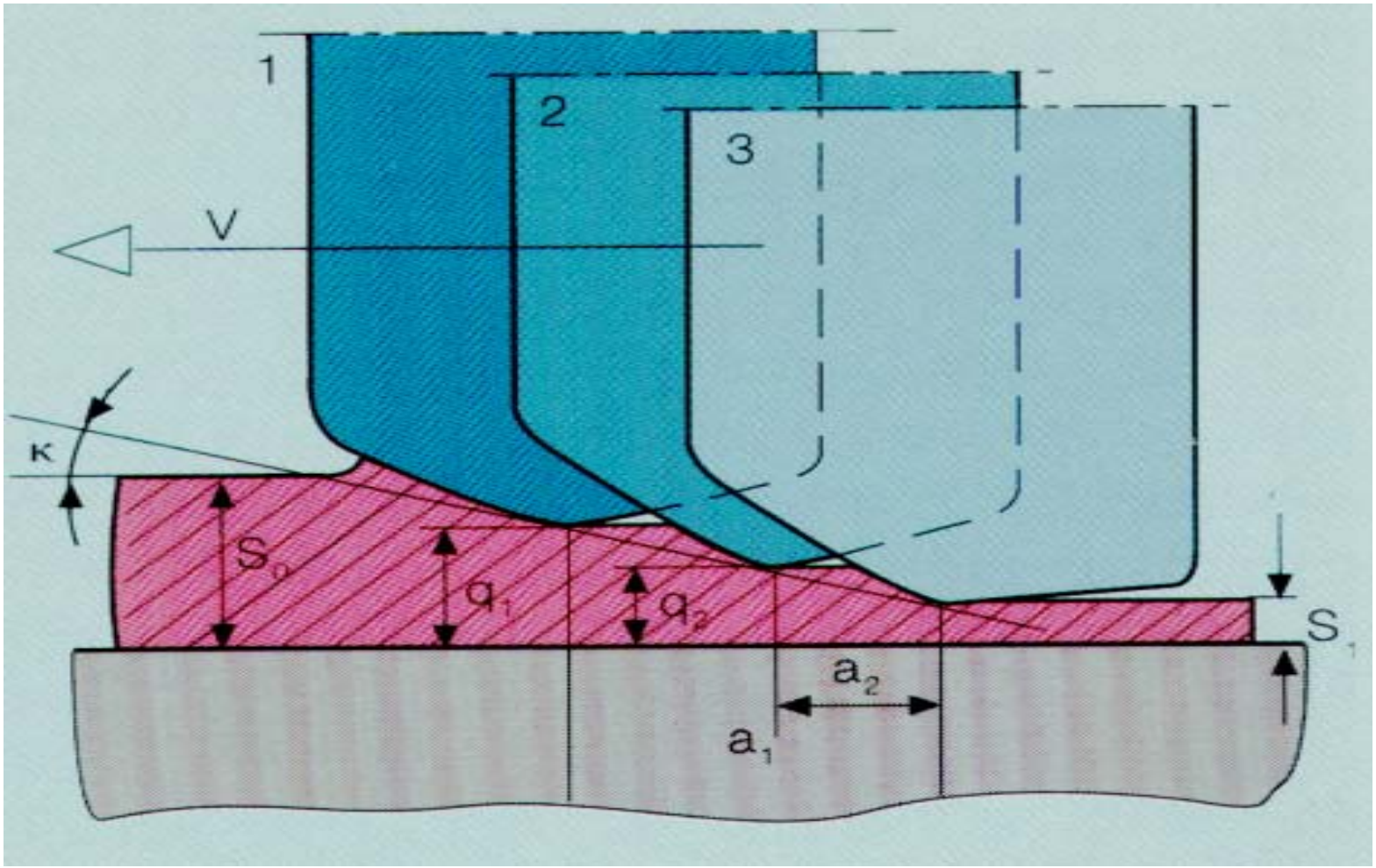
Forward – Reverse Flow Forming



3 Roller Flow Forming Machine



Radial+Axial Roller Offset



Flow formed tubes made from PM 2000

Demonstration tubes

Tube	Total cold deformation	Passes	End.OD x WT
No. 1	74%	1	46,8 x 1,30
No. 2	76%	1	46,6 x 1,20
No. 3	72% (41+62)	2	47,2 x 1,40
No. 4	74%	1	46,8 x 1,30
No. 5	73%	1	47,0 x 1,30
No. 6	47%	1	49,4 x 2,60
No. 7	92% (43+70+56)	3	45,2 x 0,50
No. 8	83% (47+72)	2	46,0 x 0,90
No. 9	81% (43+76)	2	46,2 x 1,00
No. 10	90% (54+72)	2	45,4 x 0,60

Flow formed tubes made from PM 2000

Cold deformed demonstration tubes

Tube 1 (74%)

Tube 9 (81%)

Tube 10 (90%)

Flow formed tubes made from PM 2000

Pre-pilger rolled tubes

Tube	Total cold deformation	Passes	End.OD x WT
P 0	51%	1	55,7 x 5,20
P 1	80% (51+59)	2	49,8 x 2,25
P 2	83% (51+65)	2	49,2 x 1,95

Flow formed tubes made from PM 2000

Cold deformed pre-pilgered tubes

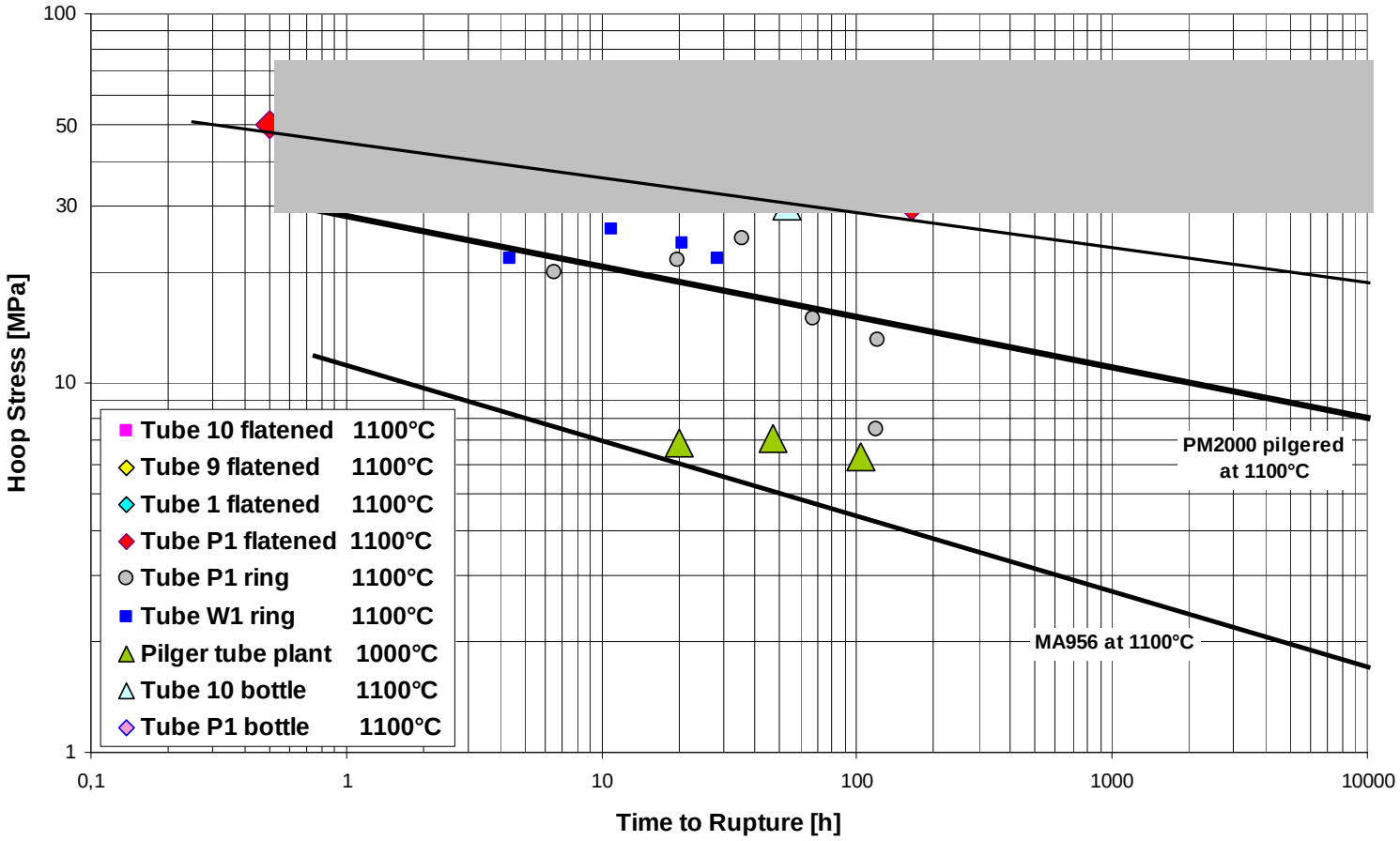
P 0 (51%)

P 1 (80%)

P 2 (83%)

Flow formed tubes made from PM 2000

Hoop creep properties



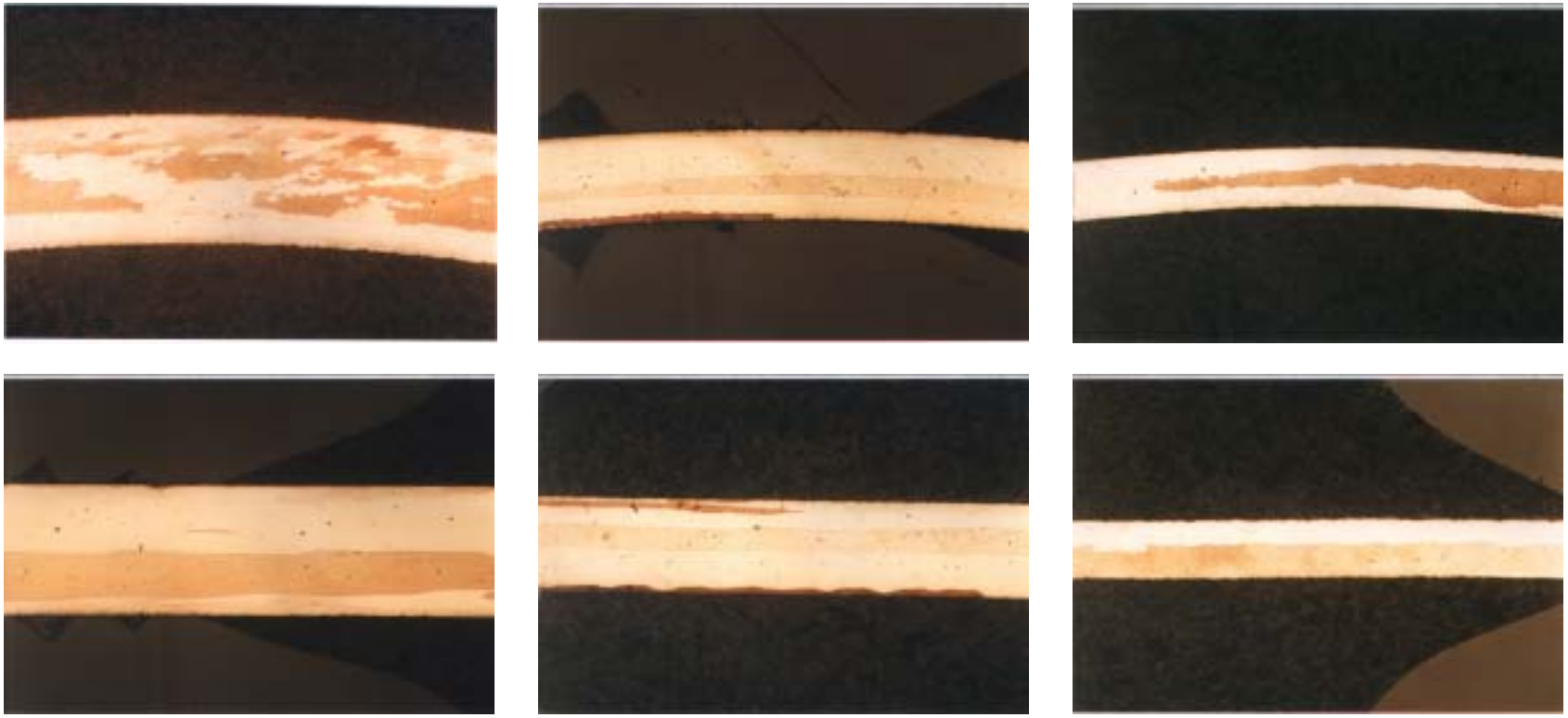
Flow formed tubes made from PM 2000

Warm formed tubes

Tube	Total warm deformation	Passes	End.OD x WT
W 1	52%	1	46,9 x 2,30
W 2	45%	1	47,5 x 2,60
W 3	78% (42 + 61)	2	46,5 x 1,10
W 4	72% (42 + 52)	2	47,1 x 1,43
W 5	80% (43 + 65)	2	47,0 x 1,40
W 6	86% (51 + 72)	2	45,6 x 0,67
W 7	86% (52 + 71)	2	45,7 x 0,70
W 8	88% (54 + 74)	2	45,5 x 0,60

Flow formed tubes made from PM 2000

Warm deformed tubes



W 4 (72%)

W 5 (80%)

W 8 (88%)

Flow formed tubes made from PM 2000

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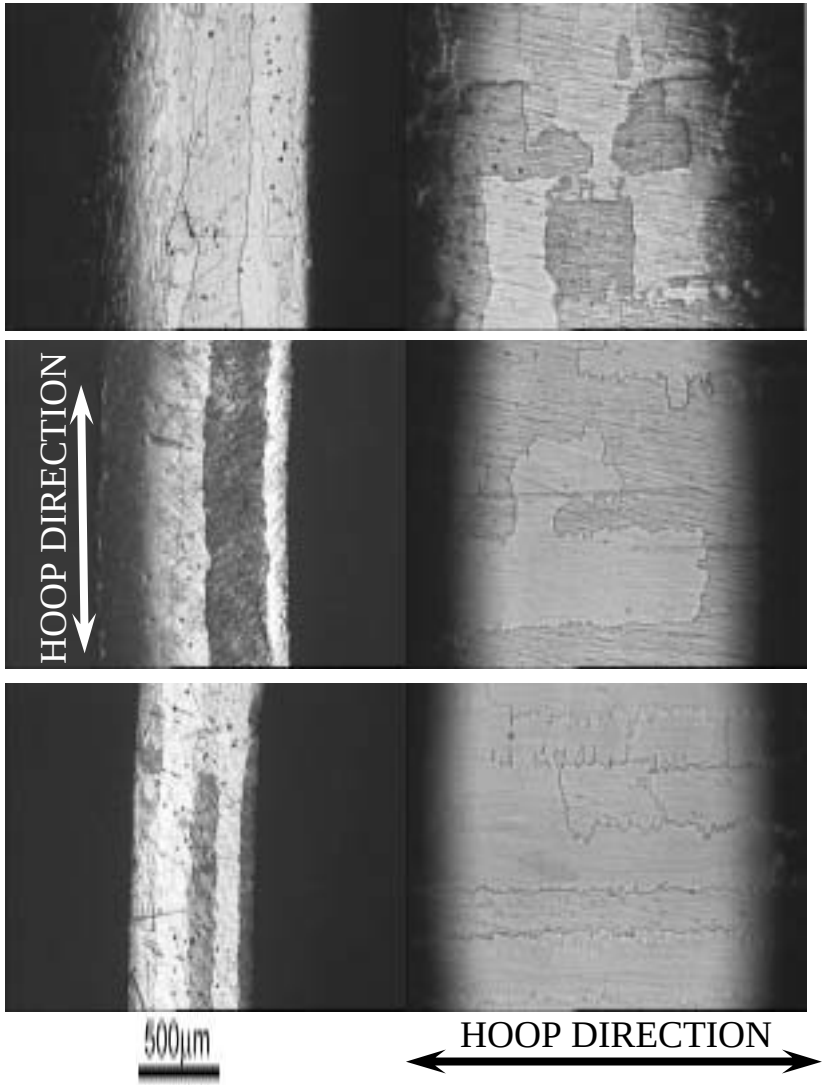
Warm deformed tubes



W4 (72%)

W3 (78%)

W7 (86%)

Flow formed
@ 600 - 650ºC

+

Recrystallised
1380ºC / 1 hour

Flow formed tubes made from PM 2000

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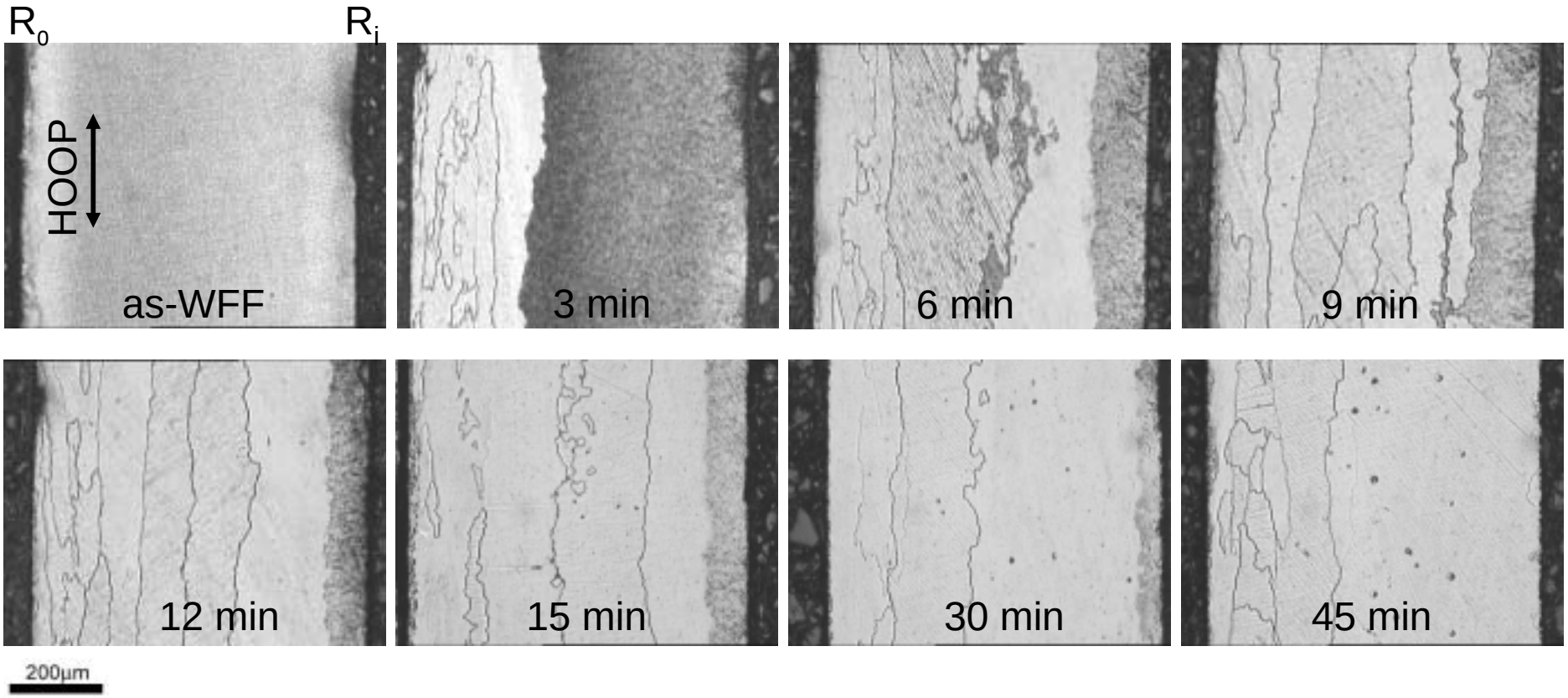
Warm deformed tube – W7 (86%)



Annealed @ 1380ºC

Flow formed tubes made from PM 2000

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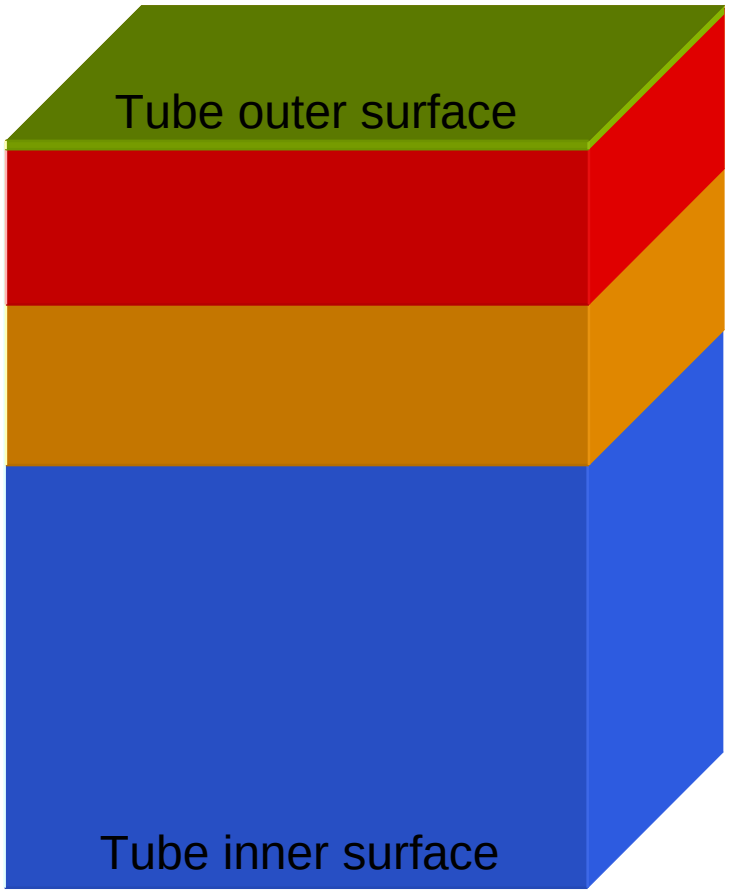
Warm deformed tube – W7 (86%)

Region A (10μm)

Region B (140μm)

Region C (150μm)

Region D (400μm)



Flow forming Rolls

Mandrel surface

Flow formed tubes made from PM 2000

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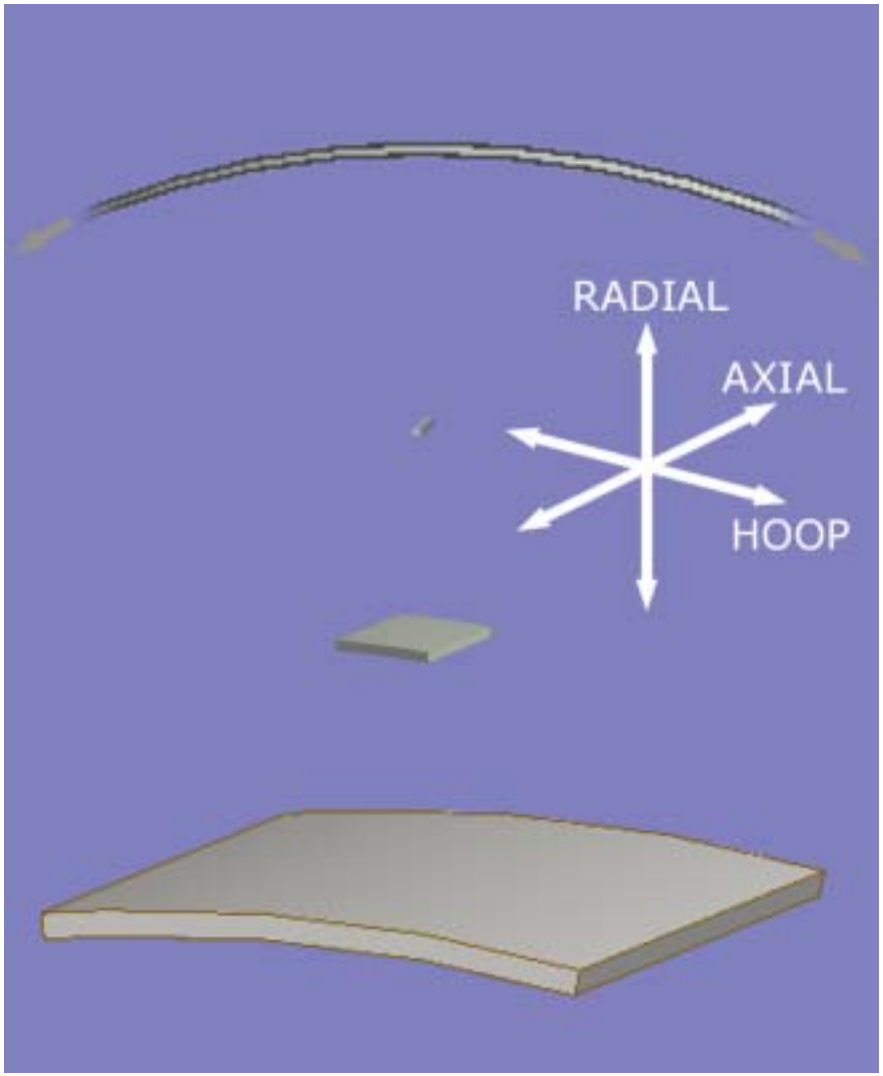
Warm deformed tube – W7 (86%)

O



I

	Axial [μm]	Radial [μm]	Hoop [μm]
Region A	600	10	50000
Region B	650	90	100
Region C	2500	150	1500
Region D	10000	350	7500

Flow formed tubes made from PM 2000

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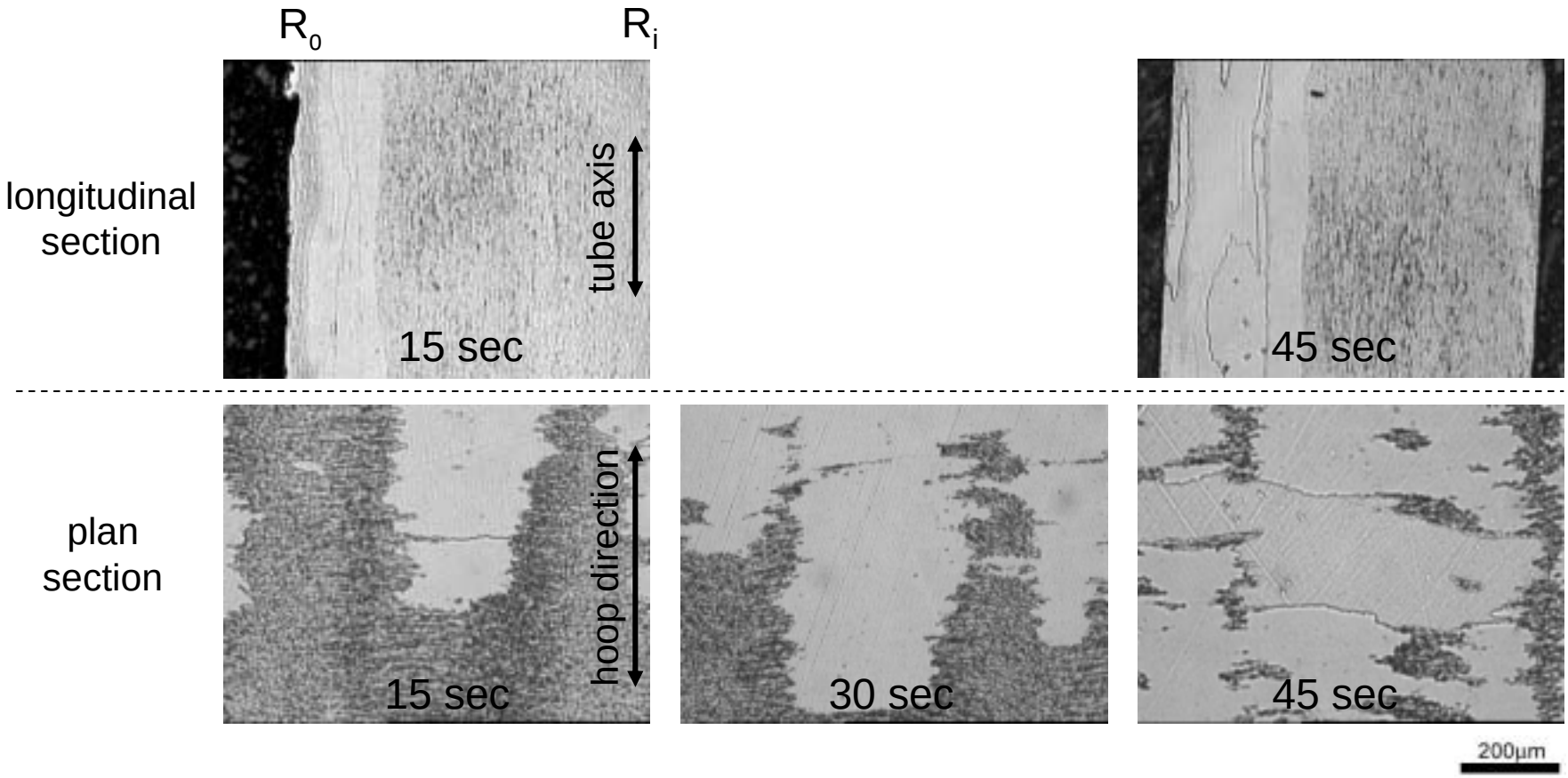
Warm deformed tube – W7 (86%)



Annealed @ 1380ºC

Flow formed tubes made from PM 2000

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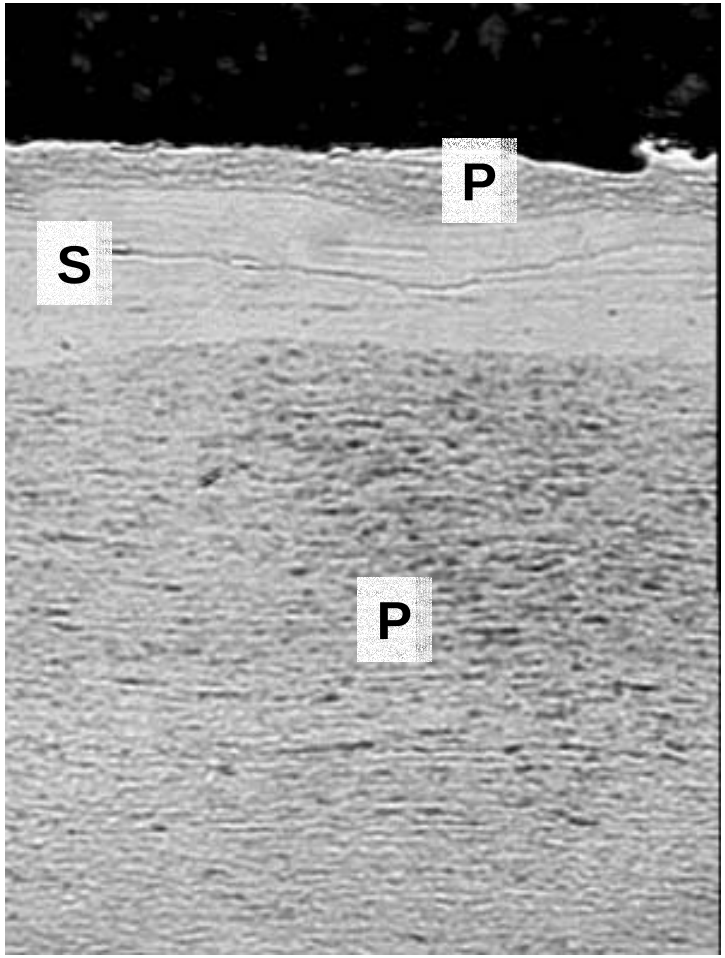
Warm deformed tube – W7 (86%)

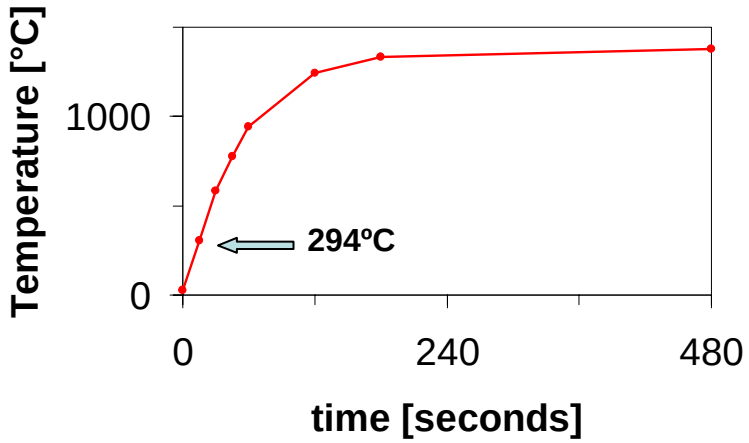


Annealed 1380ºC / 15 seconds

primary (P) and secondary (S) recrystallised regions.

Longitudinal section

Measured sample surface temperature versus time in furnace.



Flow formed tubes made from PM 2000

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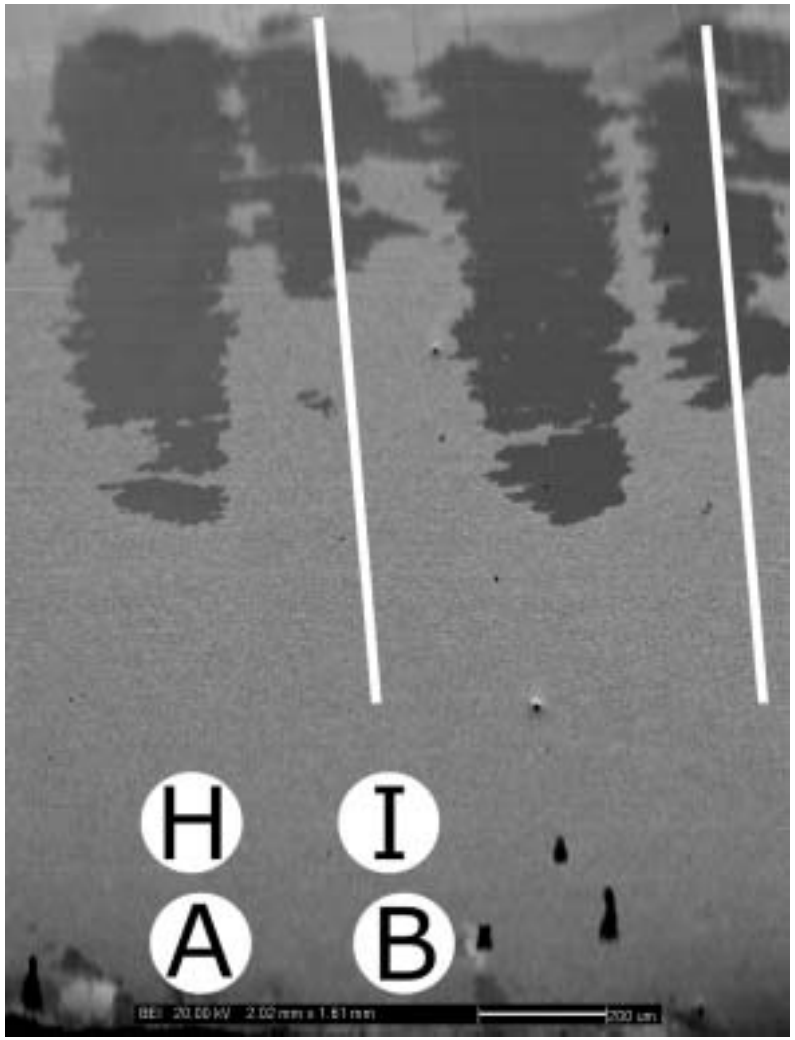
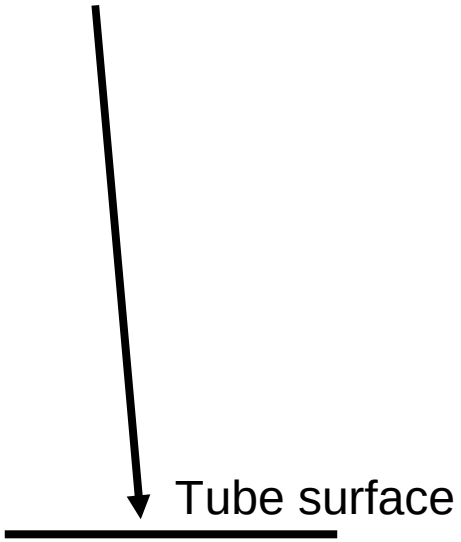
Warm deformed tube – W7 (86%) – taper section for EBSD analysis





Flow formed tubes made from PM 2000

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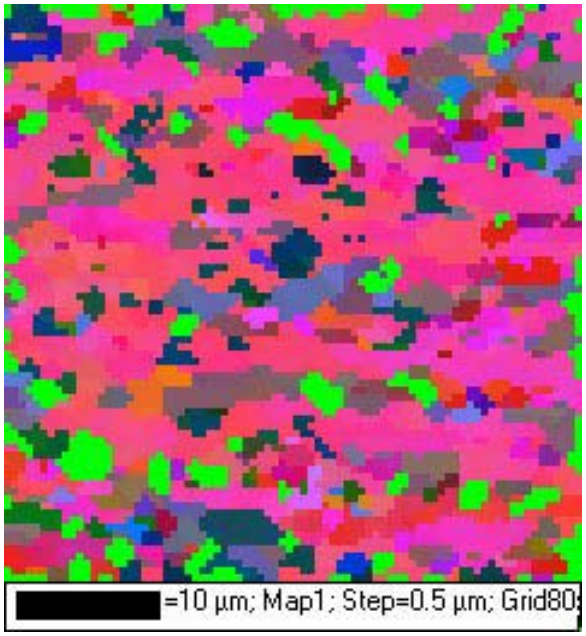
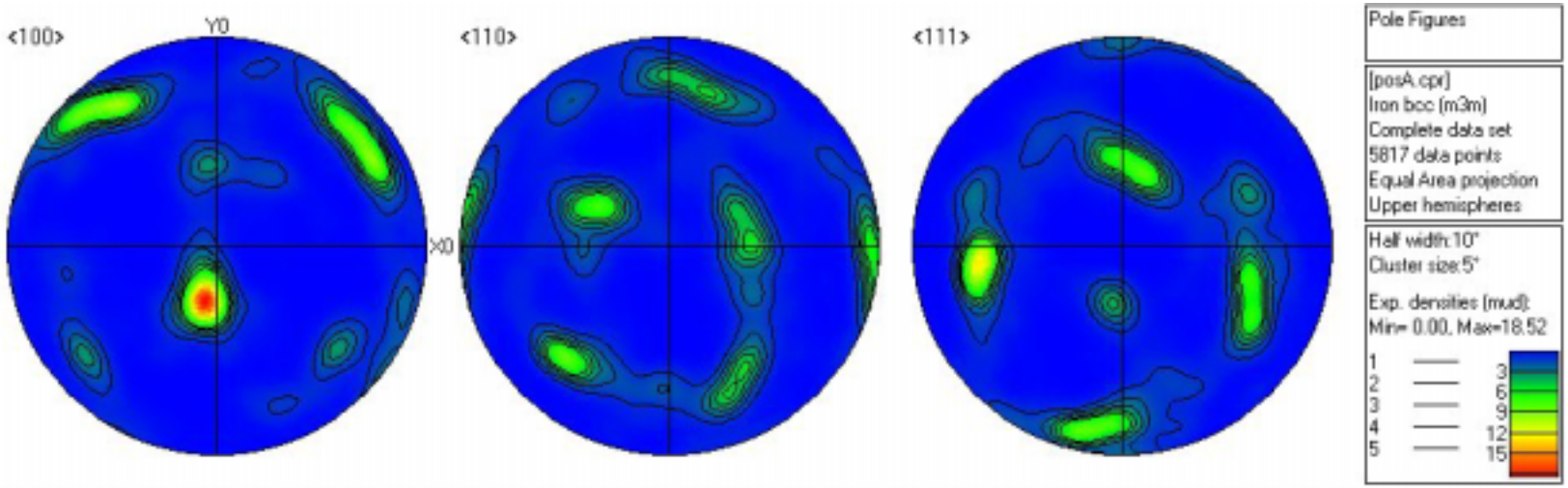
Warm deformed tube – W7 (86%)

Area A





Flow formed tubes made from PM 2000

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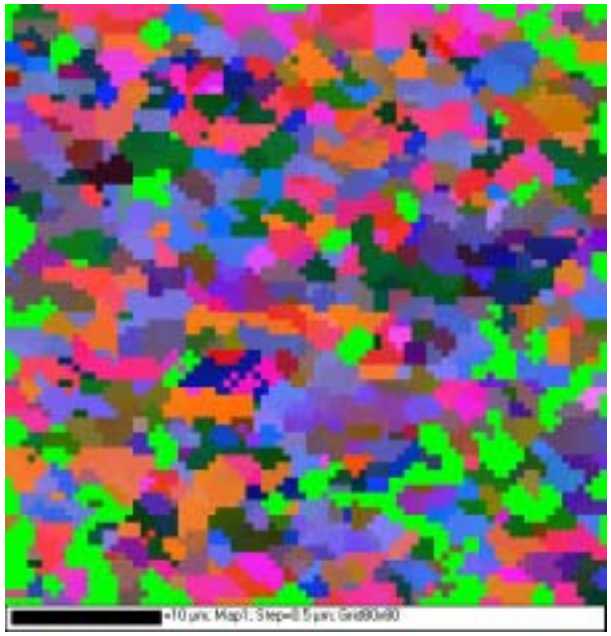
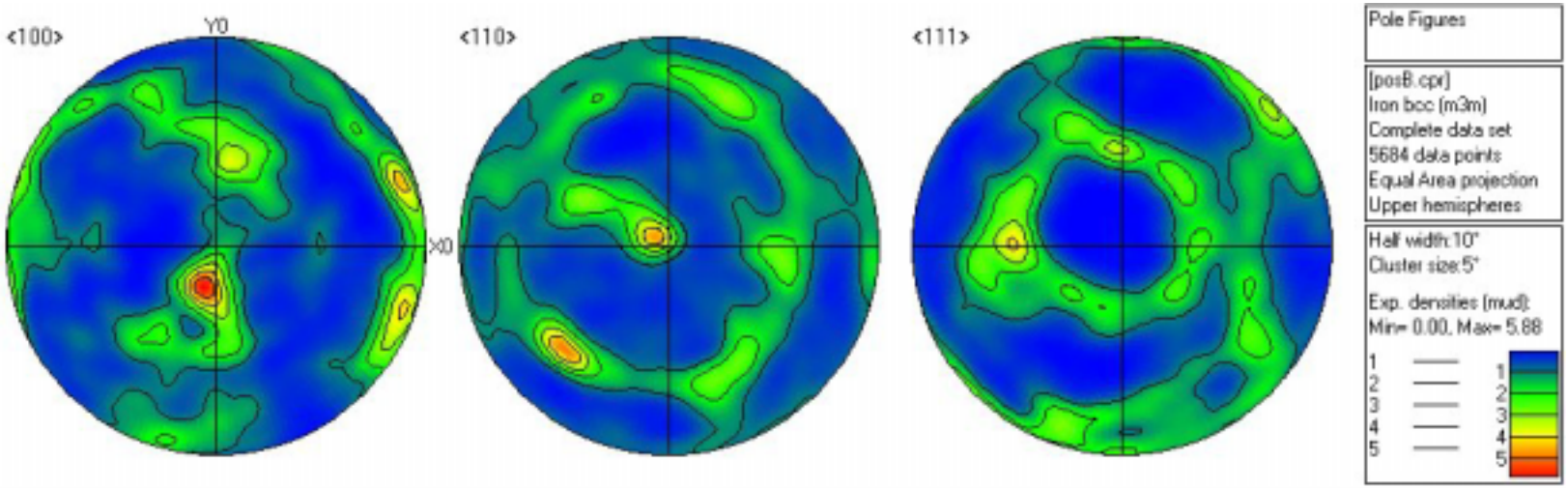
Warm deformed tube – W7 (86%)

Area B





Flow formed tubes made from PM 2000

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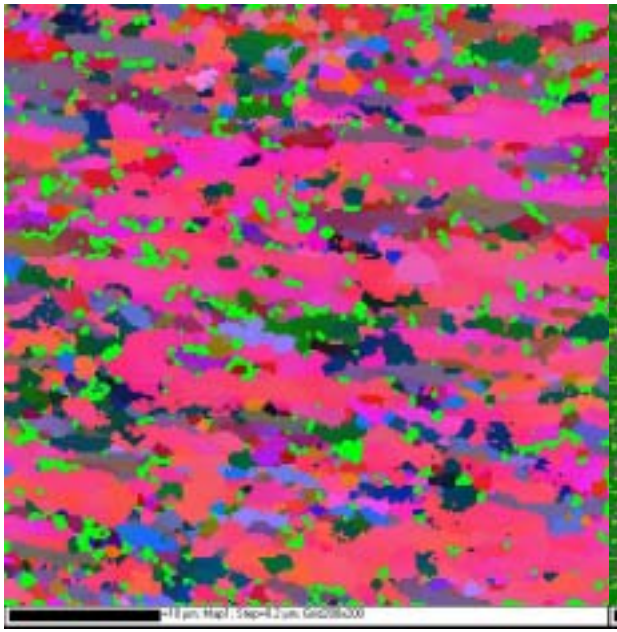
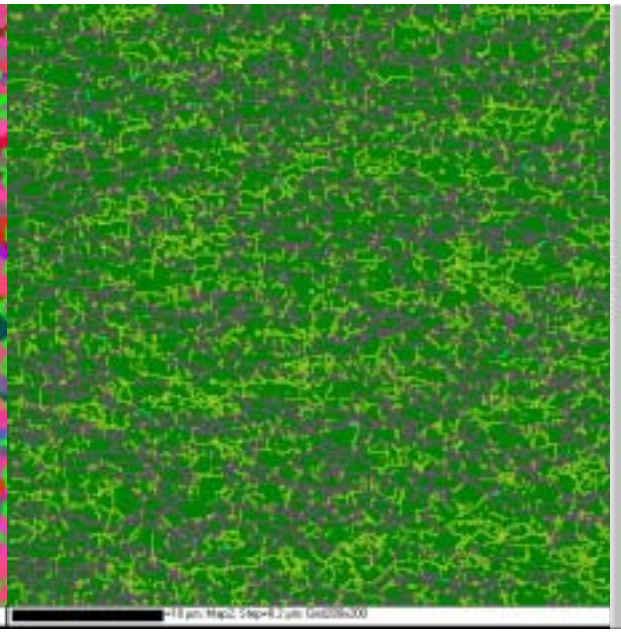
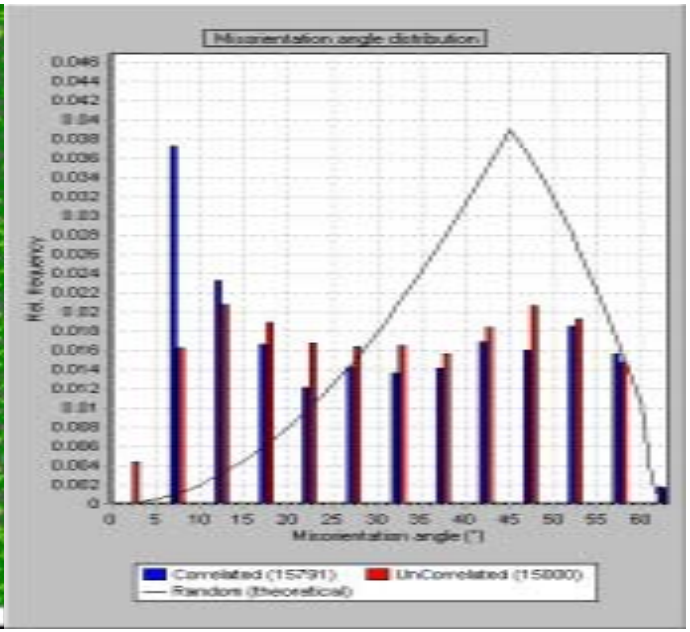
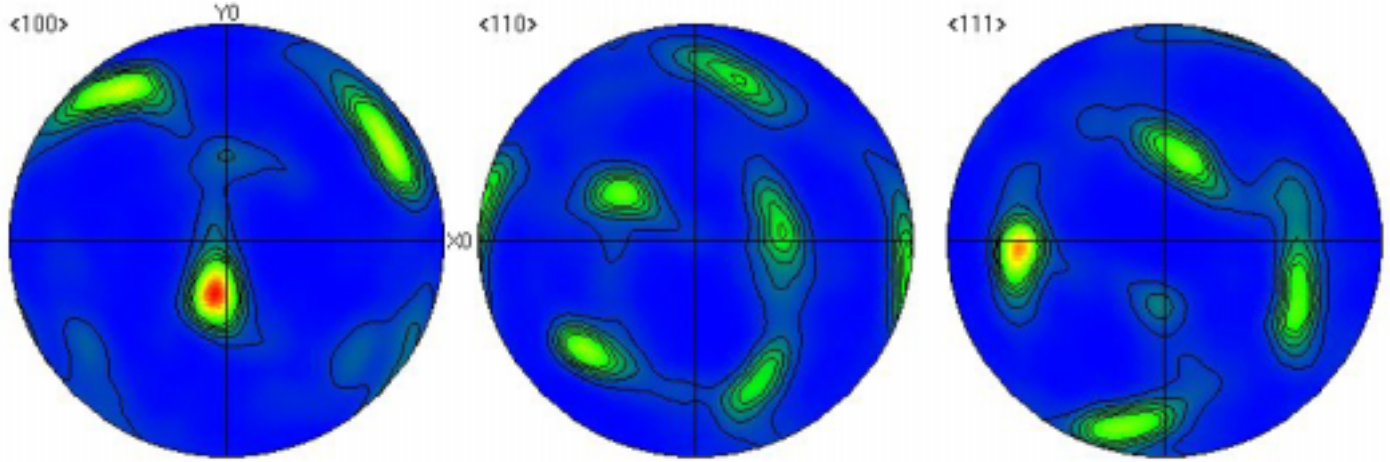
Warm deformed tube – W7 (86%)

Area H (high res.)









Pole Figures

[posH_hires.cpr]
Iron bcc (m3m)
Complete data set
39994 data points
Equal Area projection
Upper hemispheres

Half width:10°
Cluster size:5°

Exp. densities (mud):
Min= 0.00, Max=15.65

1 — 3
2 — 6
3 — 9
4 — 12
5

Flow formed tubes made from PM 2000

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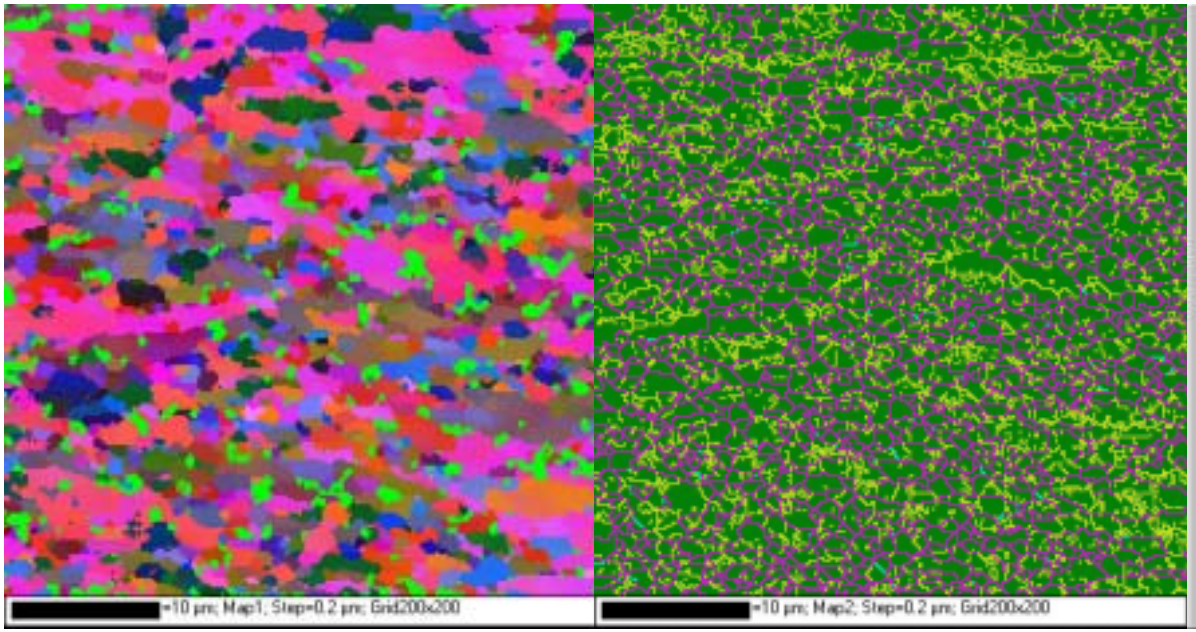
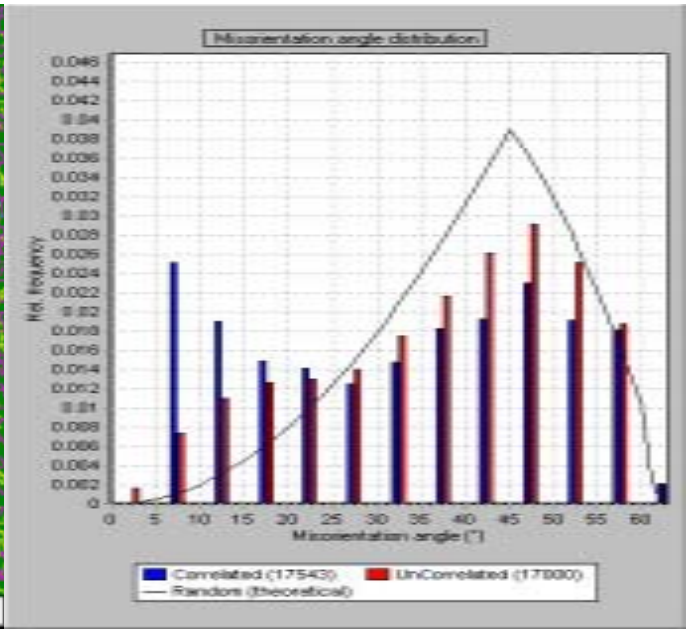
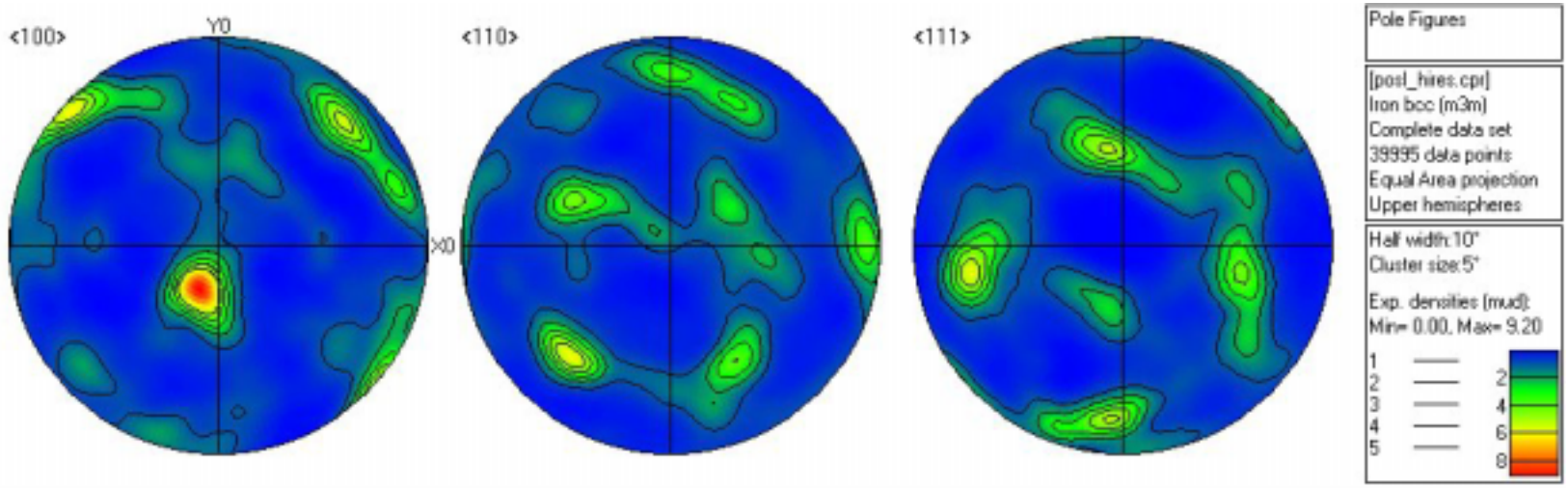
Warm deformed tube – W7 (86%)

Area I (high res)







PM 2000 Grain Structures

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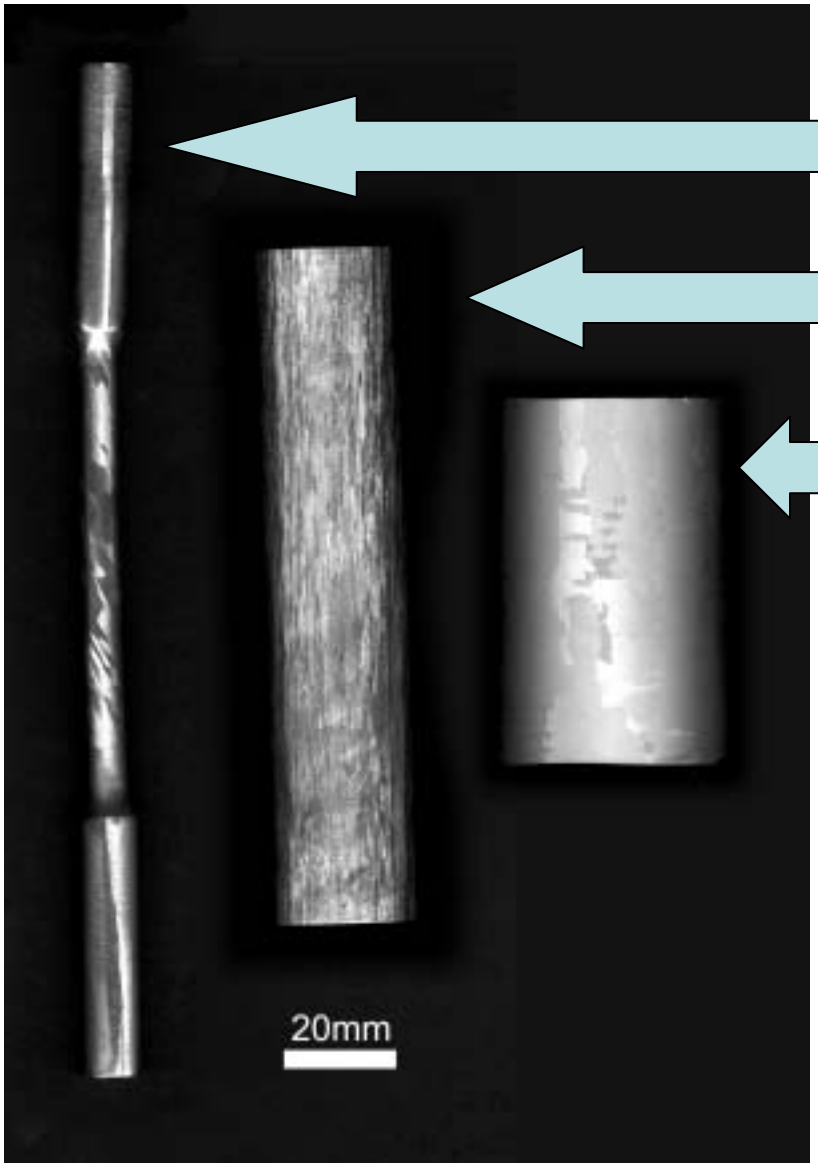

Hot torsion

Standard tube

Flow formed

ODS Fe_3Al Defect Grain Structures

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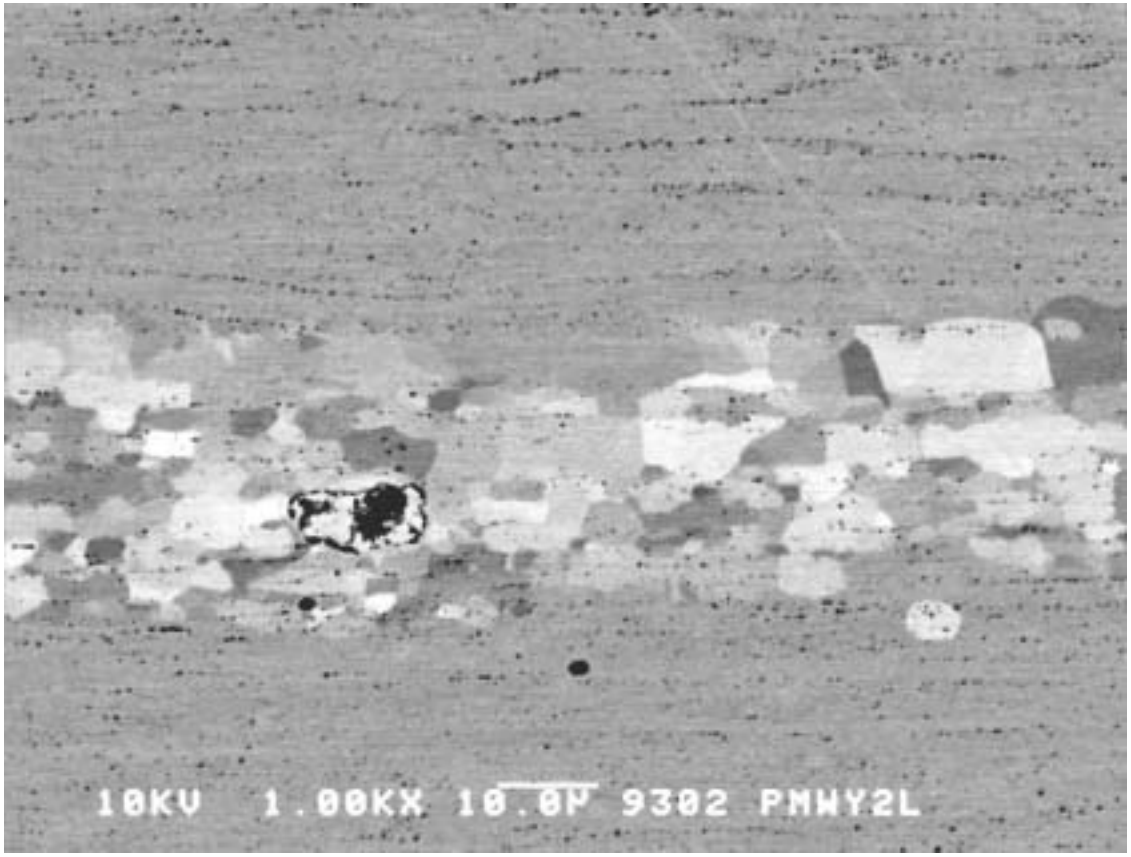

Extruded 1050ºC + annealed 1h /1275ºC (PMWY2 - Longitudinal section)

ODS Fe_3Al Defect Grain Structures

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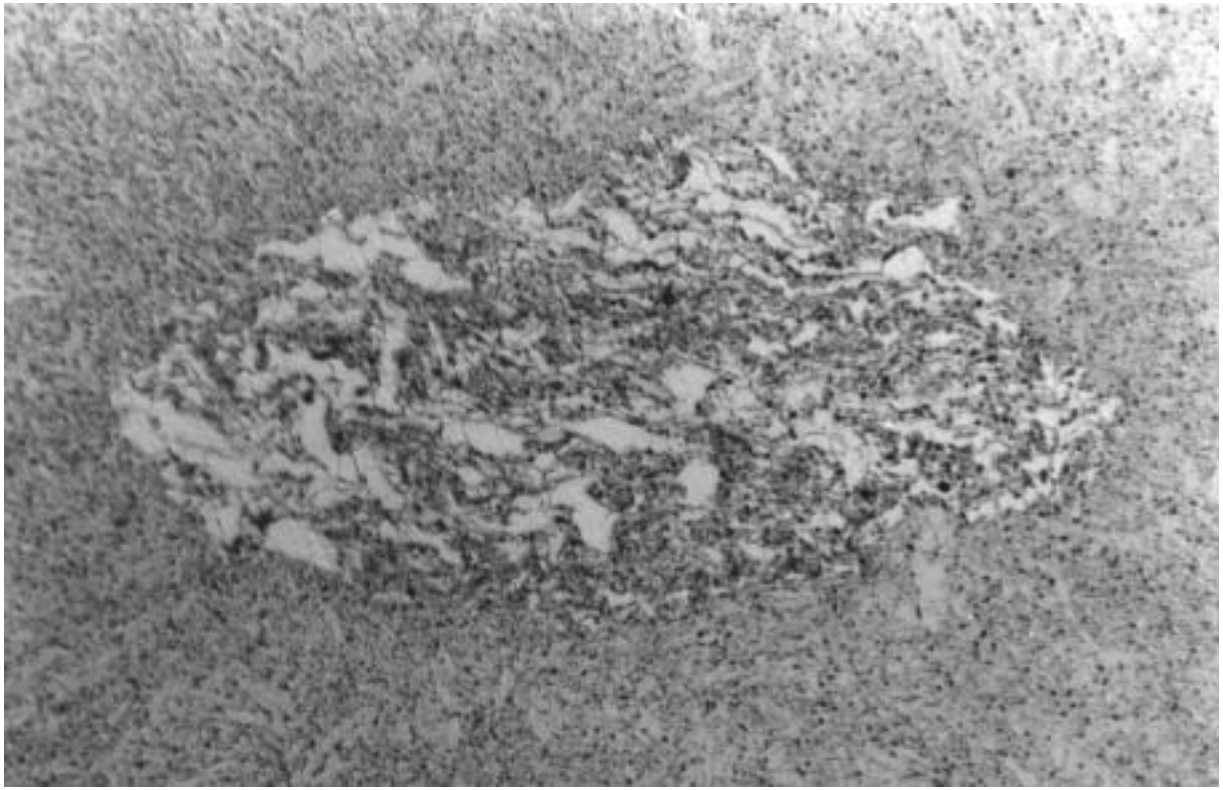

Extruded 1050ºC (PMWY2 - Transverse section)

PM2000 variant alloys

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PM2000 variants

1. Aim

Investigation of recrystallisation behaviour in alloys with known defects:

(i) Y_2O_3 (ODS) free regions
(ii) Ceramic powder additions to stimulate nucleation of recrystallisation
((iii) influence on recrystallisation of mild steel container)

2. **Alloy fabrication**

(i) PM2000 alloy + 1wt.% ODS-free Fe (25 µm< 100% <300µm; 127µm mean)
(ii) PM2000 alloy + 1wt.%Al_2O_3

1. *Manufactured by Plansee GmbH, Lechbruck*
2. *Fully MA,standard PM2000 powders tumble mixed with 1% powder additions*
3. *Extruded as rod under standard condition with 9:1 extrusion ratio*
4. *Mild steel container, **not** m/c off after rods straightened*

PM2000 variant alloys

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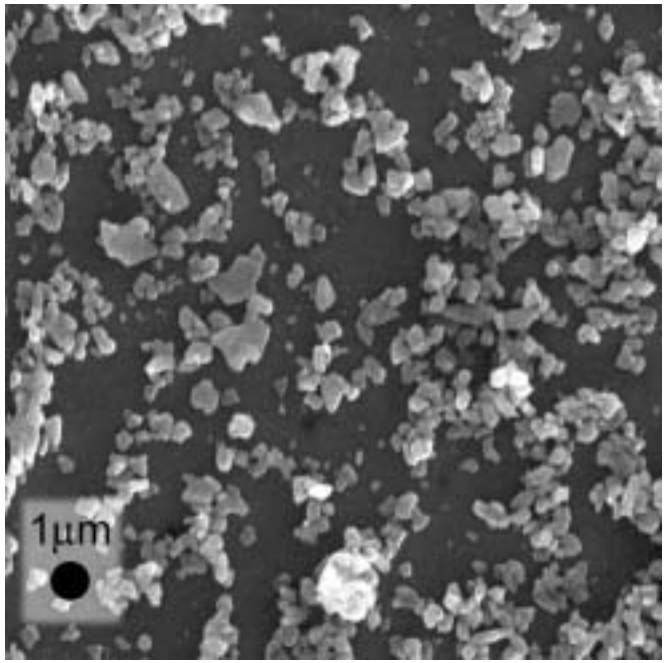

Supplier: Reynolds Chemicals

Code: RCT-HPT DBM

Particle size: MPD 0.86µm (0.4 to 2.0µm)

Al_2O_3 powder used to produce PM2000 variant

PM2000 variant alloys

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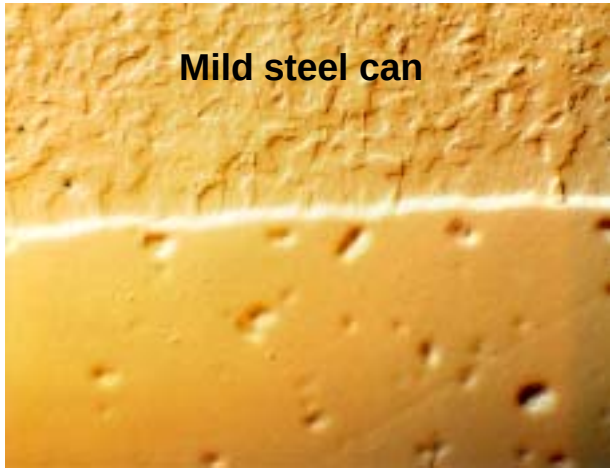
PM2000 alloy + 1wt.% ODS-free Fe



As-extruded

(Transverse section)

5 min / 1380ºC

(Longitudinal section)

PM2000 variant alloys

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PM2000 alloy + 1wt.% ODS-free Fe

1 h / 1380ºC

(Longitudinal section)

1 h / 1380ºC

(Transverse section)

PM2000 variant alloys

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PM2000 alloy + 1wt.% Al_2O_3

As-extruded | 5 min / 1380ºC | 1 h / 1380ºC

Transverse sections

Summary

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Flow forming

- Flow forming has been used to produce PM2000 alloy tubes with enhanced hoop creep strength
- Grain structures formed in flow formed and SRex. PM2000 tubes can be very complex and are influenced by:
  - -the macroscopic level of deformation
  - -through-thickness variations in the pattern of deformation
- Further optimisation of flow forming processing of ODS alloy tubing is possible

PM2000 variants

- PM 2000 alloy variants have been produced containing up to 1 wt.% of either ODS-free Fe-powder or Al_2O_3
- early results suggest similarities between the recrystallisation behaviour of the ODS-free Fe variant and ODS Fe_3Al (variant PMWY2) containing fine-grained stringers