23rd Annual Conference on Fossil Energy Materials, Pittsburgh May 2009

UK-US Phase 1 Report

Gordon J Tatlock
University of Liverpool

ODS Alloy Development

UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

ODS Alloys

US Inputs

UCSD
- Non-fusion joining: IW,MPW
- Microstructural modification: Flow forming

ORNL
- Collation of joining data
- Non-fusion joining: TLP, PADB
- Collation of oxidation data
- Mech. Prop. testing

UK Inputs

University of Liverpool
- Collation of published weld data
- Identify most appropriate welding techniques
- Microstructural manipulation

Cranfield
- Collation of oxidation data
- Coatings

Siemens
- Advice on materials/conditions
- Supply of legacy welds and spun cans

Published Data + **Joining** → **Microstructural modification** → **Oxidation Life**

ODS Alloys

UK Team

University of Liverpool

Gordon Tatlock, Andy Jones,
Justin Ritherdon, Hameed Al-Badairy, Chun-Liang Chen,
John Walker, Yaw-Wang Chai

Cranfield University

Nigel Simms, Jim Norton

Siemens (UK)

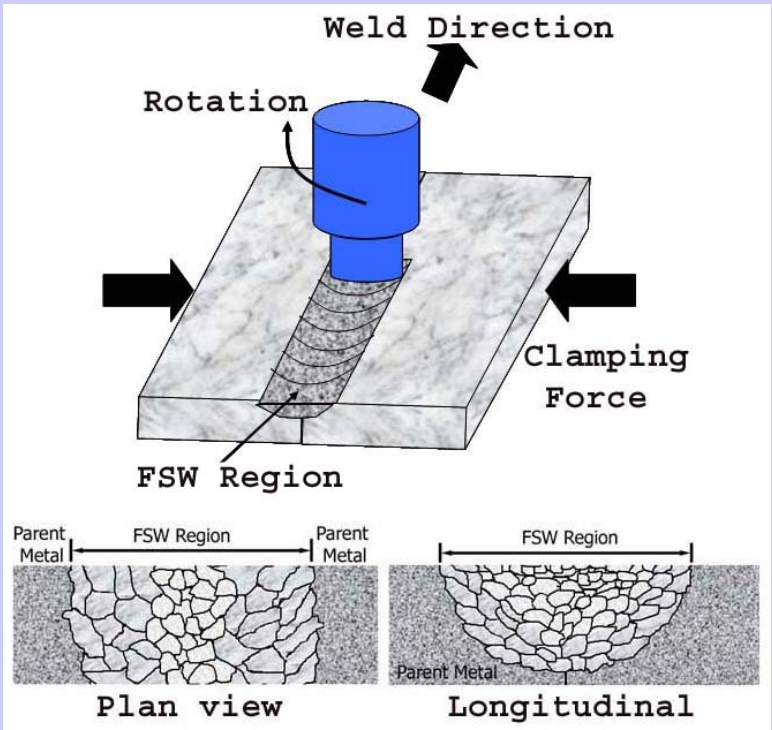
Gordon McColvin

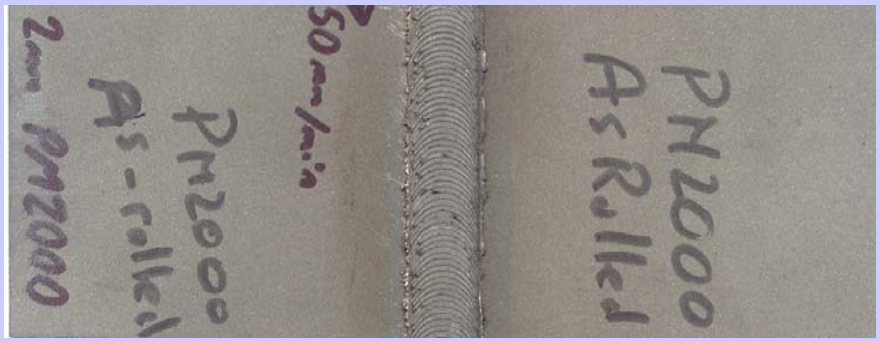
ODS Alloys

Aims and Objectives

- Establish and review the current state of knowledge regarding joining of ODS-FeCrAl alloys
- Identify the most appropriate techniques for joining sheet and tubing and collaborate with partners to apply these techniques to generate quantitative data
- Establish and extend the current state of knowledge regarding microstructural control of ODS-FeCrAl alloys, especially in torsionally orientated structures
- Investigate the use of coatings on ODS alloys for enhanced oxidation and thermal protection

Friction Stir Welds in PM2000



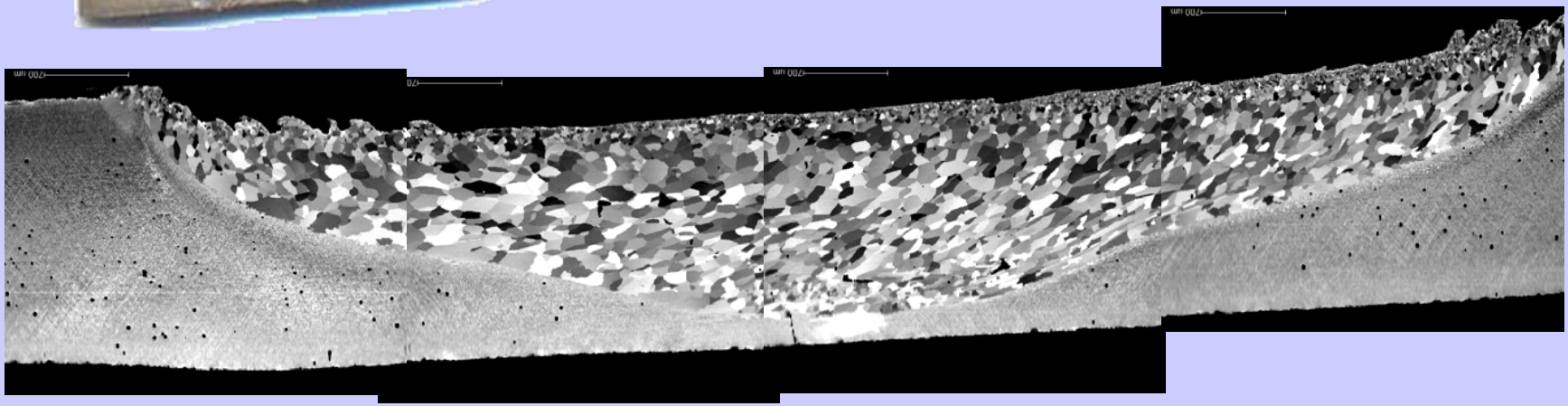


10 mm

UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

Friction Stir Welds in PM2000

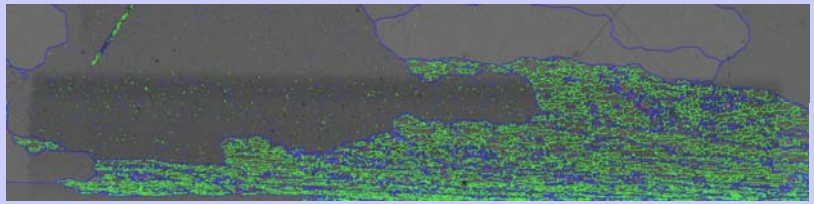
10 mm



1mm

low angle g.b

high angle g.b

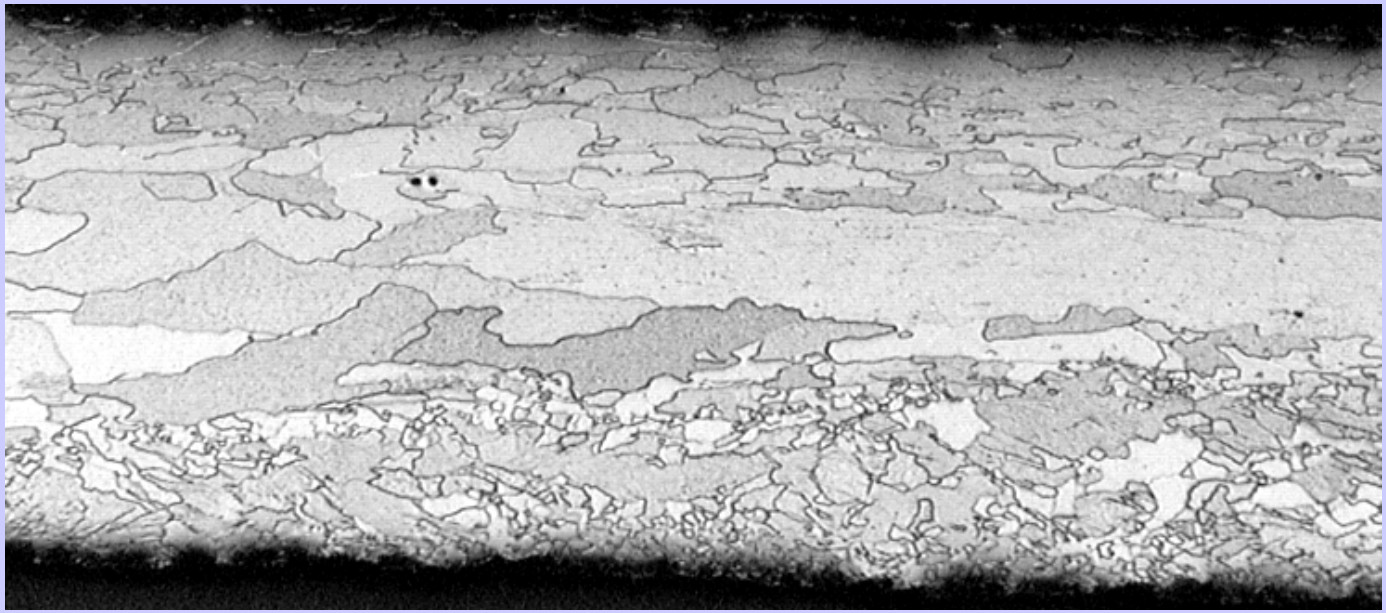


50µm

UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

UNIVERSITY OF LIVERPOOL

Friction Stir Welds in PM2000



100µm

Warm rolled at 175ºC, 40% reduction, then recrystallised at 1380ºC for 1h.

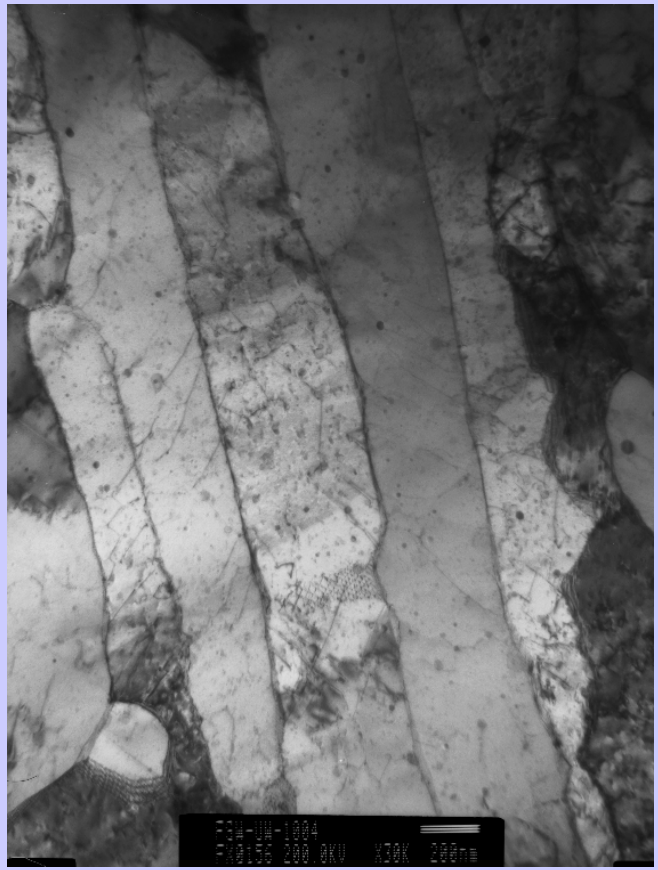
UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

UNIVERSITY OF LIVERPOOL

Dispersion Size Measurements

1μm

Parent Region



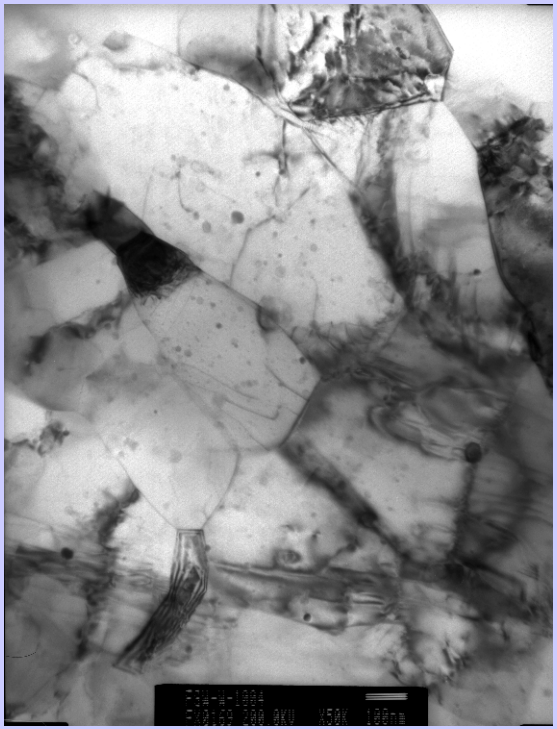
1μm

before recrystallization treatment

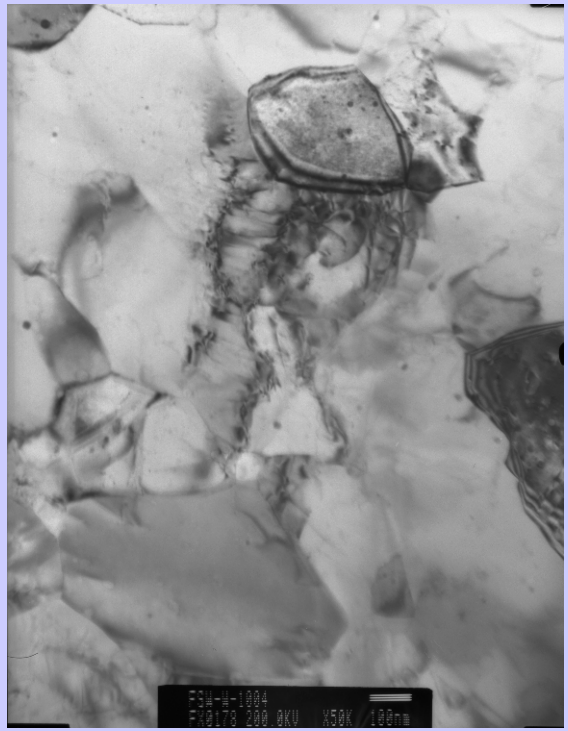
UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

UNIVERSITY OF LIVERPOOL

Dispersion Size Measurements



1μm



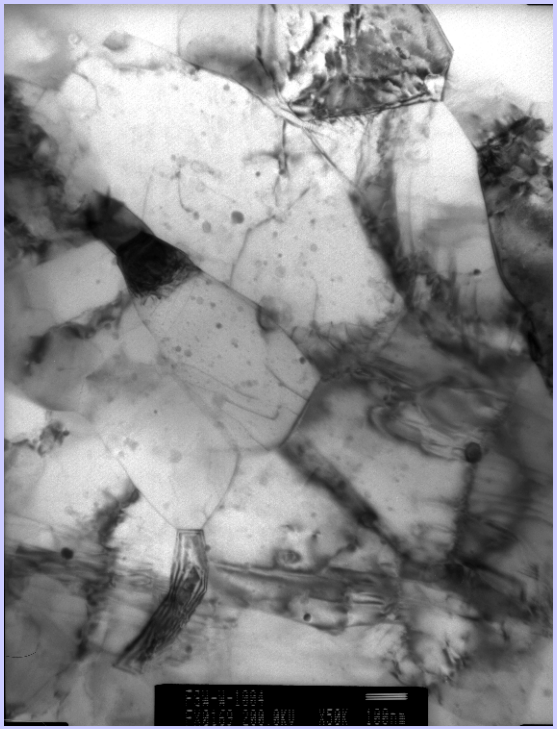
1μm

Welded Region

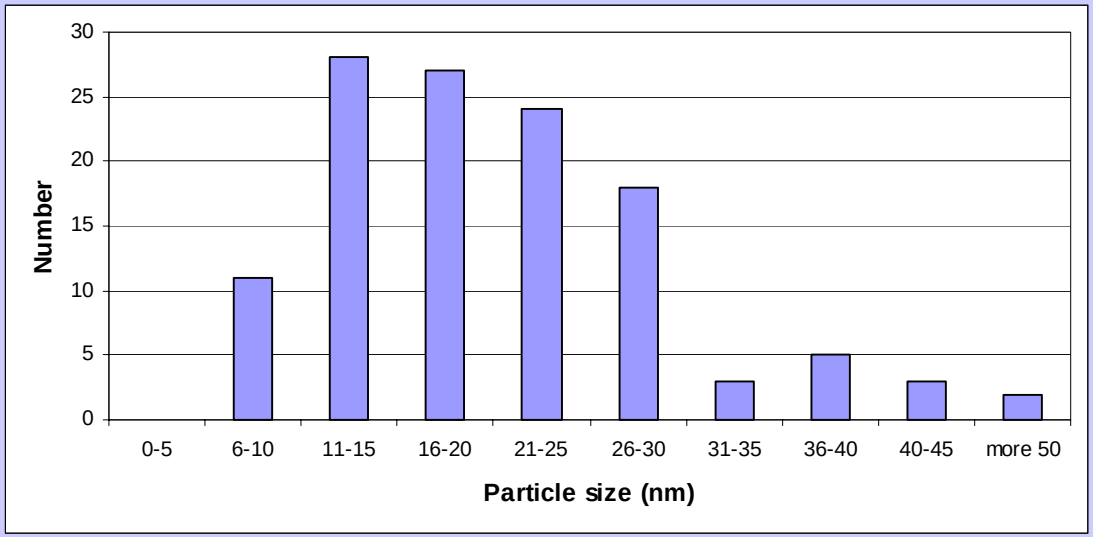
before recrystallization treatment

UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

Dispersoid Distribution after FSW of PM2000



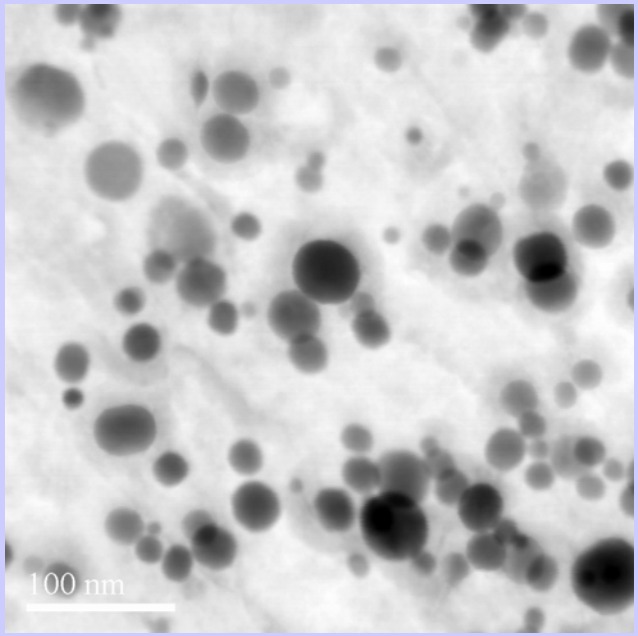
1μm

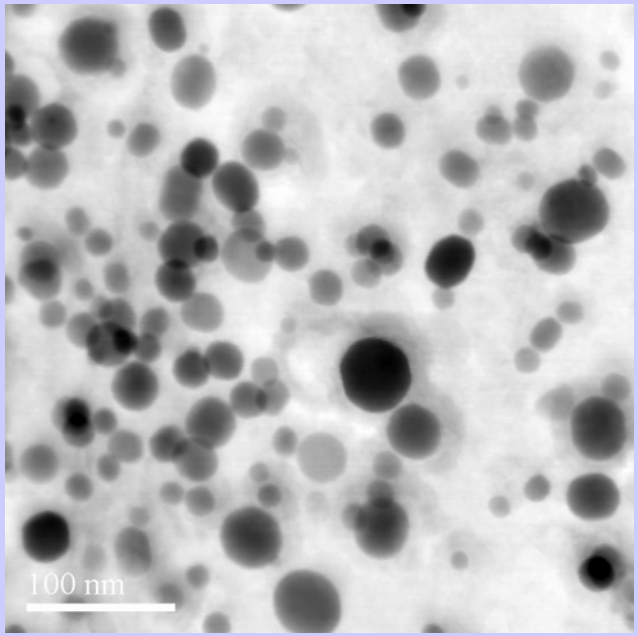


Welded Region

before recrystallization treatment

Dispersion Size Measurements

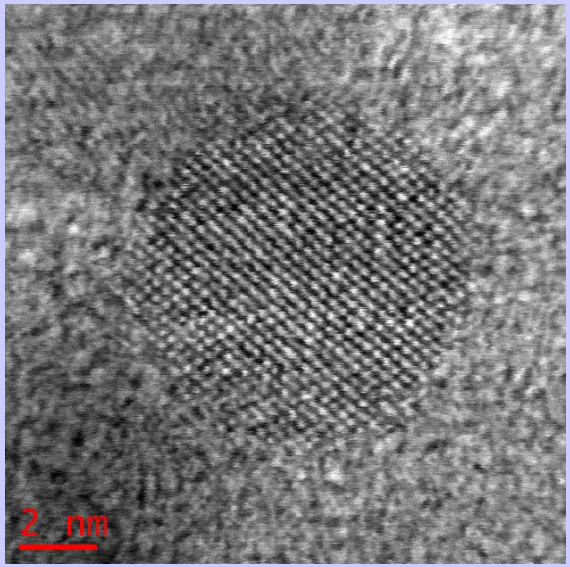




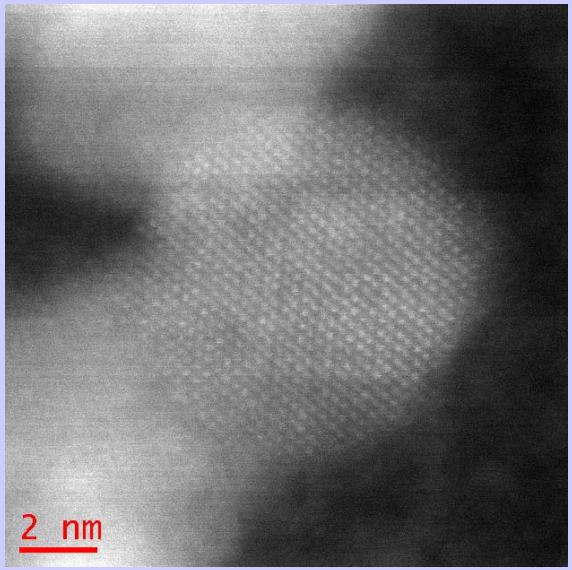
FSW region- 1380ºC 1hr

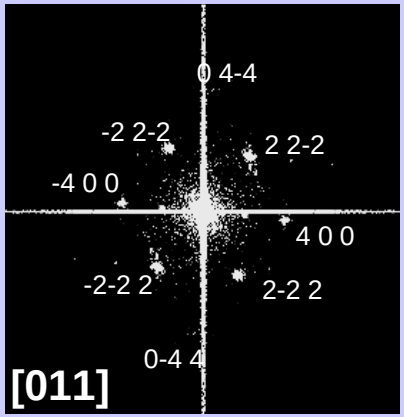
Extraction replicas of sample

Dispersion Evolution

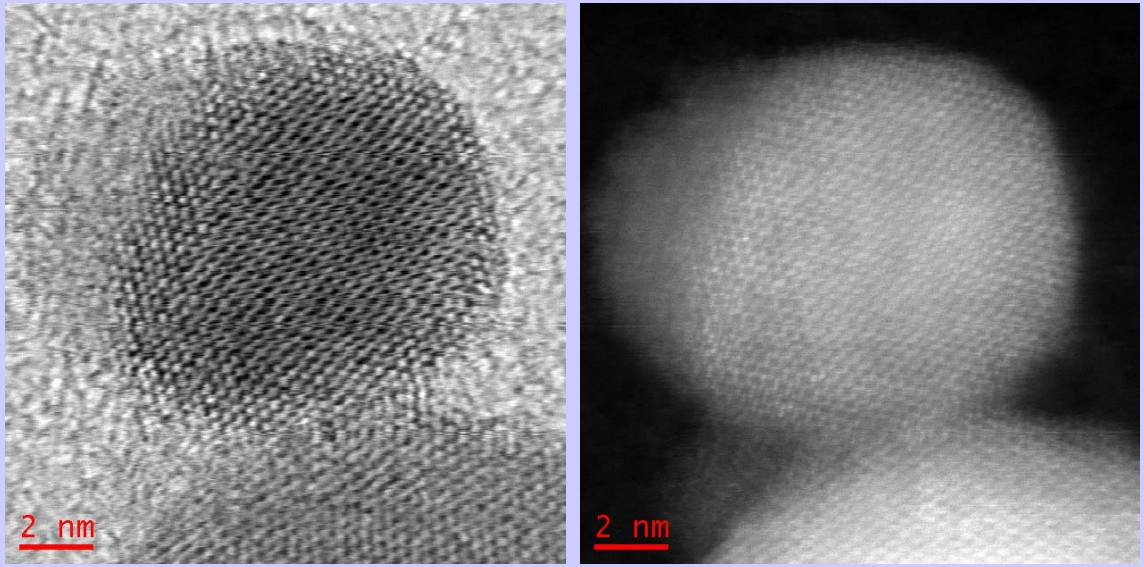


Cubic -Y_2O_3



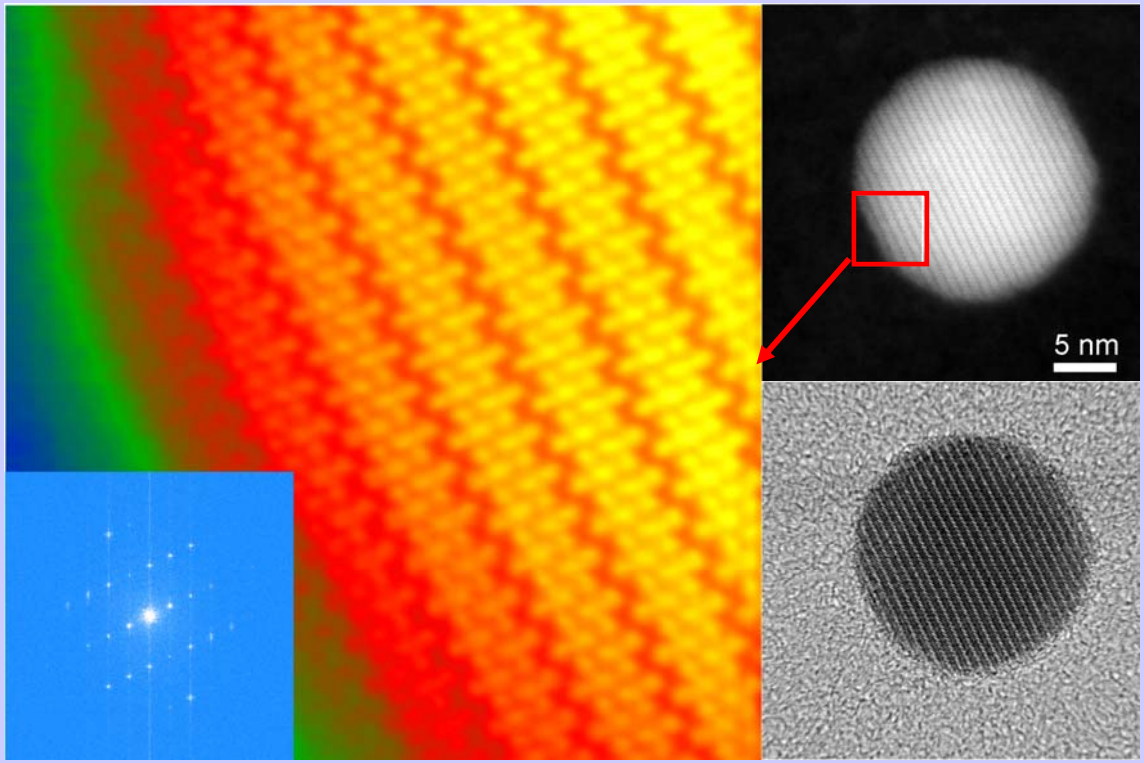


Dispersion Evolution



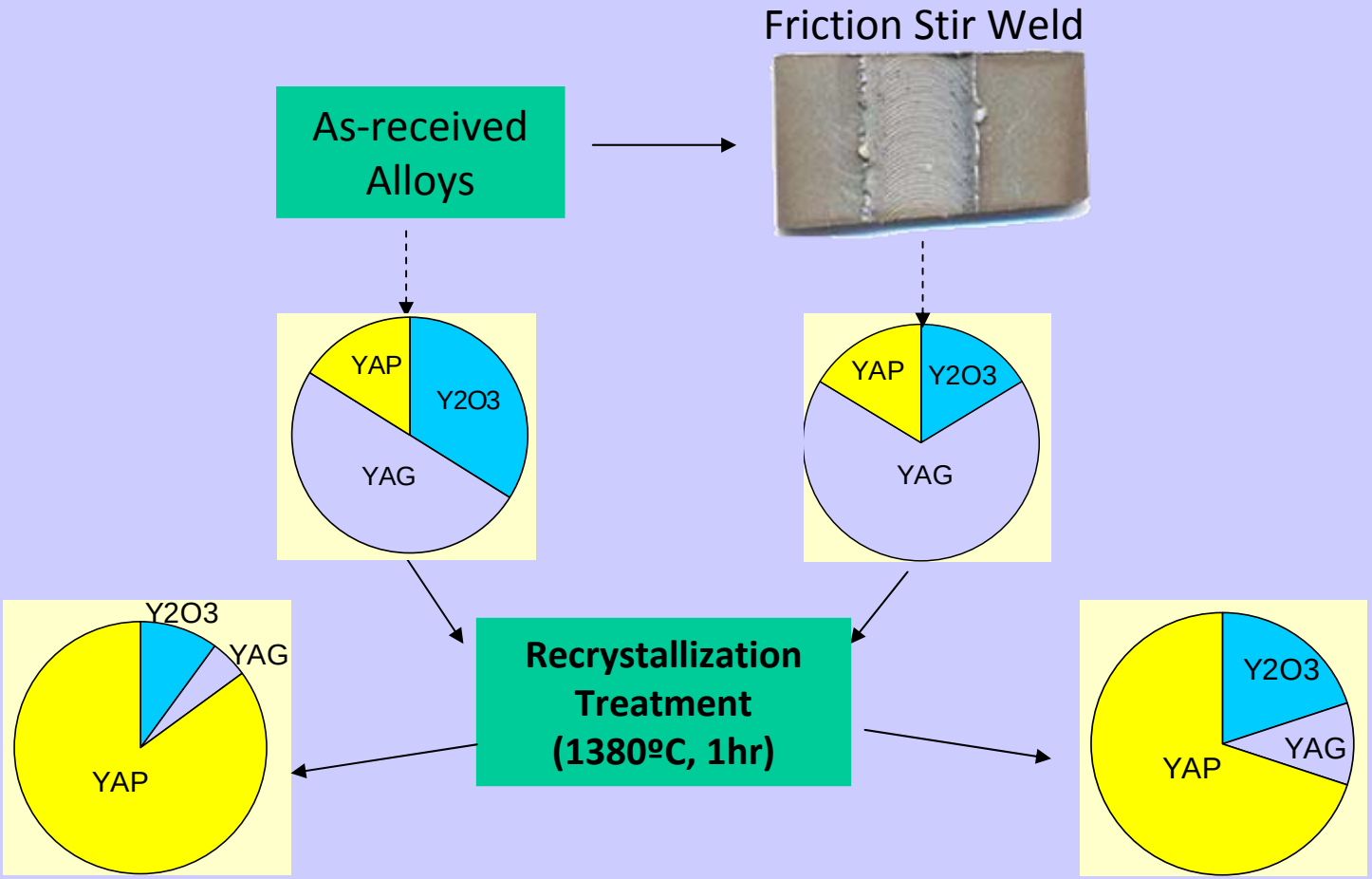
$Y_3Al_5O_{12}$ Garnet (YAG)

Dispersion Evolution



Yttrium – aluminium oxide nanoparticle

Dispersion Evolution

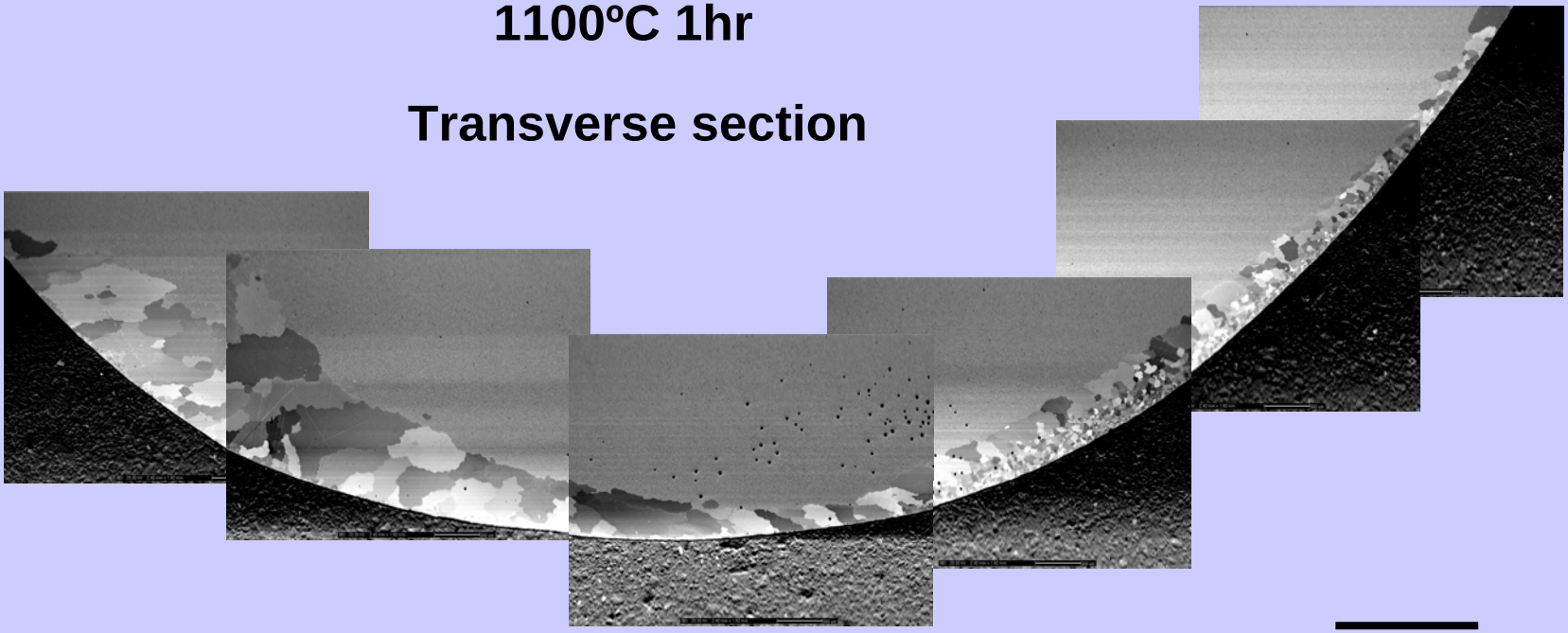


UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

Partial Recrystallisation of rods of PM2000

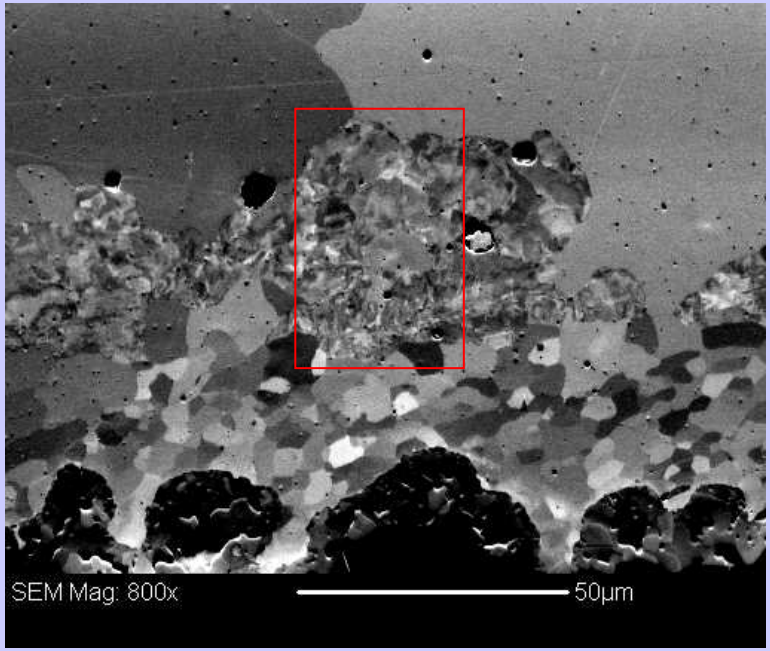
1100ºC 1hr

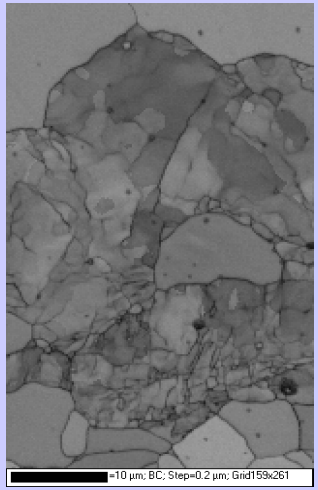
Transverse section

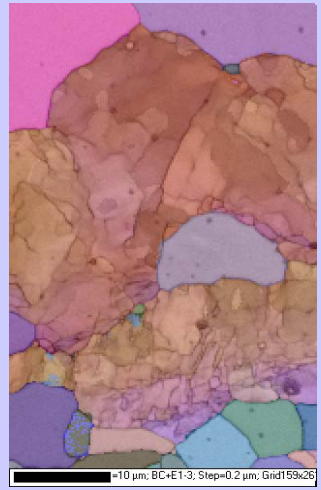


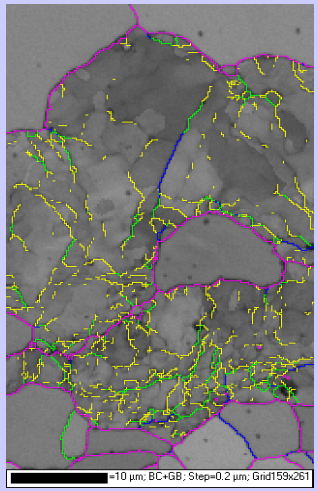
UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

Primary and Secondary Recrystallisation in Rod





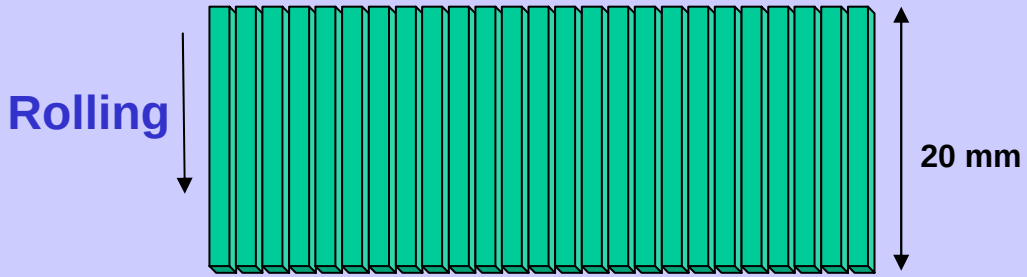




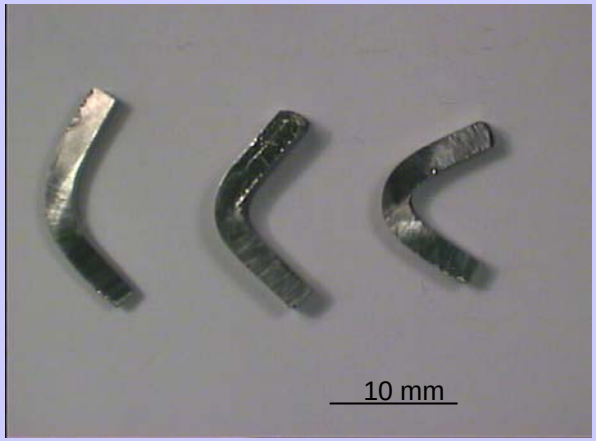
1380°C for 1hr

UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

Deformation of Rods Cut From Sheet



Bent samples



120º → 90º → 45º

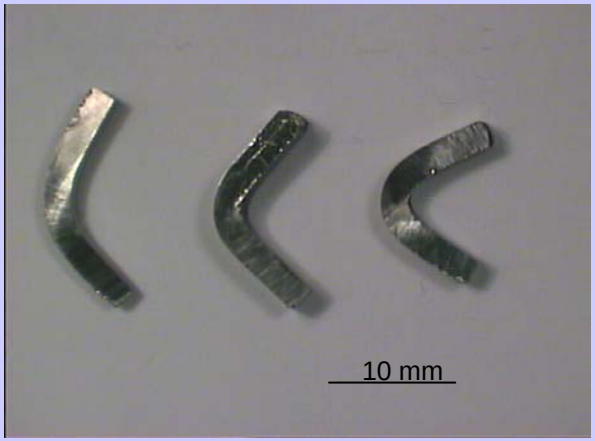
Twisted samples

360º →270º → 180º → 90º

Heat treatment
1380ºC, 1 hour

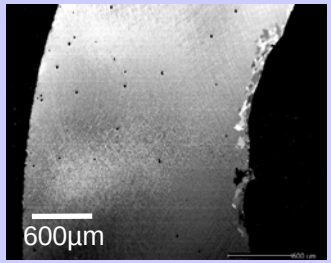
Deformation of Rods Cut From Sheet

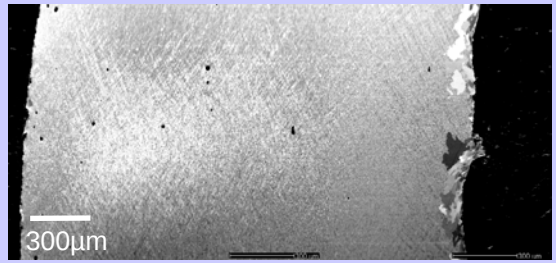
Recrystallisation after deformation



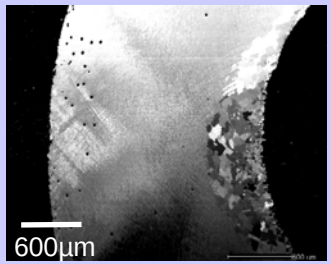
Bending angle

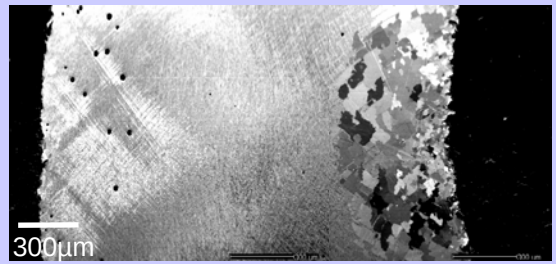
120º



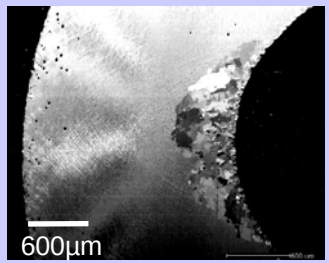


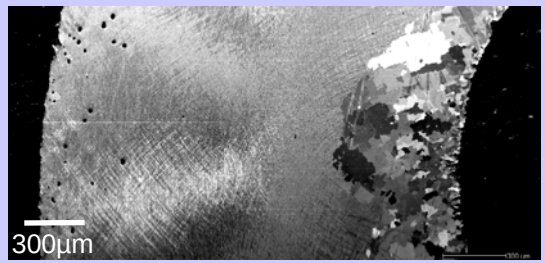
90º





45º





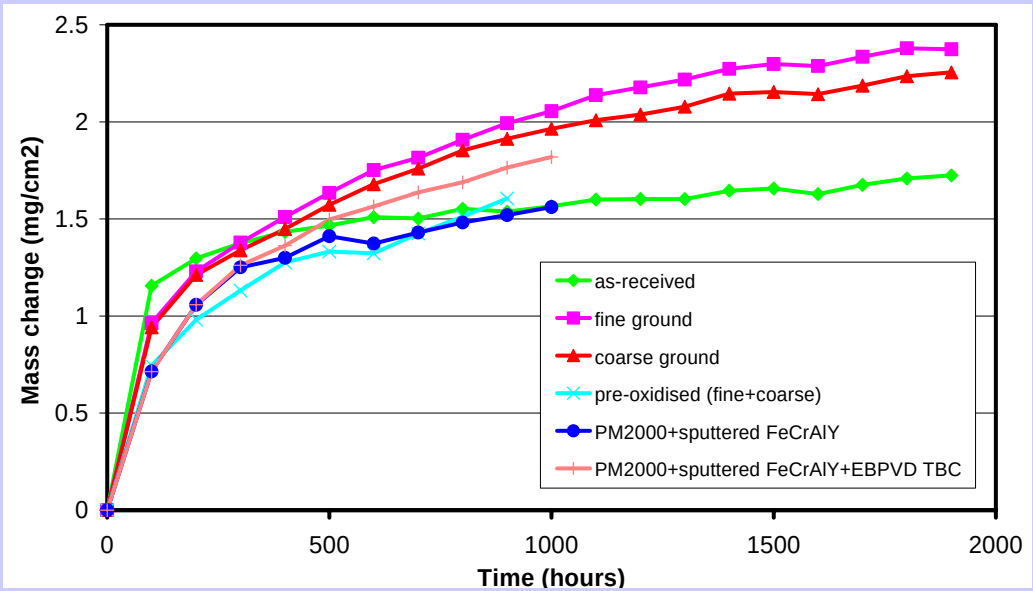
UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

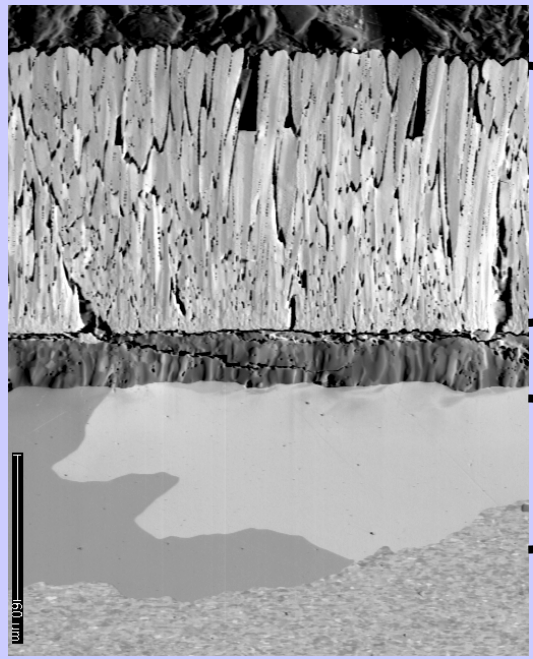
UNIVERSITY OF LIVERPOOL

Coatings on PM2000

Coated and oxidised ODS alloys

PM2000 + sputtered FeCrAlY
+ EBPVD TBC 500h 1200°C

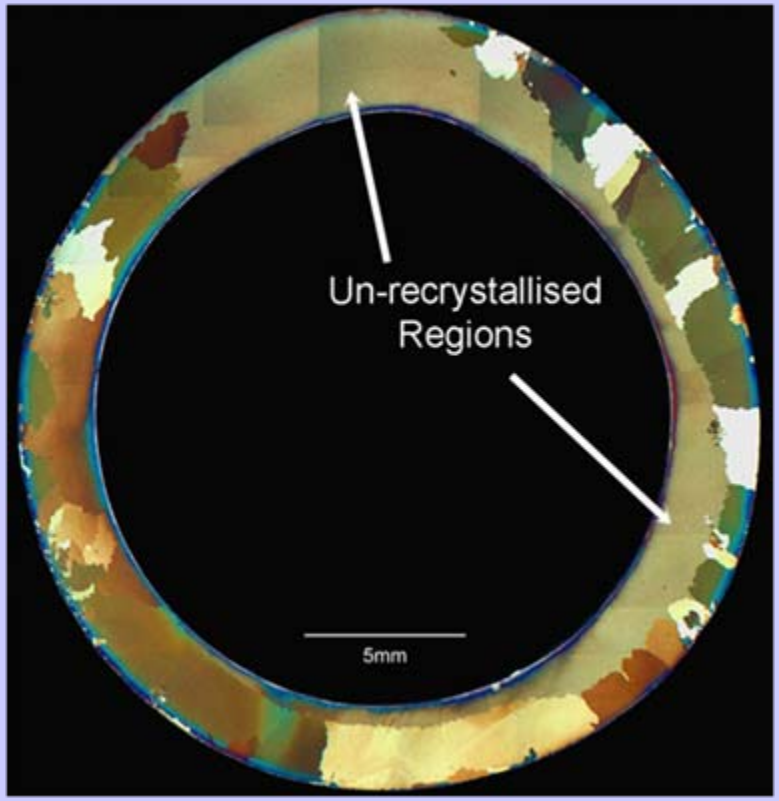




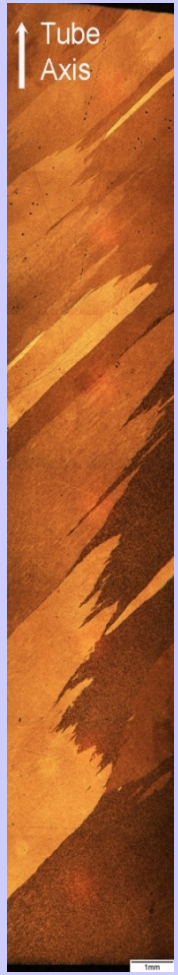
UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

Torsional Deformation

10 mm



Transverse section



Plan section

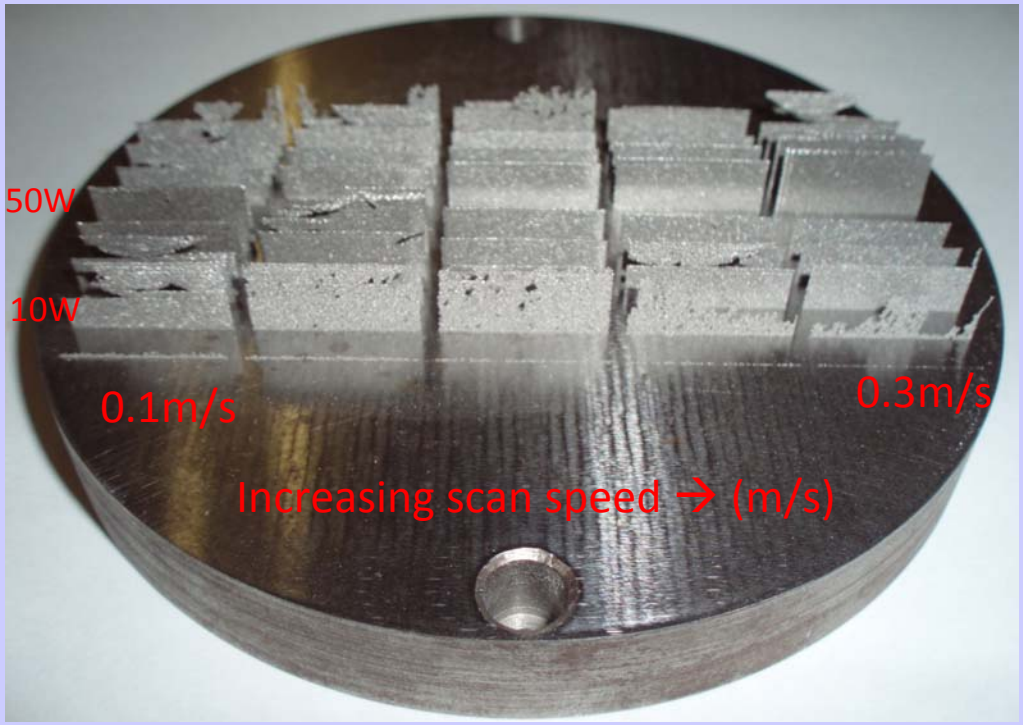
PM2000 tube torsionally deformed
45^0/1010-1025^{0}C + SR 1380^{0}C/1h

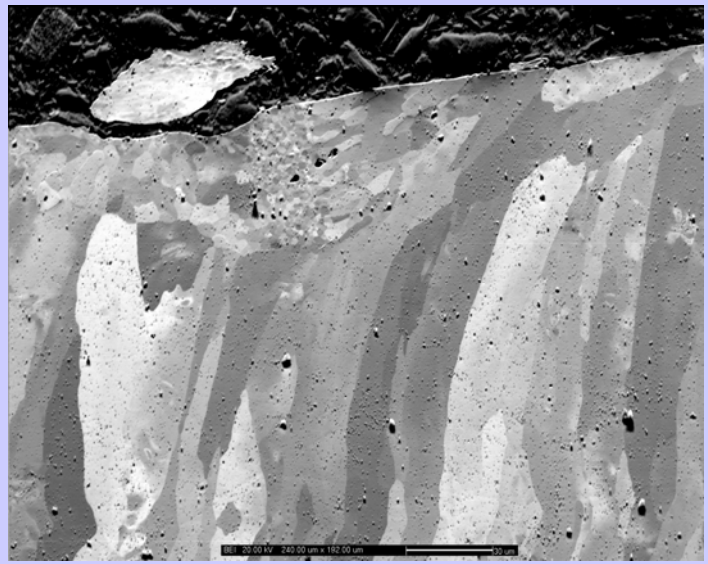
UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

UNIVERSITY OF LIVERPOOL

Selective Laser Melting of PM2000 Powder

Increasing laser power → (W)





UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

Task 8 Key Benefits

- Brought together a wide range of complementary expertise from both countries.
- Good combination of fundamental and applied research producing solutions in an important area.
- Strengthened existing links between ORNL and the University of Liverpool (UK Task Leader spent 3 month sabbatical at ORNL working on ODS alloys)
- Developed much greater understanding of the key problems when using ODS alloys, by pooling knowledge and expertise.
- Developed new solutions to the joining and tailoring of microstructure and coatings on ODS alloys.

23rd Annual Conference on Fossil Energy Materials, Pittsburgh May 2009

UK-US Phase 1 Report

Gordon J Tatlock
University of Liverpool

ODS Alloy Development

UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

Task 8 Phase 2

- Characterisation of new ODM powder and consolidated sheet and tube.
- Secondary recrystallisation trials on sheet and torsionally deformed tubes.
- Friction stir welding of butt joints in new ODM sheet plus secondary recrystallisation and creep testing.
- High resolution electron microscopy to determine sequence of oxide dispersion transformations with time and temperature and link with secondary recrystallisation behaviour.

Task 8 Phase 2

- Production and testing of welded demonstrator component out of new ODM alloy.
- Organise a series of seminars/ workshops to raise industrial awareness of new ODS alloys and their capabilities.

UK – US Collaboration on Fossil Energy Research and Development - Advanced Materials

ODS Alloys

Background

- Need to drive down CO_2 emissions from fossil fuelled power plant by increasing efficiency.

- Need to increase the maximum operating temperature by developing materials with better high temperature capabilities.

- Oxide Dispersion Strengthened (ODS) alloys have superior high temperature creep resistance and oxidation resistance over current alloys.

ODS Alloys

Background

- Two main problems to overcome:

- Joints fabricated by conventional fusion welding techniques have low creep strength at high temperatures;

- Secondary recrystallisation needs to be optimized to produce grain structures where large grains can be custom orientated with respect to the principal hoop stress.

ODS Alloys

Deliverables

- Comprehensive description of all joining techniques applicable to ODS alloys **completed**

- Review of oxidation lifetime data (new) **completed**

- Database of quantitative information on joints applied to ODS alloy sheet and tubing **Joint UK-US report completed**

ODS Alloys

Deliverables

Torsionally orientated grain structures and coatings developed and tested

completed

Report on the influence of metal spinning parameters on sheet ODS alloy microstructures

Replaced by study of dispersoid evolution

completed

Assessment of feasibility/performance of TBCs deposited on ODS alloys without bond coatings

completed