Shear Compaction Processing of Product Forms Directly from ODS Powders

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Fe-Based ODS Alloys: Role and Future Applications

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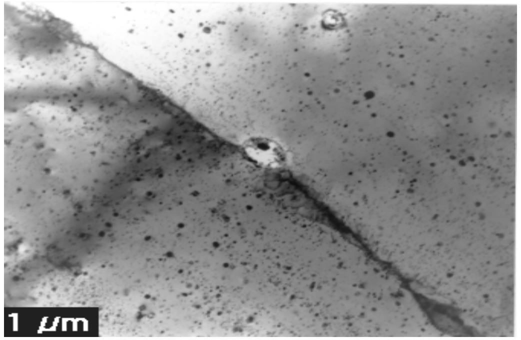
Barriers to Implementation

ODS Alloys: Incorporate a dispersion of nanoscale oxide particles (such as Y_2O_3) in the ferritic matrix to mitigate grain boundary movement and allow greatly improved creep and high temperature strength while maintaining good toughness



MA 956

H. K. D. H. Bhadeshia, Univ. of Cambridge website

Barriers:

- Traditionally produced by powder metallurgy methods that tend to be costly - Commercial viability requires new processing and manufacturing technology
- Unfavorable anisotropic properties can result if processed improperly for the application
- Cannot be welded by melt/solidification processes

Are there alternative process routes that can remove the some of the cost when going from powder to semi-finished product

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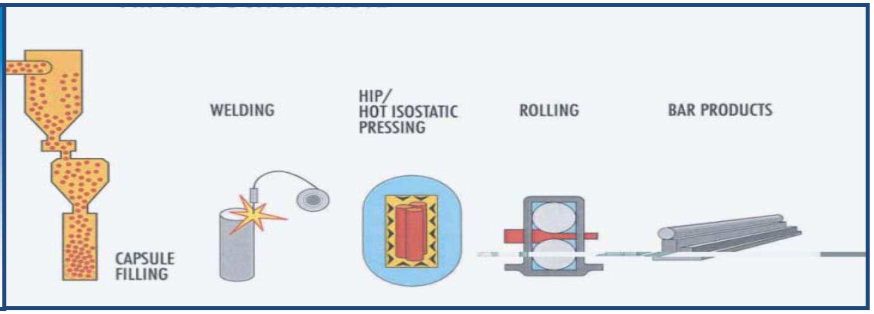
ODS Cost Drivers

- The high cost of ODS alloys and components is driven by:
  - The multistep process of fabrication from powder (melt, milling and mixing of oxide particle, vacuum canning, densification CIP/HIP or HIP, decanning, and processing to semi-finished form (extrusion or rolling), machine or roll to tube, heat treat for microstructure
  - Batch Process
  - Machining operations produce significant waste. Many ODS materials produced in the past for pipe or clad applications are extruded and then gun drilled.



Cost estimates for current processing route

Front End (Powder processing): $37.50/lb to $100.00/lb
Back End (Consolidation): $80.00/lb

Traditional ODS materials prepared by MA routes can be up to $120.00/lb to $180.00/lb and wrought, semi-finished products can be $200 to $500 per lb

For example: Gas atomized Kanthal can be $80.00/lb in plate form.

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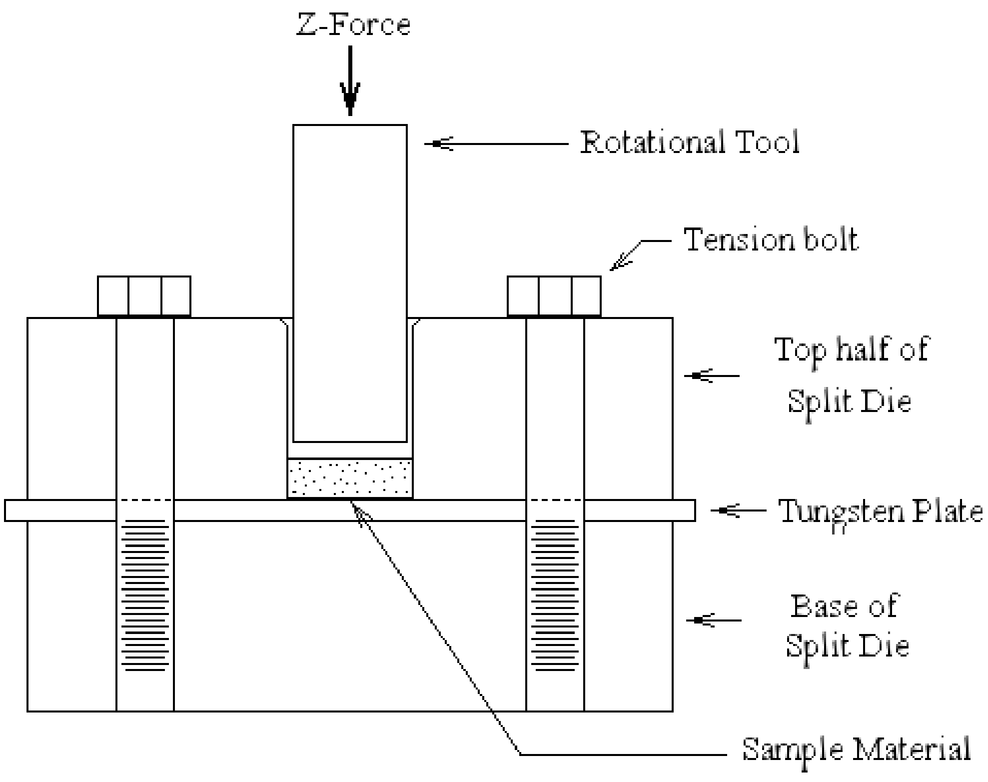
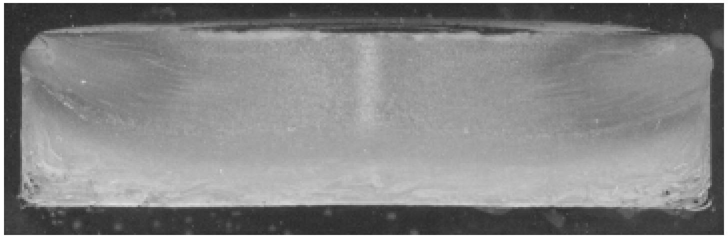
Shear Consolidation Process

- Powder is loaded directly into cylindrical hole in die
- Spinning cylindrical tool is inserted in top half of split die and downward axial force is applied while spinning tool
- Heat is generated initially by friction between particles, but as the powder consolidates the heat is generated by plastic work energy dissipation.
- Fully dense compacts result





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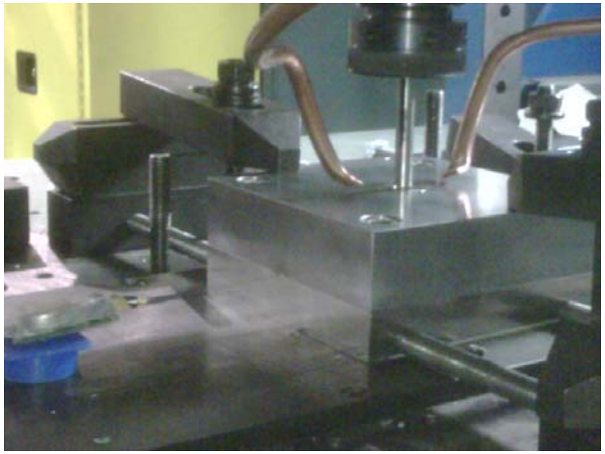
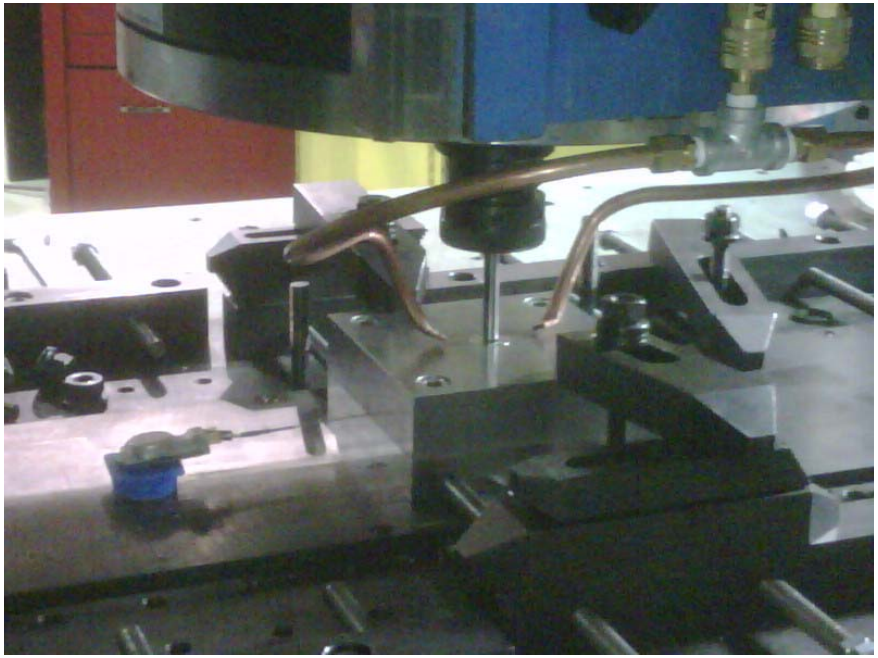
Objective

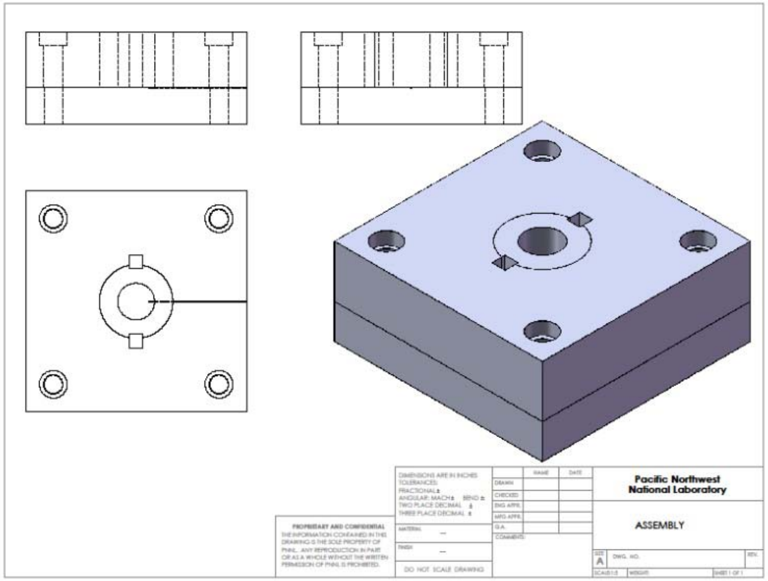
- Demonstrate a low-cost method of fabricating wrought ODS ferritic billet, rod, and tube directly from oxide-doped stainless steel powder, thereby eliminating costly, batch-based MA process, and can/HIP/extrude densification step

- Approach
  - We will utilize a thermomechanical process that directly consolidates a mechanically alloyed (MA), or preferably a lower cost MA-precursor, powder under extensive imposed shear strains.
  - Preliminary work suggest that powder can be directly consolidated into billet. rod or tube geometry potentially on a continuous basis without intermediate steps such as powder canning, HIPing, and rolling or extrusion.
  - In evaluating the efficacy of the process, our initial focus will be to:
    - (1) verify that high density (i.e. pore-free) rod or tube stock can be fabricated by this approach,
    - (2) demonstrate that the oxide dispersoids are nanoscale (i.e. on the order of 10 – 30nm in size) and uniformly distributed throughout the steel matrix
    - (3) the mechanical properties (creep and strength at temperature) approximate those of the current ODS alloys being evaluated for FE applications

SC Die set on bed of FSW machine at PNNL







- Die lower half and inner can: Ni 718
- Die upper half: H13
- Spinning tool: 1" diam W25Re
- RT die shown, but version with cartridge heaters is in plans
- Argon cover shield used, Rube Goldberg version shown in pictures

Pictures show small SiN rod but ODS work is done with 1 inch diam. W-RE rod

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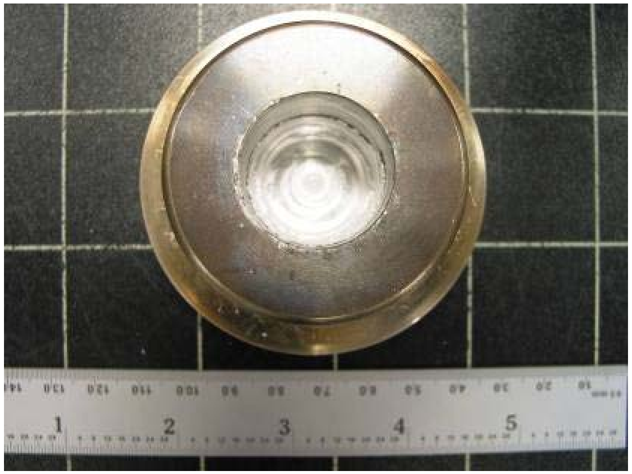
Extruding Aluminum Rod from machining chips

Consolidation/extrusion Chamber



Extrusion die: H13

Extruded Rod

(a)

(b)

(c)

Solid Al rod fabricated directly from powder via a friction stir rod extrusion process. 2050 and 2195 rod extruded at: (a) 150, (b) 200, and (c) 250 rpm rotational speed.

2195 chips from milling operation

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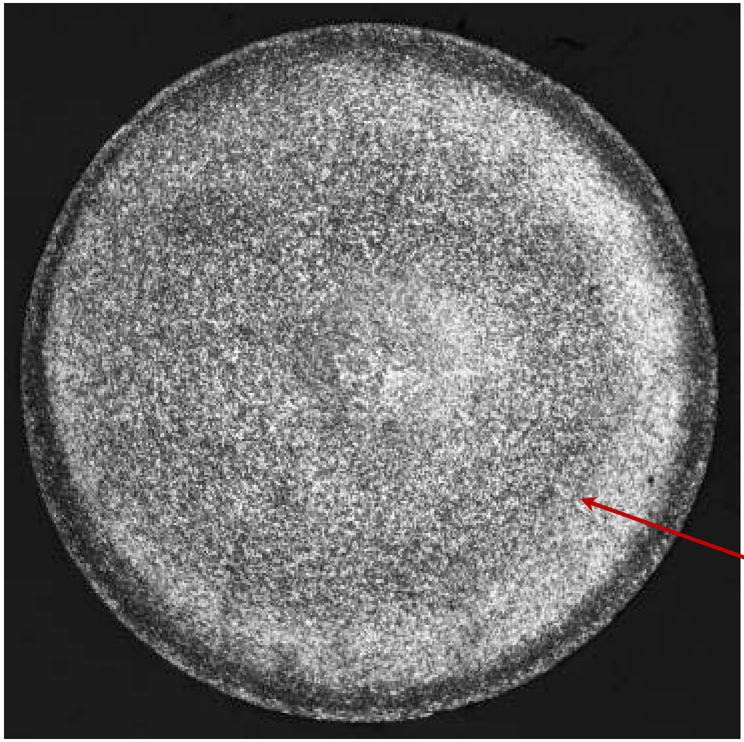
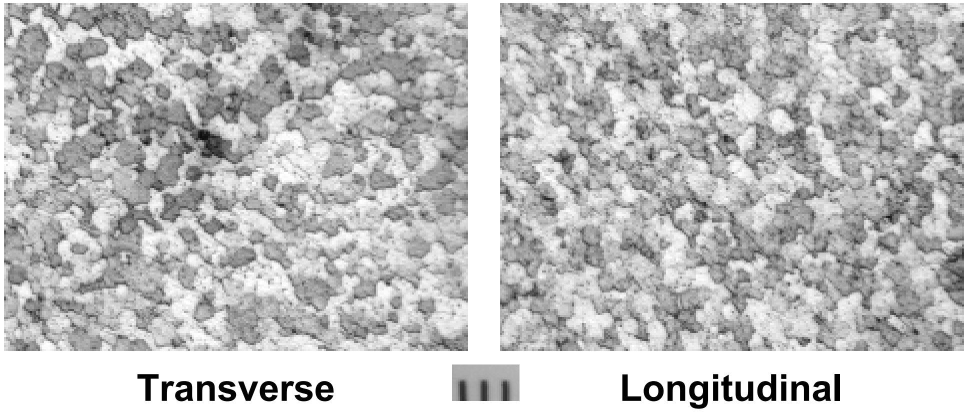
Micro-meso structures of Friction Extruded Wire from USC





Transverse **20 μm** **Longitudinal**

(micrographs from Reynolds, Univ. of South Carolina)

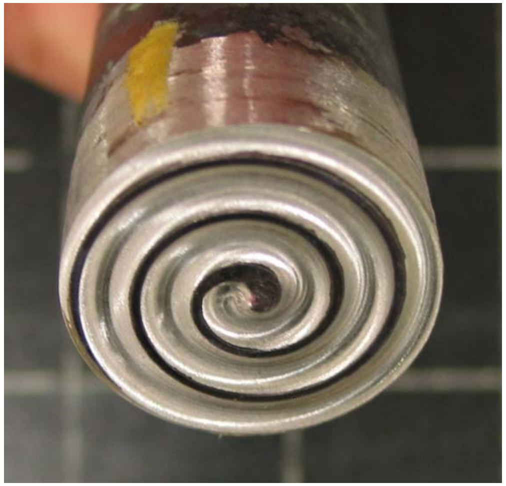
2195 wire cross section

- **Fully consolidated cross sections exhibit equiaxed grain structure, not elongated in extrusion directions**
- **This may have very important implications for microstructureal control during heat treatment**

ODS Powder work (MA 956 powder form Special Metals)

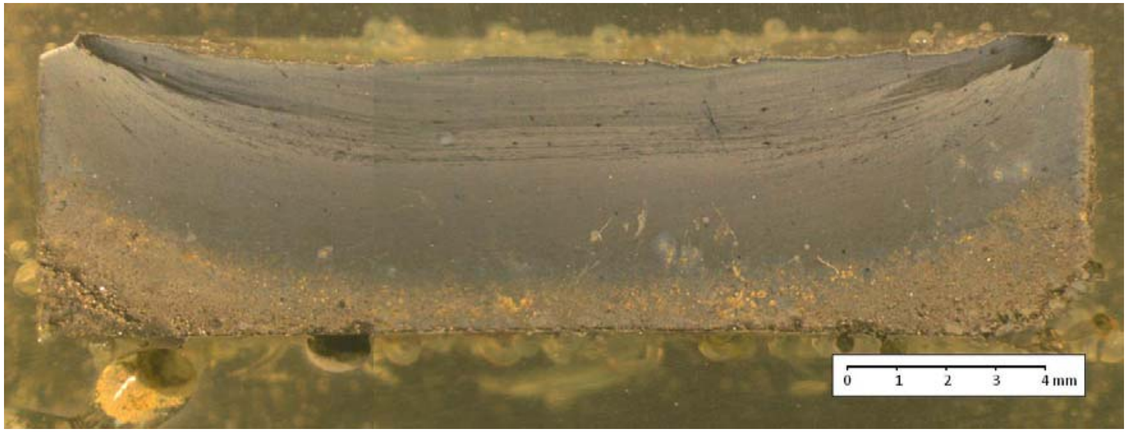
Initial process responses and scrolled die

No	RPM	Z force, lbs	Time, sec	Torque, N-m	Power, W	Work (kJ)	Tool
1st	500	5000	54	101	5355	291	Smooth
3416-1	500	5000	94	86	4386	411	Scroll
3416-2	500	5000	146	80	4213	614	Scroll
3417	300	10000	121	139	4382	528	Scroll

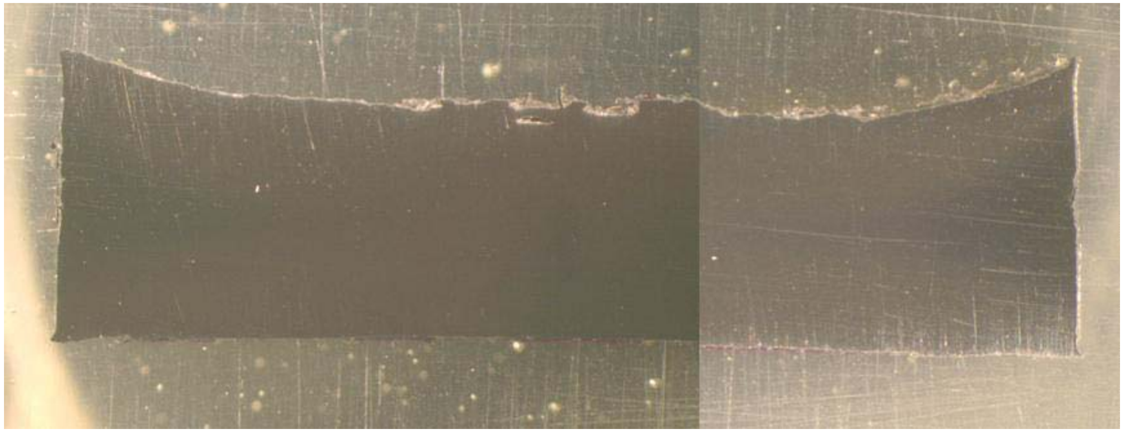


- Design of Experiment study of the effects of scroll variables underway at USC (NASA funding)
- Small seed efforts on ODS consolidation underway at PNNL/USC (NE funding)

Proof of concept trials



500 rpm 5000 lbs



300 rpm 10000 lbs

- Main process variables:
  - Torque/power
  - Extrusion rate
  - Plunger Rod face design
  - Extrusion force

Very good densification of MA956

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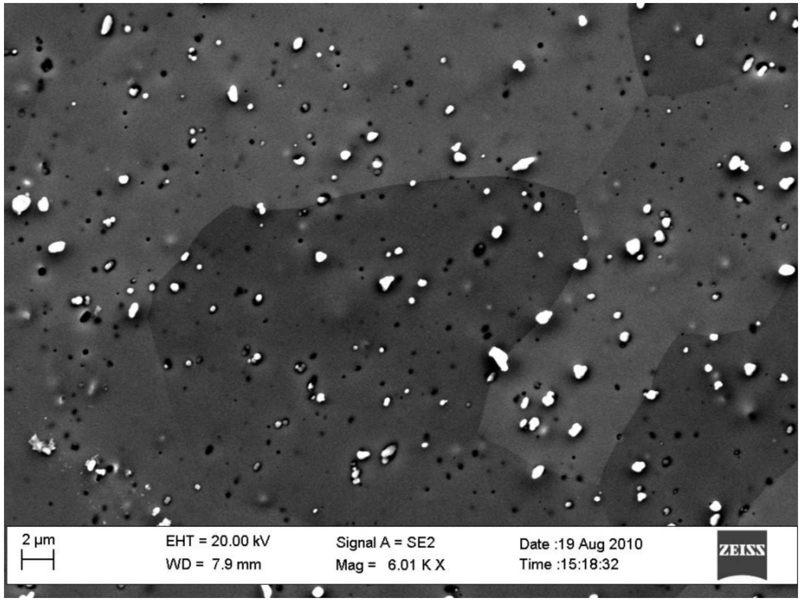
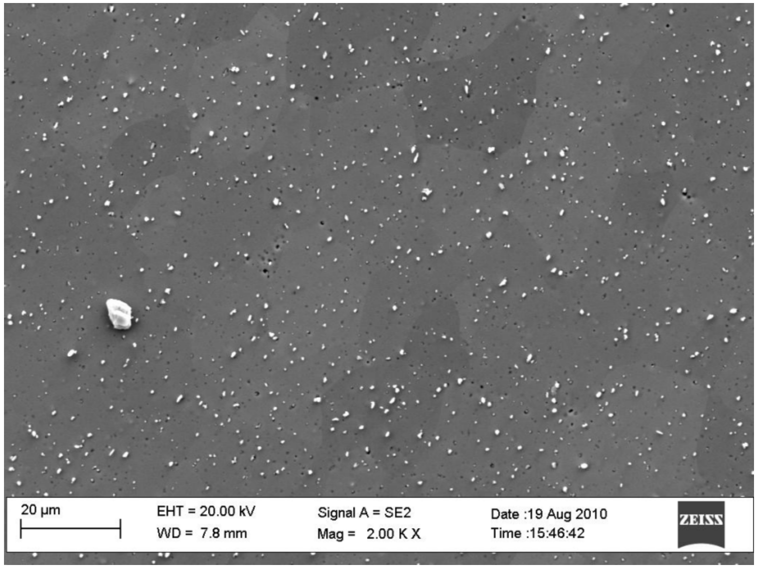
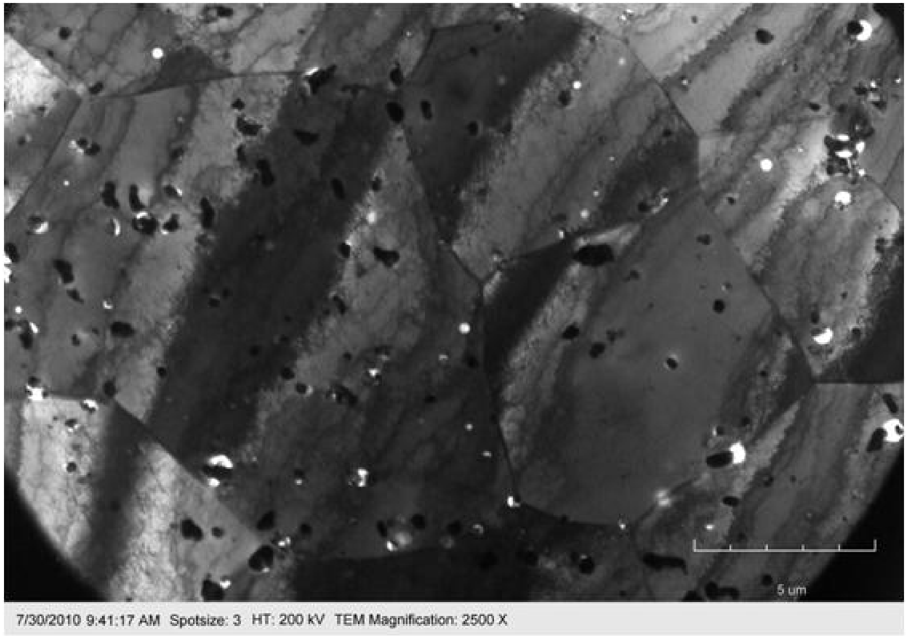
Microstructure of MA 956 Compacts





- Homogeneous particle distribution of coarse oxides
- Grain size quite variable across compact



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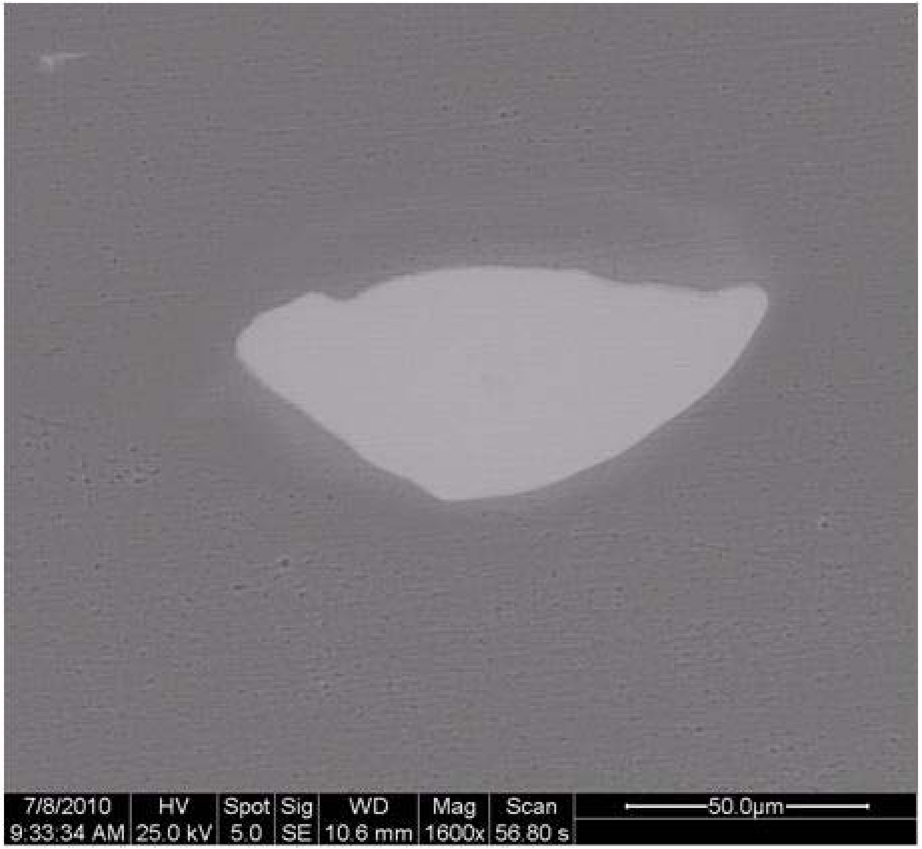
Tool wear from W25Re plunger rod



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Potential Applications and Benefits

- Ability to produce product forms directly from powder, eliminating numerous /costly processing steps (e.g. mechanical alloying, canning, HIPing, extrusion, etc.
  - Application to near-net shape processes (Rod or plate? Or shape?)
  - Application to tubing and piping (back extrude tube around plunger)
  - Potentially continuous process
- Process has the potential to produce appropriate microstructures
  - Process can create equiaxed microstructure, Heat treat studies pending
  - Process also has the potential to break up stringers allowing for reduced roll processing and reduction in probability of defects due to stringers
- Ability to process novel alloy compositions and microstructures without melt solidification steps - critical to ODS alloys and other non-equilibrium systems

Future and Ongoing work

- We have been working a collaborative project with USC to do feasibility work under NE FCRD (ODS Fuel Clad application)
- Feasibility trials are successful
- Future Work
  - Die design optimization
    - Scroll depth and pitch
    - Exit hole design
    - Coatings or material (friction coefficient)?
  - Scale up issues
    - Length
    - Diameter (also scale down)
    - Consolidation of entire charge required before extrusion initiates?
    - "Billet chamber" pre-heating?
  - Mechanical properties of the rod or tube
  - Feasibility of using low cost un-alloyed powders
  - Feasibility of using Ivar Anderson's oxidized flame spray powders