Fatigue Evaluation of Novel HVOF Spray Coated Al-based Plain Bearing Alloys

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Sponsored by :

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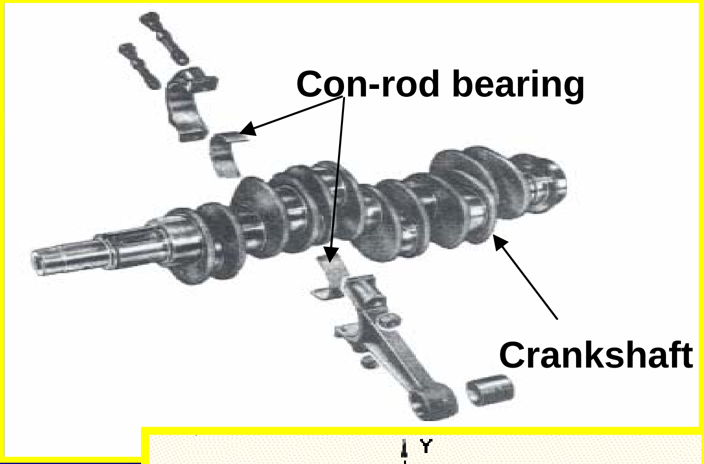
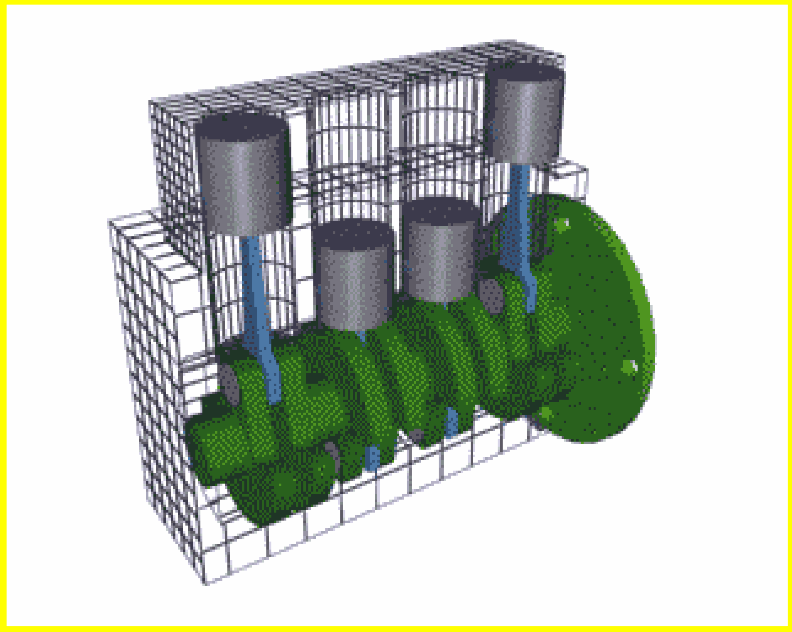
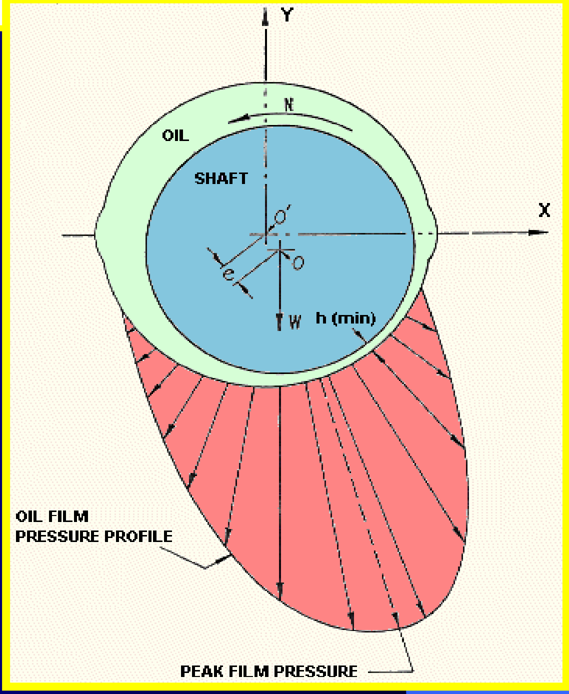
Introduction and Objective

Introduction:

- Plain bearings in automotive engines provide relative motion between the crankshaft, the engine block and the connecting rods
- The fatigue behaviour of automotive plain journal bearings whilst in service is dependent on many factors.
- Bearings experience variable loading via the hydrodynamic oil layer
- These loads are both discontinuous and rapidly changing over the bearing surface
- This loading, coupled with a multi-layer and multi-phase material system leads to complex fatigue behaviour.







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  - These loads are both discontinuous and rapidly changing over the bearing surface
  - This loading, coupled with a multi-layer and multi-phase material system leads to complex fatigue behaviour.

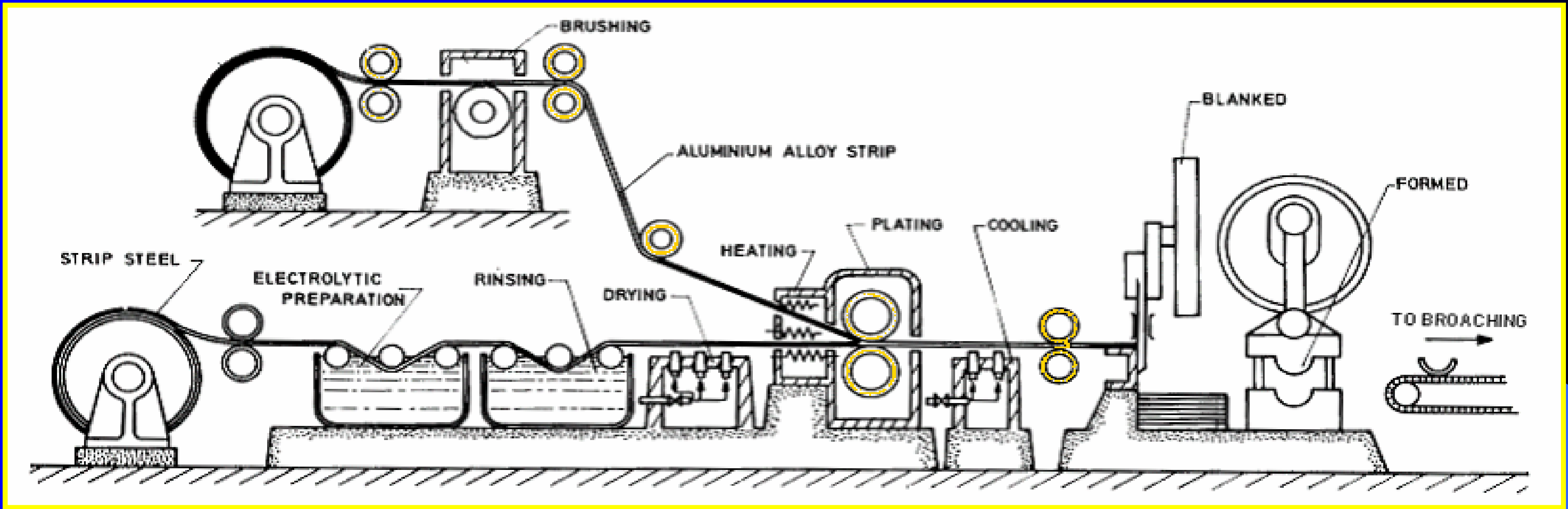
- Although fatigue failure of bearings is not observed in service, the current trends of increasing demand in automotive engine power imply that new bearing materials must be designed to provide the longest possible operating life at these higher loads.

Objective:

- **To characterise the fatigue performance of multi-phase plain bearing alloys, and optimise design of new bearing materials.**
  - **Current analysis focuses on the Al-Sn system of plain bearings**

Conventional Manufacture of Plain Bearings

- Roll bonding (RB) of cast Al alloy sheets onto steel backings:

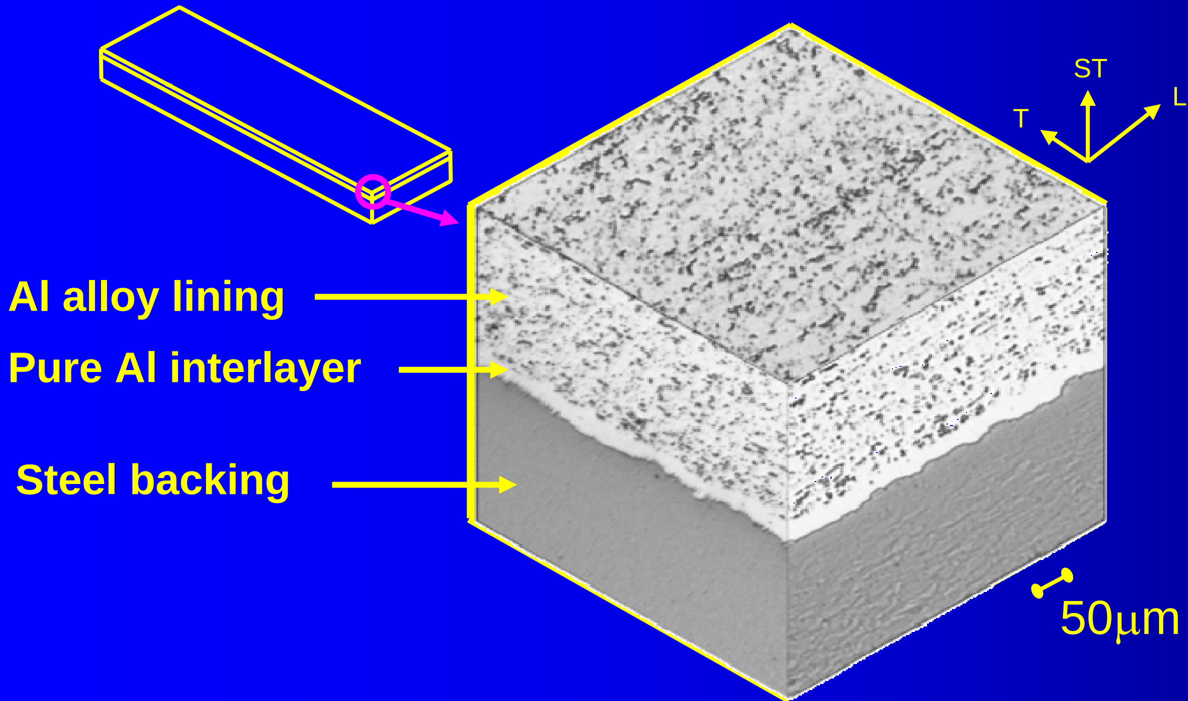


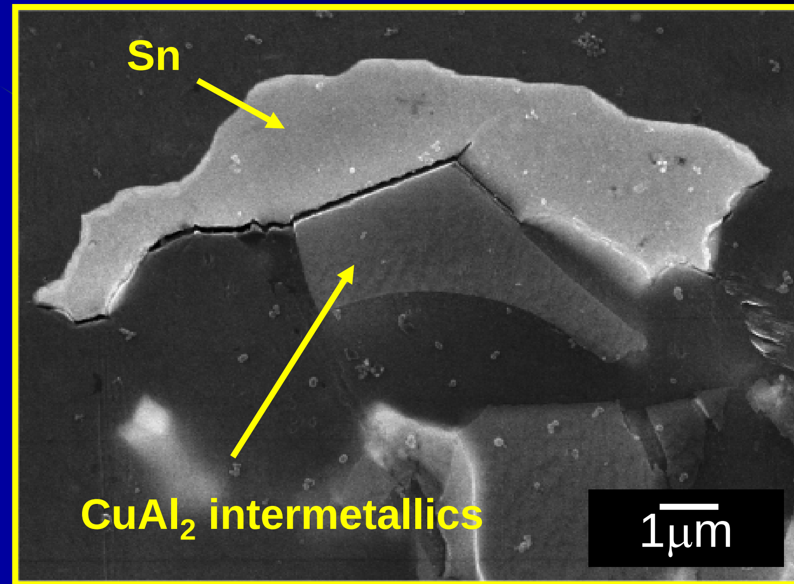
- Processing route involves continuous casting of Al alloy and then homogenising of billet prior to cladding of alloy with pure Al foil. Several rolling and annealing operations serve to reduce overall material thickness.

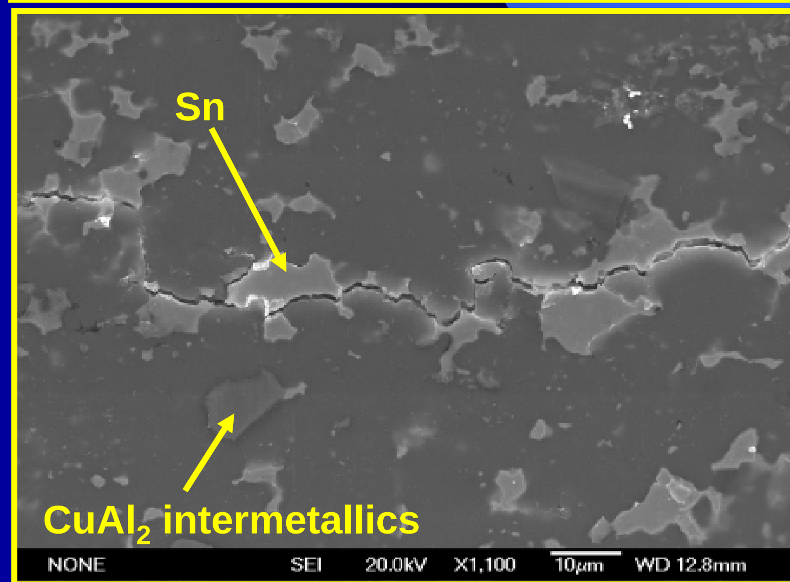
- Al alloy is then bonded to the steel backing and undergoes more rolling operations before being formed into semi-circular tri-layered plain bearings.

Fatigue Failure in RB Plain Bearings

- Multi-layered architecture and multi-phase microstructure characterised.



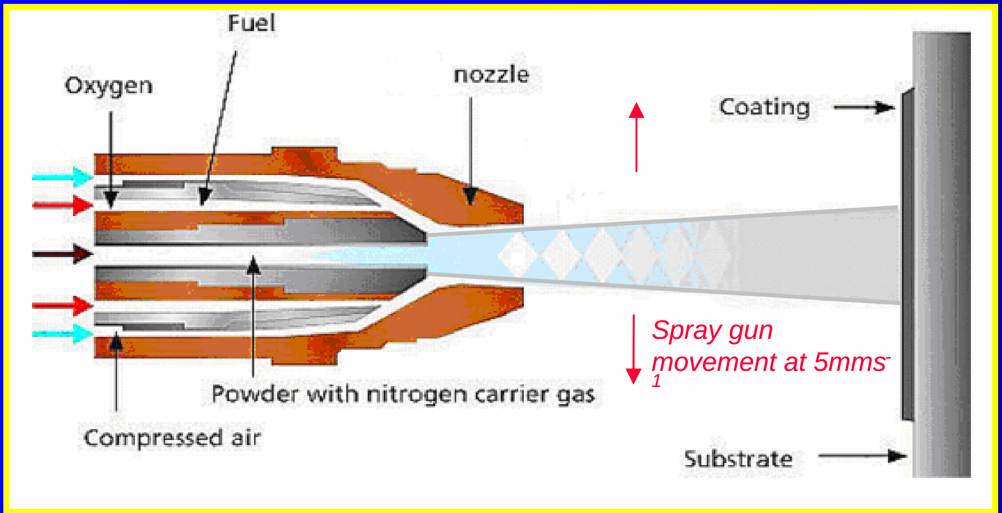


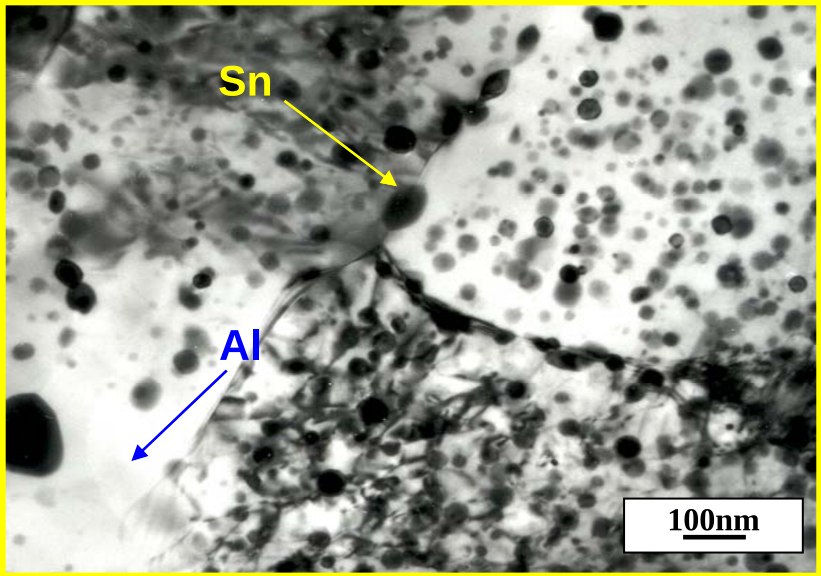


- Research at Southampton has shown that large secondary particles act as preferential fatigue initiation sites and propagating cracks seek out secondary phases (Sn);
- Hence development of more fine -scaled microstructures likely to be beneficial
- Collaboration with Nottingham University of HVOF and HVOLF spray bonding approaches.

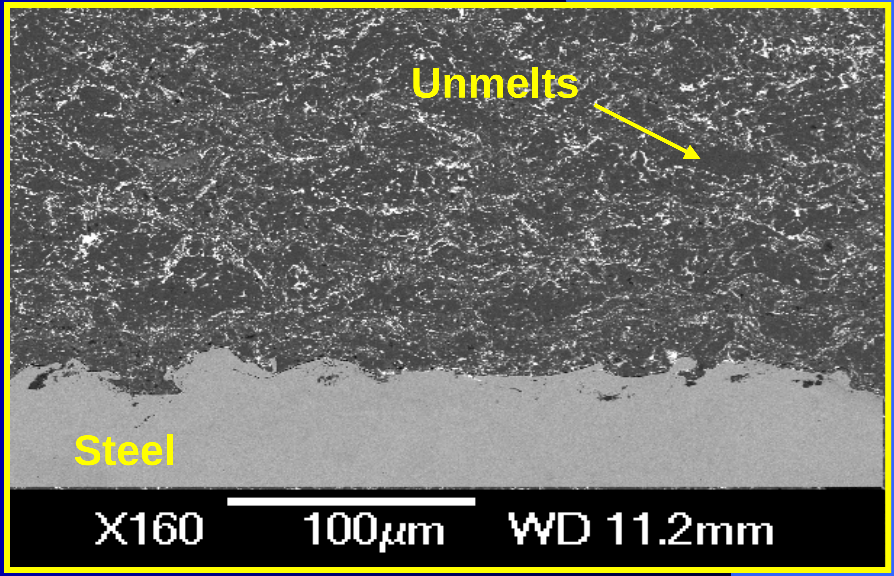
Manufacture of HVOF Plain Bearings

- HVOLF process - direct spraying onto flat strip to *close-to* required thickness



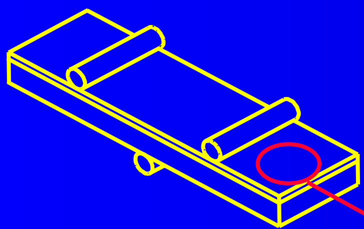


- Research at Nottingham has shown that spray coating microstructure will contain very fine (nano scale) secondary particles of Sn, though some heterogeneity in microstructure exists;
  - E.g. unmelts, coarser Sn regions around unmelts, some pores *et cetera*.

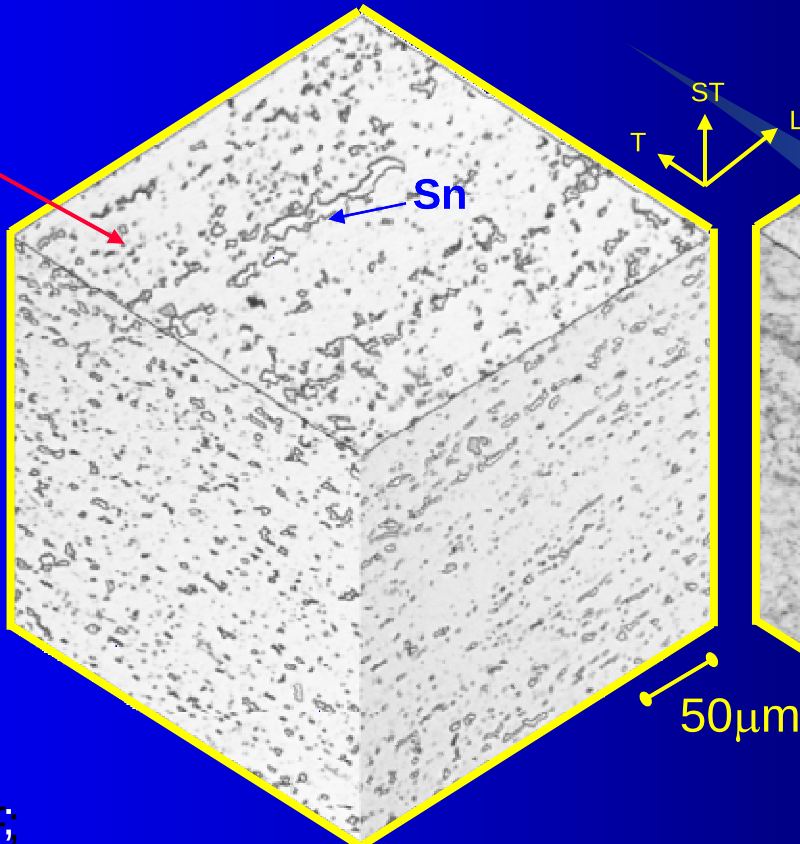


- Fatigue evaluation and comparison between the differing microstructures of the RB lining and HVOF coating is thus required.

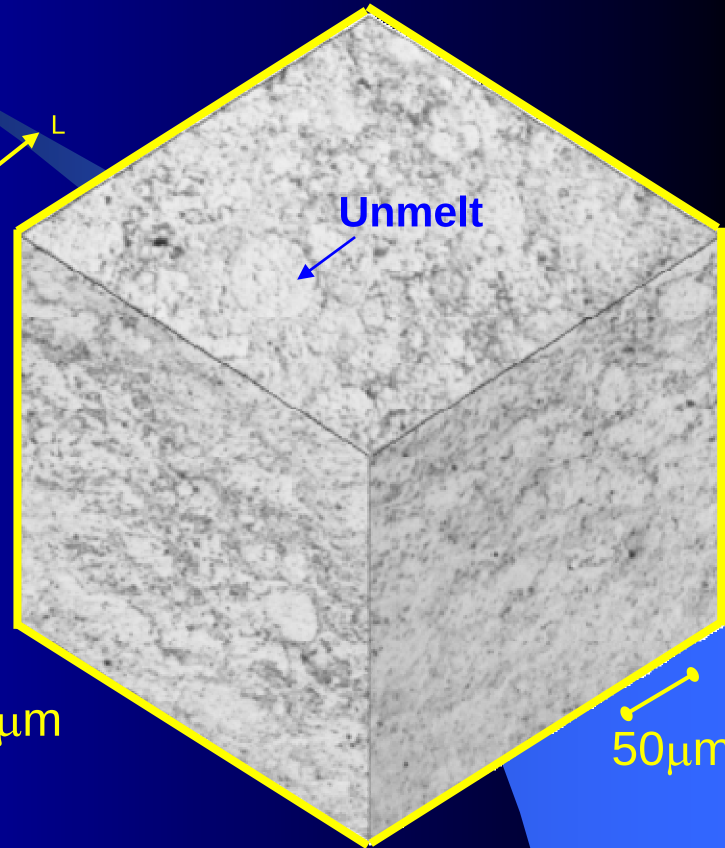
Microstructure of plain bearing specimens



Roll-bonded (AS16)



Spray formed HVOF



Compositions:

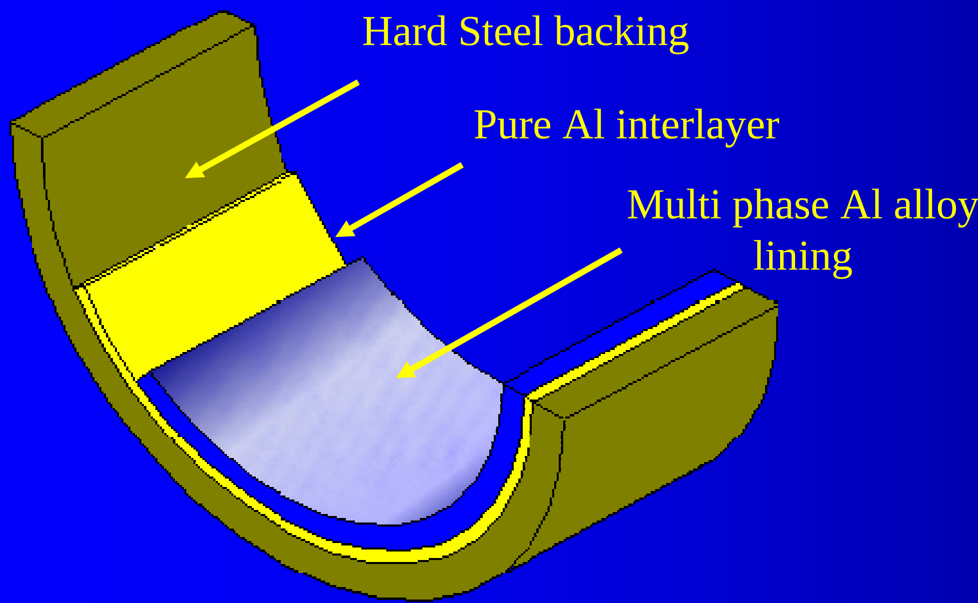
- For both RB and HVOF;
  Al-20wt%Sn-1wt%Cu. HVOF annealed at 300^{o}C in air for 1 hr.
- For initiation and growth analysis, microstructure characterised extensively

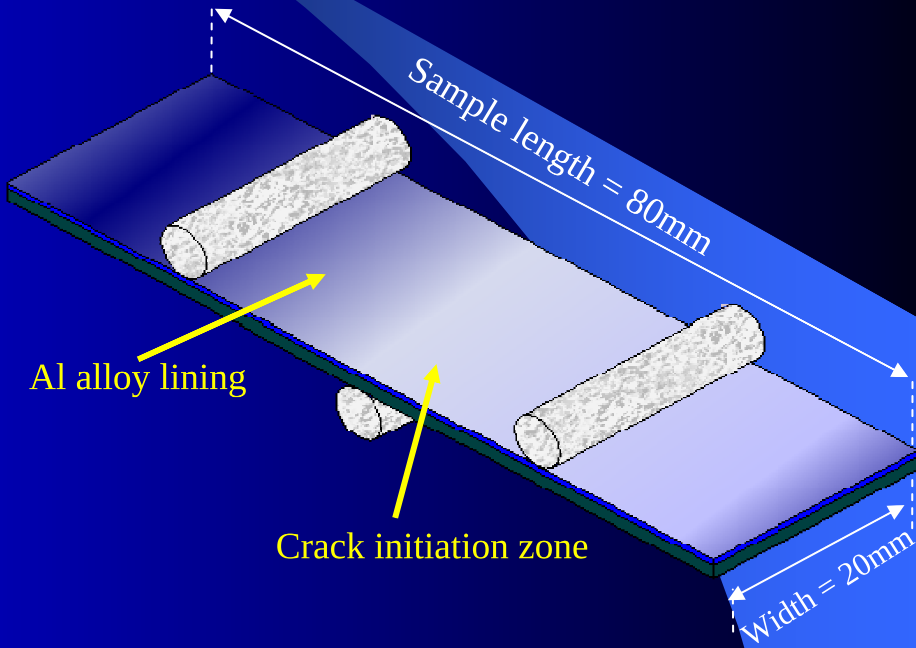
Microstructure:

- Reticular Sn distribution (5-30μm) apparent in RB lining
- HVOF coating shows evidence of unmelts

Specimen Geometry and Fatigue Test set-up

- Polished flat-strip specimens tested in 3-point bend under load control to generate lifetime data (deflection criteria for failure linked to crack propagation into steel).
- Acetate replicas taken of fatigued flat-strips to monitor crack growth



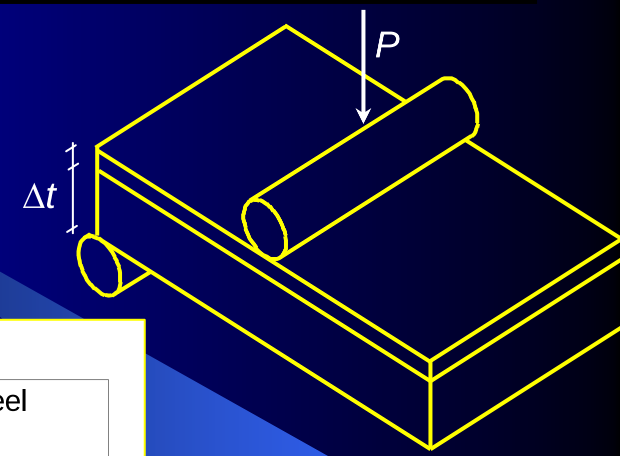


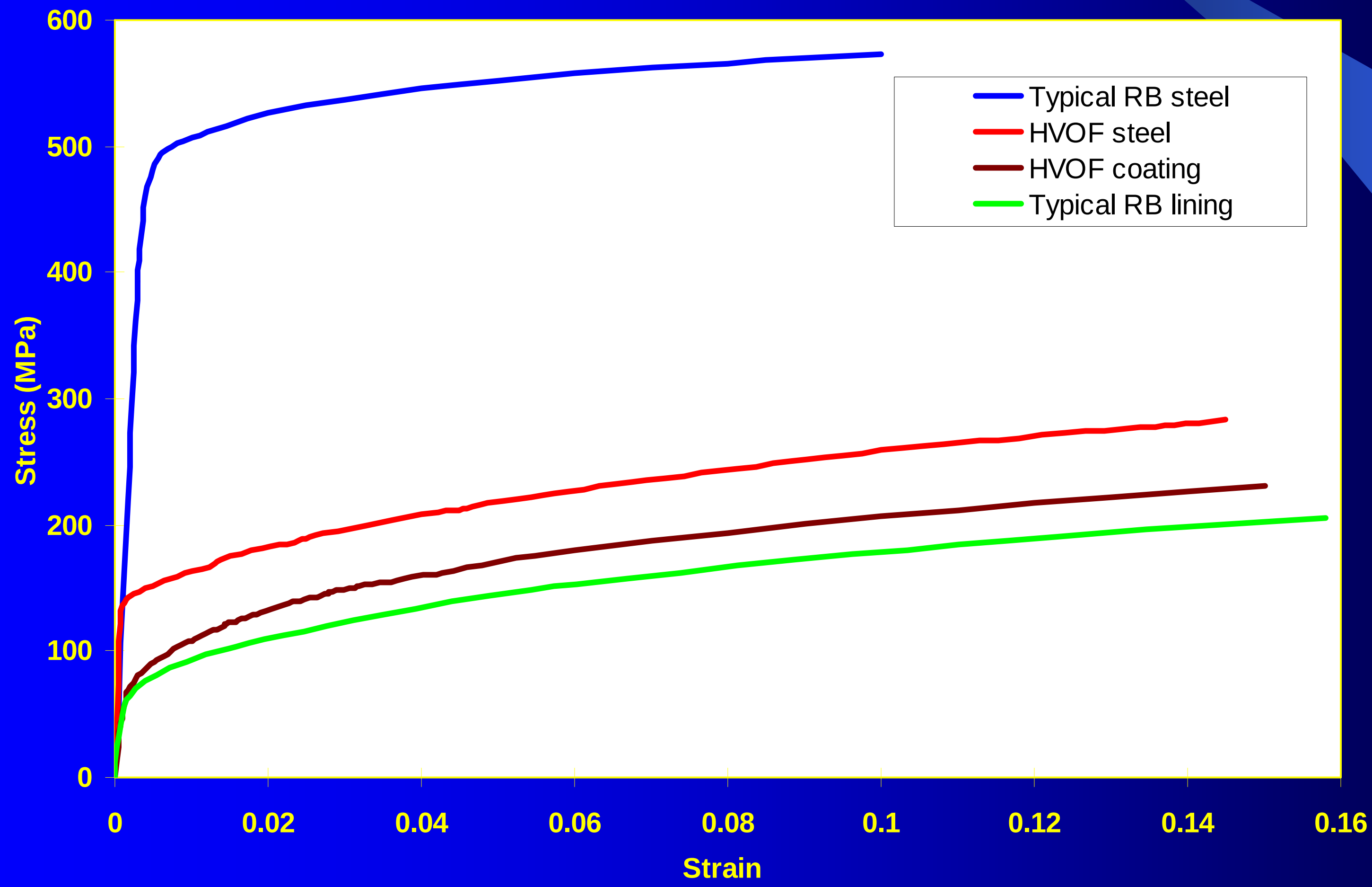
- Vickers micro-hardness indentation and Tensile testing of individual layers to obtain correct $\sigma-\varepsilon$ data $\rightarrow$ Allows better characterisation of fatigue performance.

FE model objectives and considerations

Modelling considerations

- **Materials properties differences**
- **Thickness of steel/linings**
- **Constraint issues**

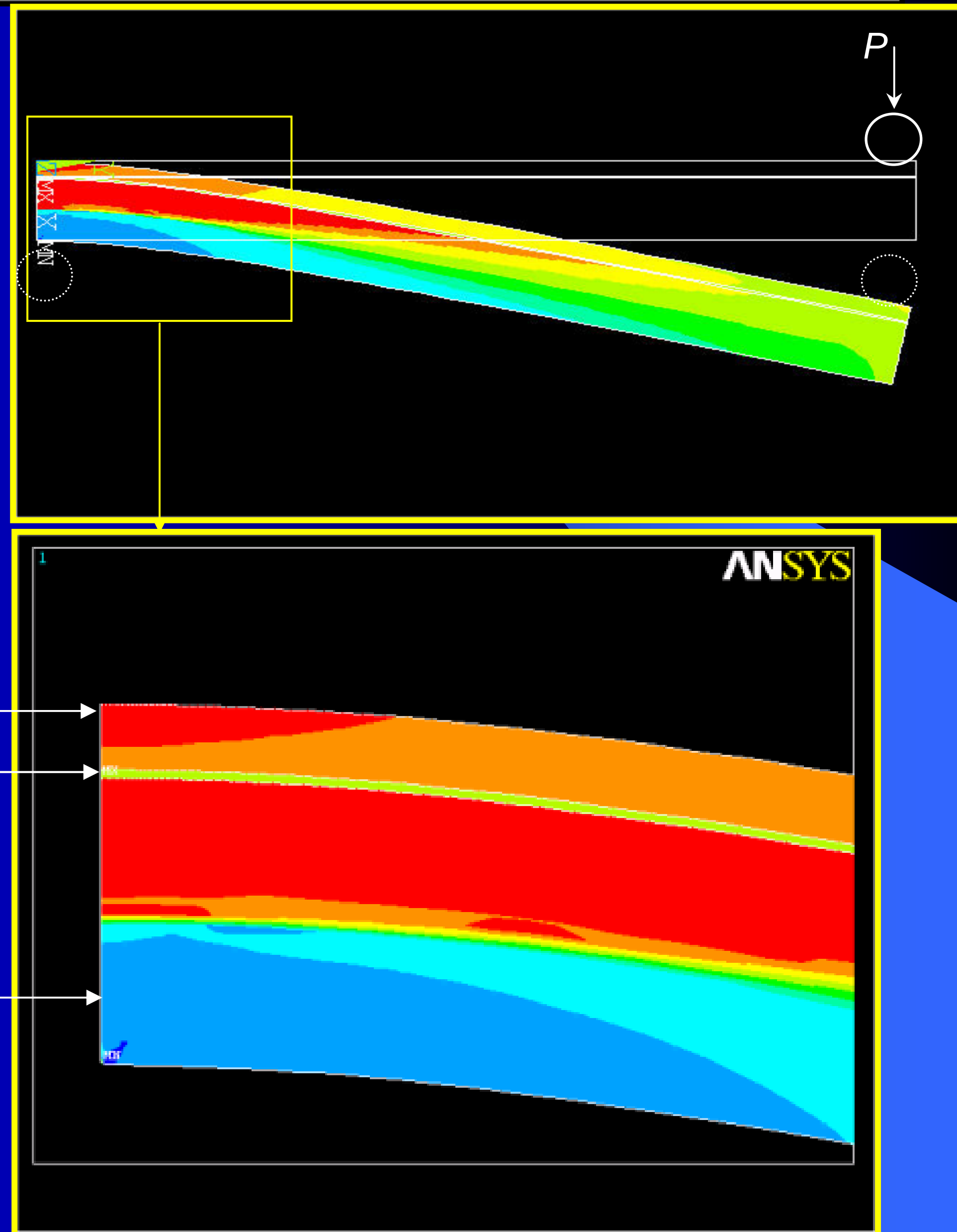




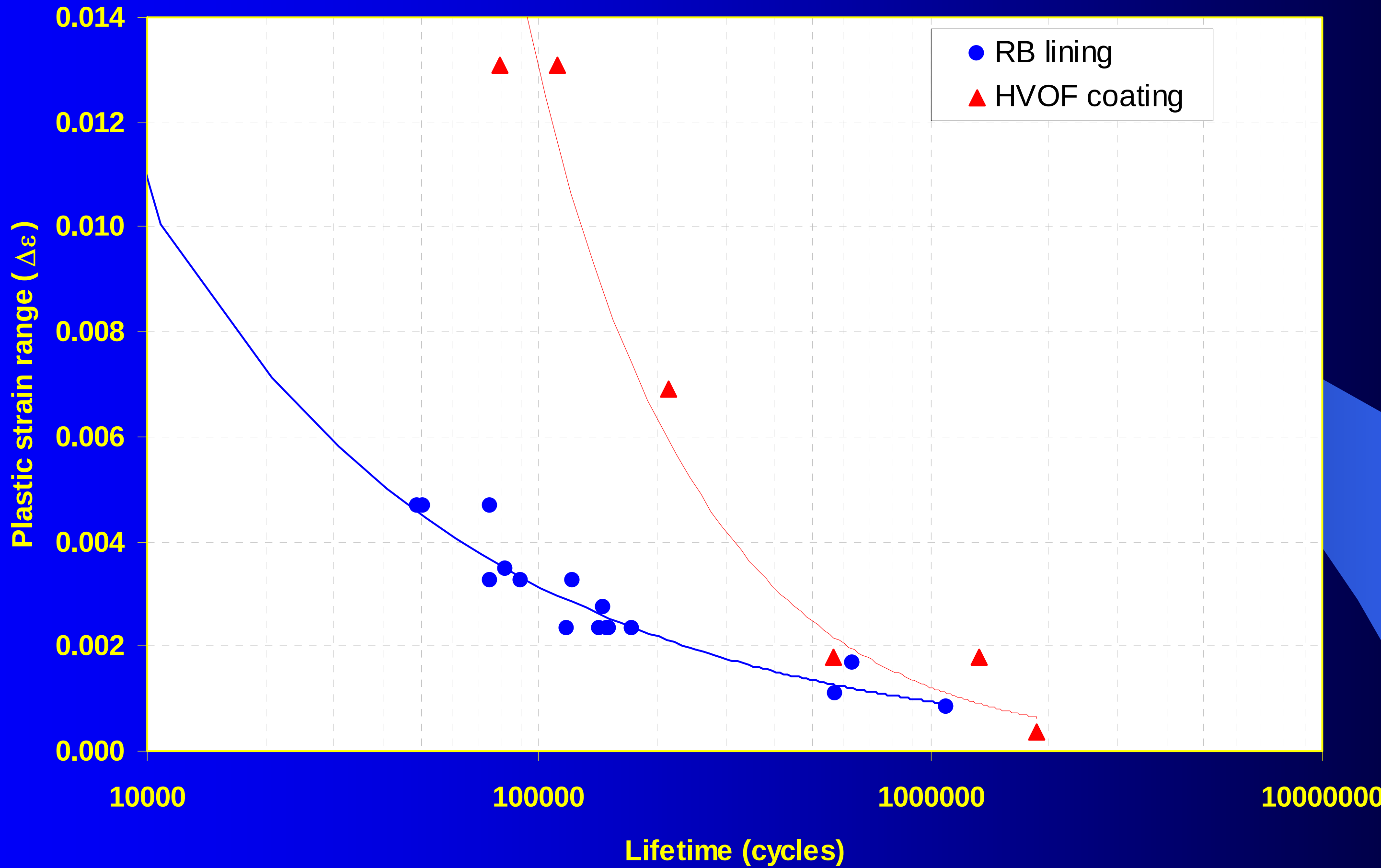
FE model objectives and considerations

Stress-Strain calculations:

- ANSYS FE models to calculate evolved $\sigma-\varepsilon$ on top-surface of a loaded flat-strip lining.
- Evolved stresses & strains vary considerably from layer to layer
- FE model assumes perfect interface bonding



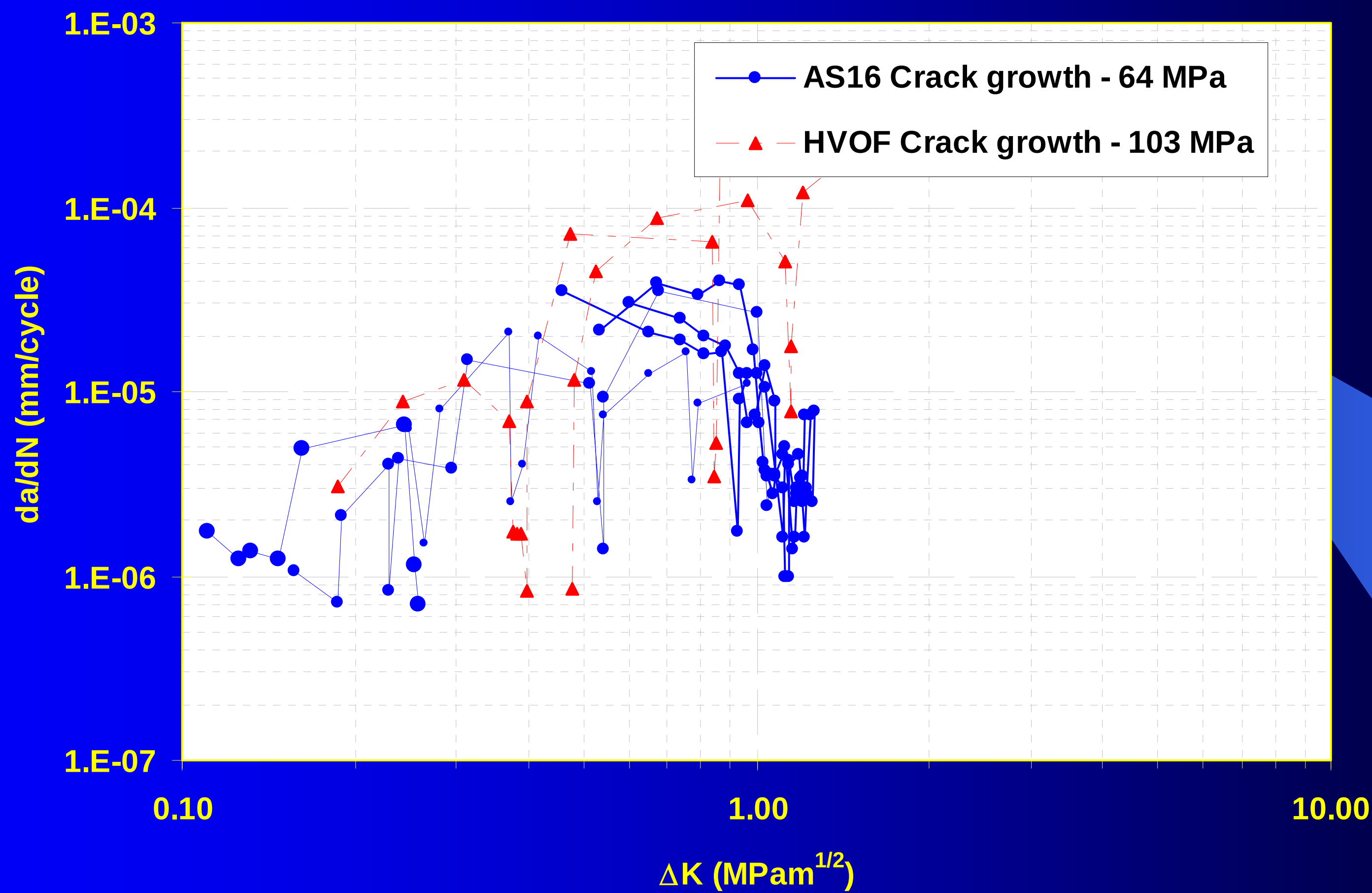
Fatigue lifetime of RB vs. HVOF linings



Fatigue lifetime performance:

- In terms of estimated Δε HVOF coating shows apparent improved fatigue performance at high Δε and comparable behaviour at the lower Δε
- In terms of applied load, performance of RB is improved due to increased steel constraint

Fatigue crack growth in RB vs. HVOF linings



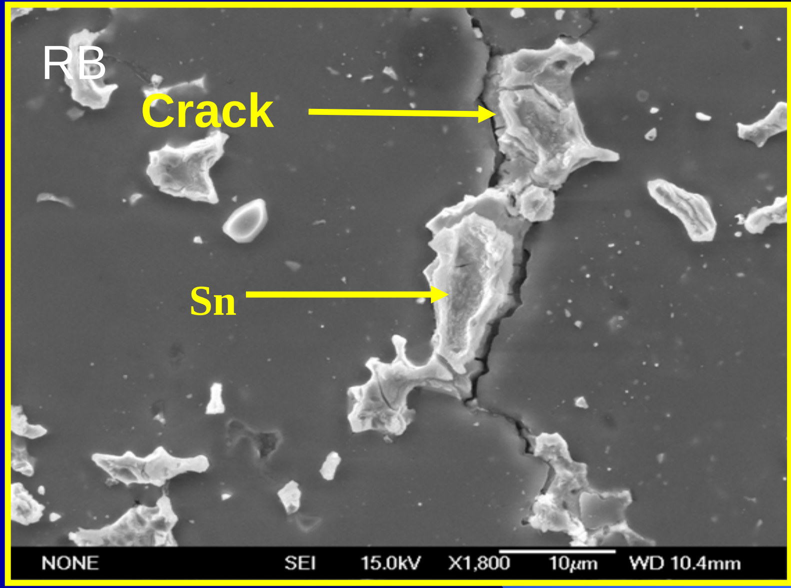
Crack growth rates:

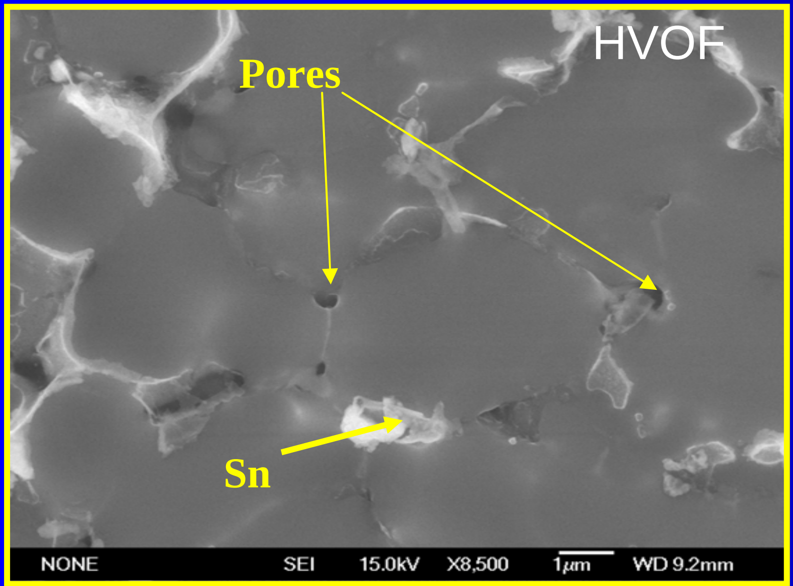
- Crack growth resistance in the two linings comparable although slightly faster rates in HVOF - estimated local stress levels in the lining very different due to constraint differences
- Possible lesser microstructural dependence in HVOF coating

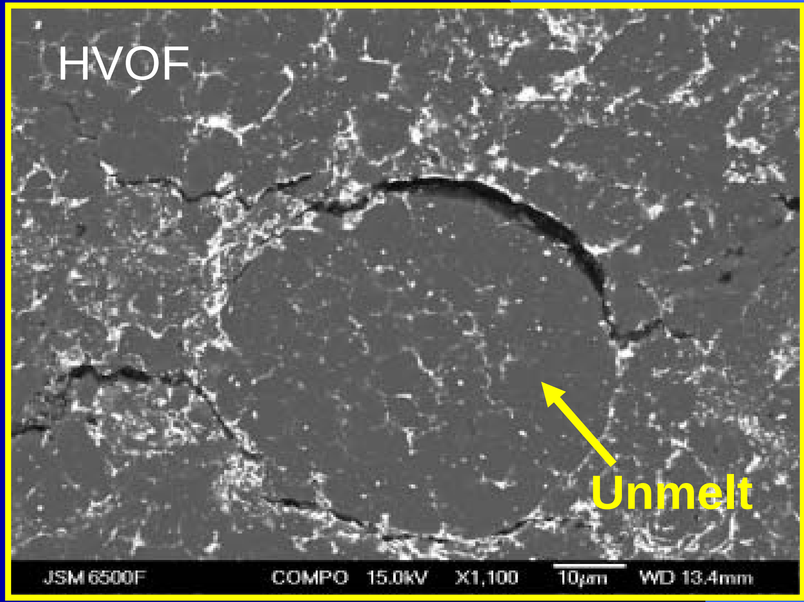
Fatigue crack initiation: RB vs. HVOF

- Multiple initiation occurring at Sn/matrix interface in RB alloys

- Sn/unmelt interface work as crack initiation sites in HVOF system
  - More Sn at unmelt boundary- Indication of weaker interface.
- Pores also seen to aid in initiation

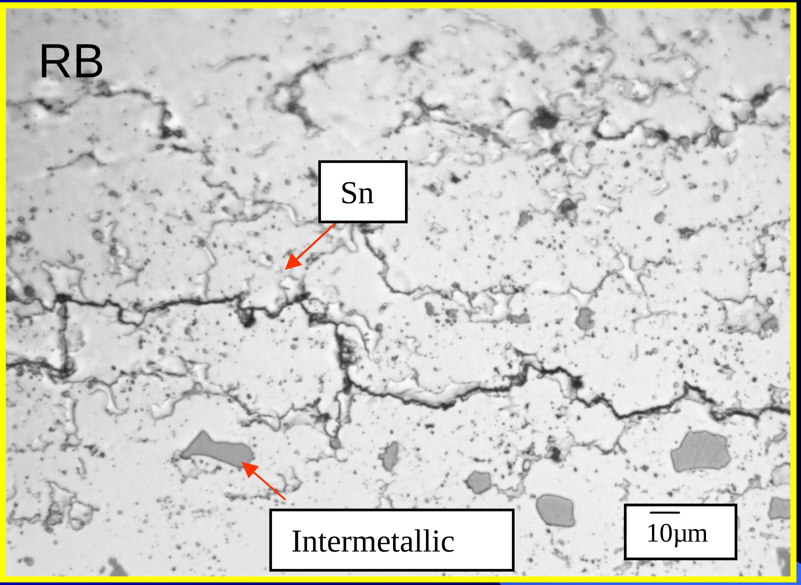


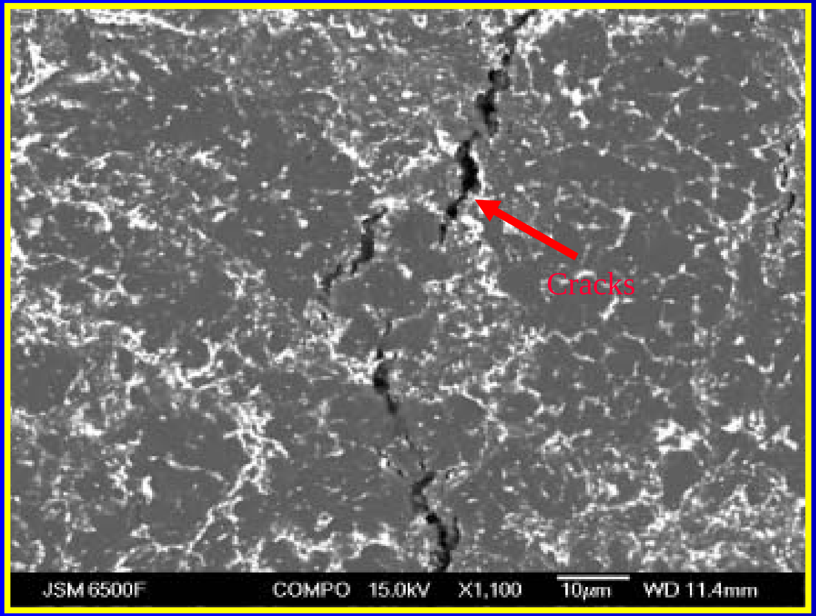


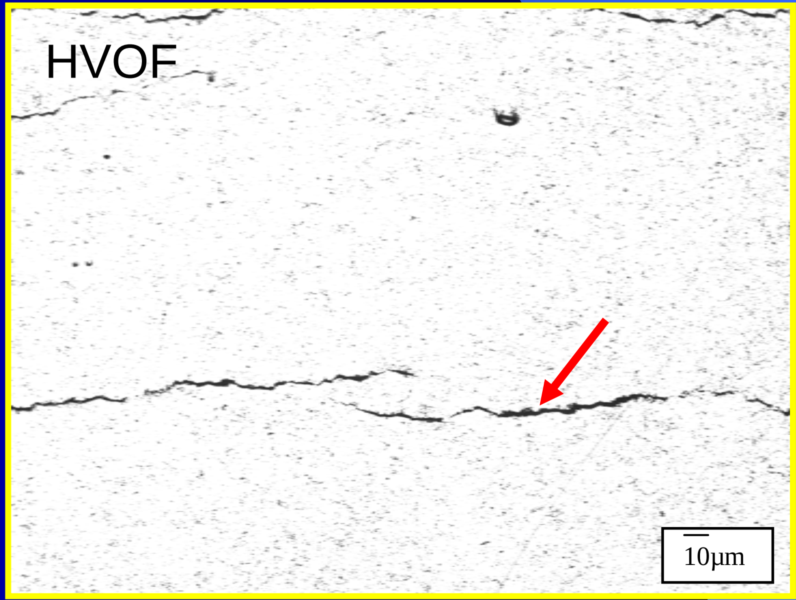


Fatigue crack propagation; RB vs. HVOF

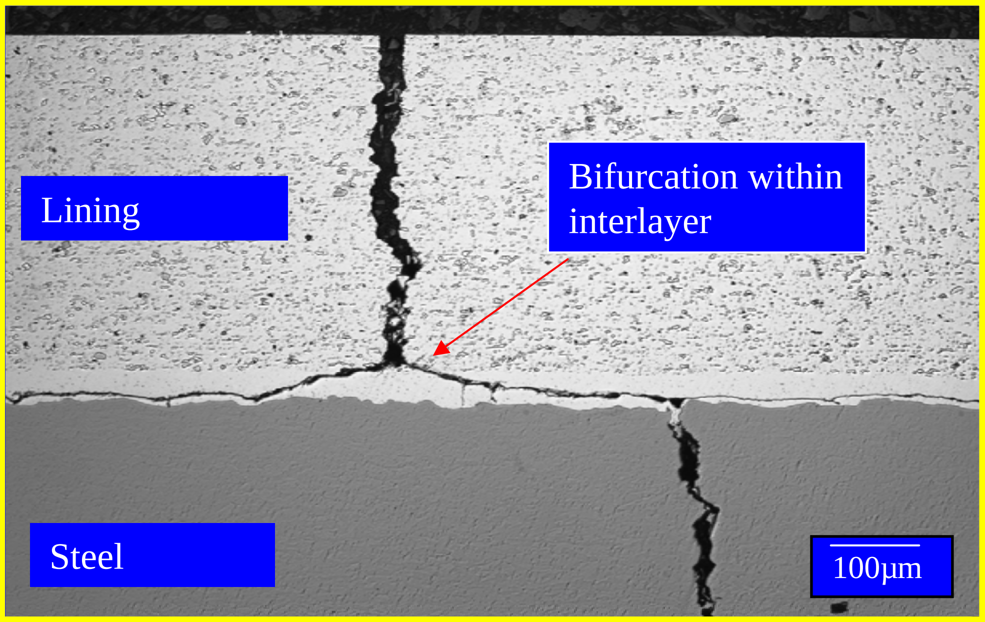
- Cracks attracted towards Sn phases in RB alloy.
  - Microstructurally dependent
  - Multiple coalescence events prior to failure
- In HVOF cracks seek out pores and unmelts within the splat morphology
  - Suggests unmelt/matrix interface to be weak

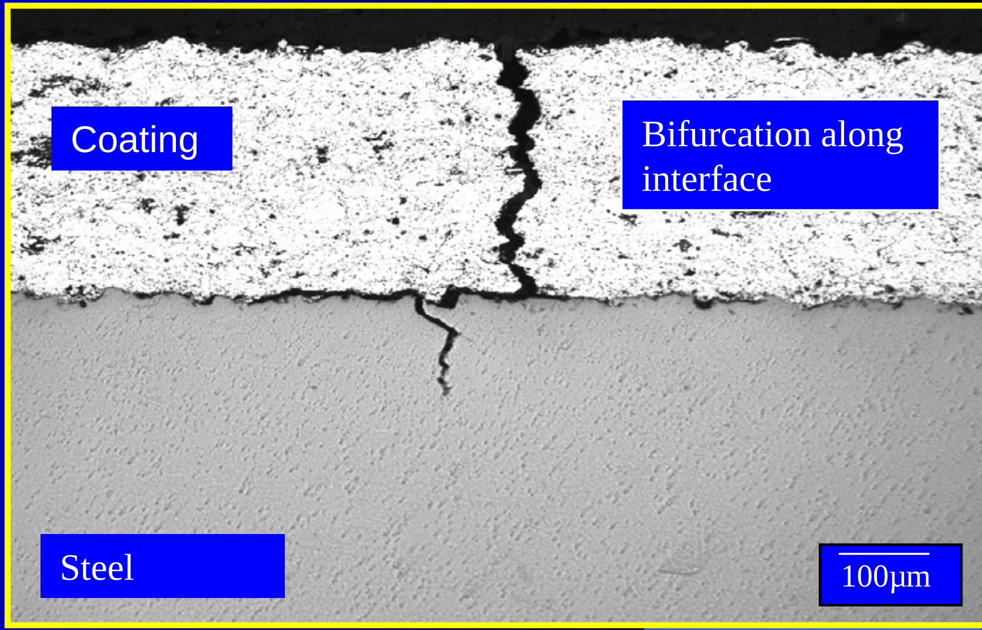






Sub-surface crack deflection and bifurcation





- Both RB and HVOF show subsurface crack deflection and bifurcation within the interlayer (RB) or along the interface (HVOF).
  - Why do cracks deflect as they approach steel layer?
- Crack approaching hard material from softer material would decelerate, deflect (giving a drop in driving force at crack tip) and finally arrest - beneficial to fatigue resistance
- Interface integrity poor in HVOF (grit-blasting) could act as weak path for continued propagation despite deflection - does this affect our FE assumption and lining stresses/strains?

Summary: HVOF performance vs. RB

Material properties and geometry:

- HVOF coating stronger/harder than equivalent RB lining and shows apparent improved fatigue performance in terms of strain lifetimes for the lining top surface.
- Differences in component architecture and material properties should be taken into account – effectively testing under different stress/strain conditions.

Initiation and propagation behaviour:

- HVOF coating thought to be more initiation resistant due to finer Sn distribution, but new initiation sites - pores/unmelt boundaries and Sn-rich regions
- Propagation around Unmelt/Sn boundaries in HVOF propagation - weak interface
- Similar da/dN in RB and HVOF (HVOF tested at effectively higher stresses)
- Subsurface crack deflection along HVOF interface - weak coating/steel interface

=> may mean that estimated strains/stresses at higher loads not likely to be achieved

- **Recommendations for improved fatigue performance of lining:**
- Reduction of porosity in HVOF coating likely to delay onset of initiation
- Reduce unmelts. Currently difficult as unmelts are tradeoffs from improved manufacturing process
- Interface integrity between the coating and grit blasted steel should be improved (but still ensuring good adherence of the spray coating)

Acknowledgements

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