Effects of pitting corrosion on fatigue performance of legacy cast iron pipe materials

Luke Ronayne
Prof. Philippa Reed, Prof. Julian Wharton

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PROJECT BACKGROUND

Project focusing on behaviour and performance of EN-GJL-250 flake graphite cast iron; representative material of failing water pipelines

Pipelines manufactured over a century ago; over-engineered with considerably thicker pipe walls than necessary

Pipelines now beginning to fail at increased rate; 46% over the last decade

Research preceding this project defined the ‘leak-before-burst’: the majority of failed pipelines showed signs of failure in the form of pinhole leaks, which then further deteriorate the condition of the pipeline, until a catastrophic failure occurs

MICROSTRUCTURE / MANUFACTURE

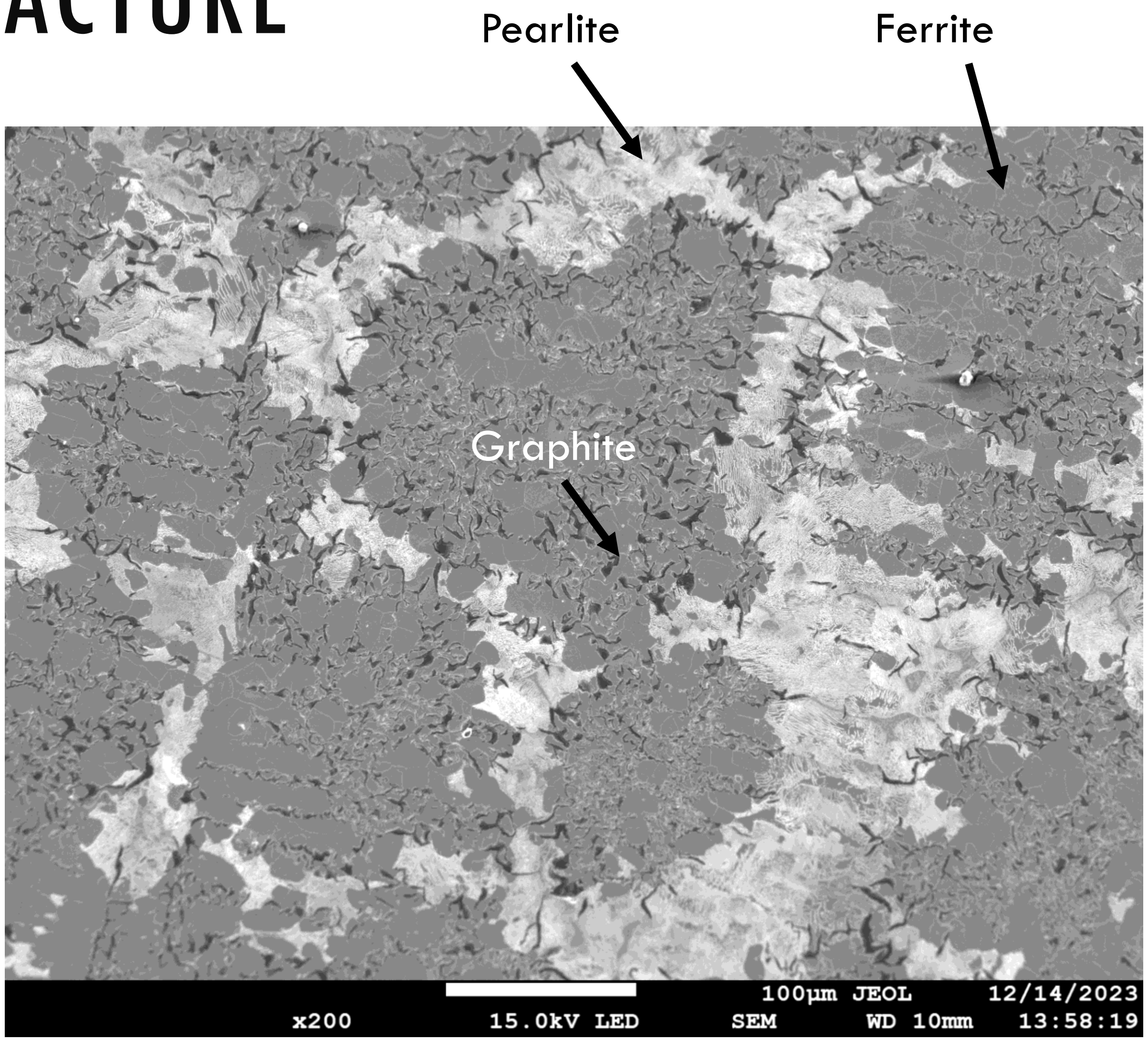
Grade 250 flake graphite cast iron used; three key phases in material: ferrite, graphite and pearlite

Microstructure extremely stochastic; affected by cooling rate and manufacturing technique

Cast iron pipes either pit cast or spun cast; thicker wall sections in pit casting leads to slower cooling rates, allowing fully ferritic phases to form with graphite flakes running through

Spun cast iron cools faster, allowing more carbon to precipitate as cementite, and the formation of more pearlite, improving the strength of the pipeline

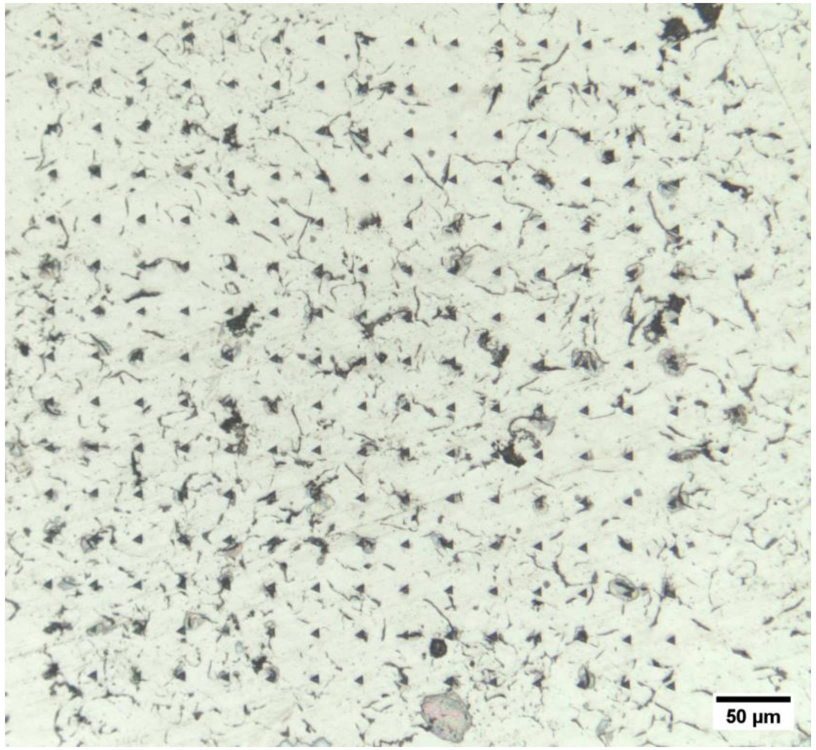
Element	Fe	C	Si	Mn	P	S	Cr	Al	Cu
% composition	92.30	3.61	2.52	0.80	0.41	0.07	0.31	0.02	0.25

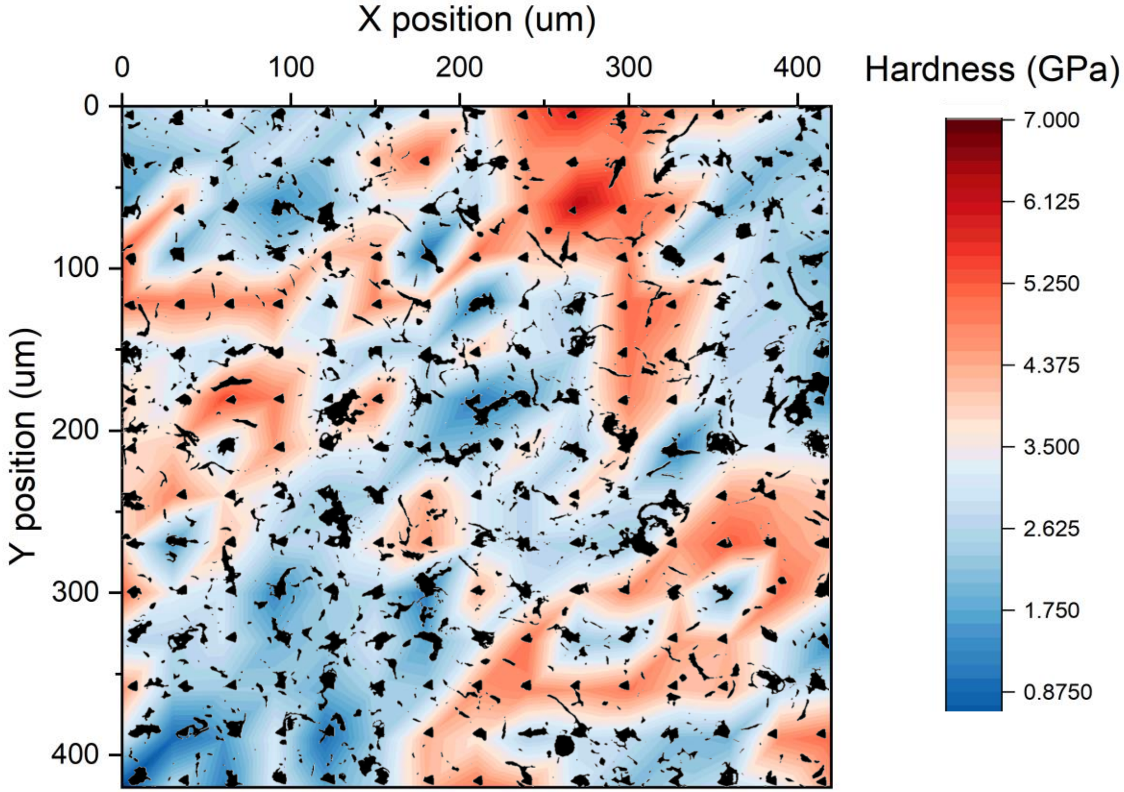


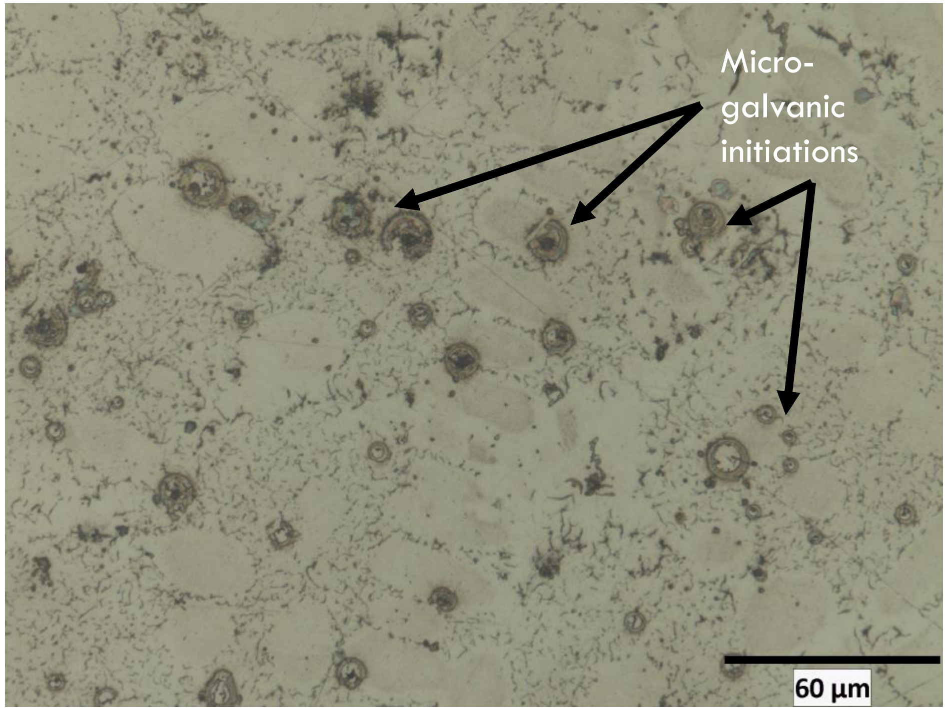
HARDNESS

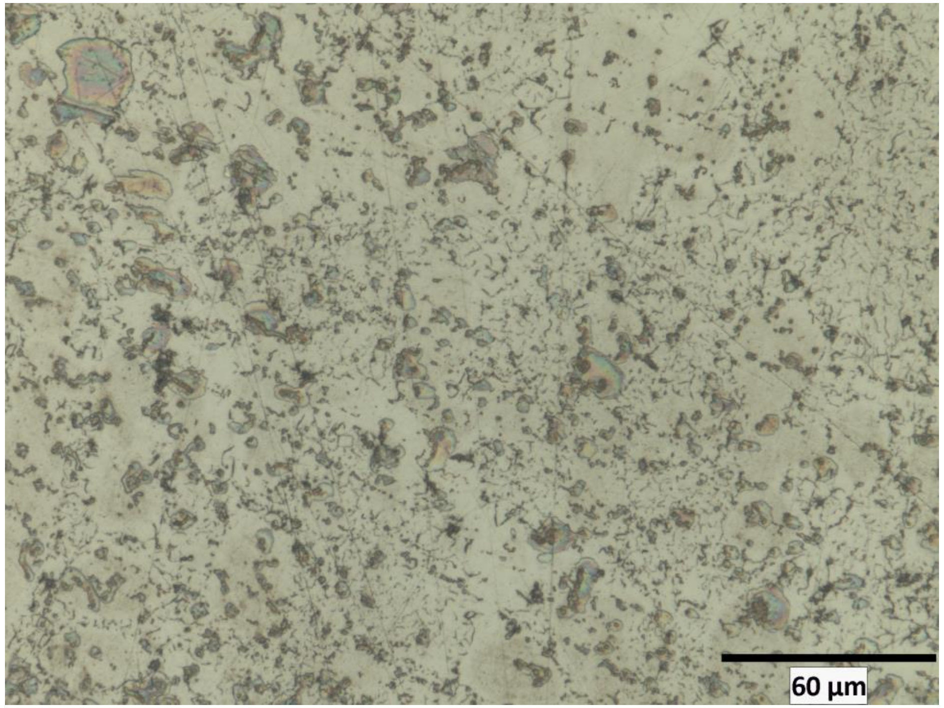
Nano-hardness data shows high concentration of graphite flakes reduces hardness

Areas with higher hardness likely pearlite phases









INITIAL PITTING

Micro-galvanic cells initiate on the surface of the material when exposed to an electrolyte

Interface between ferrite phases and graphite flakes act as preferred initiation points, due to the significant difference in electronegativities

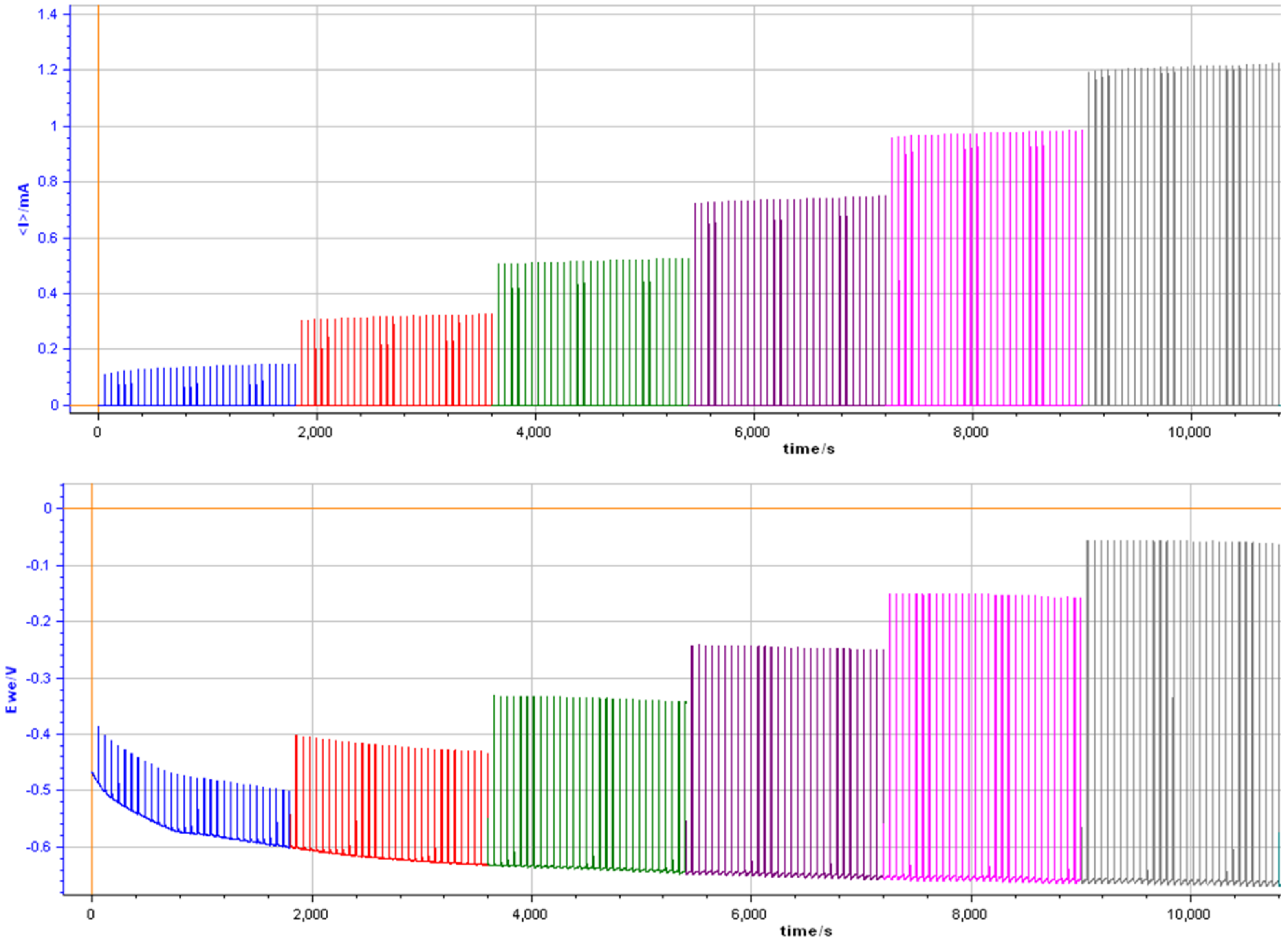
Pit nucleations grow through the ferrite phase and grow around the graphite flakes

Potentiostatic pulse testing (PPT) carried out to investigate pitting potential and quantify the activity of these initiation sites

CORROSION

Potentiostatic pulse testing carried out to interrogate the activation, propagation and passivation of initiation sites.

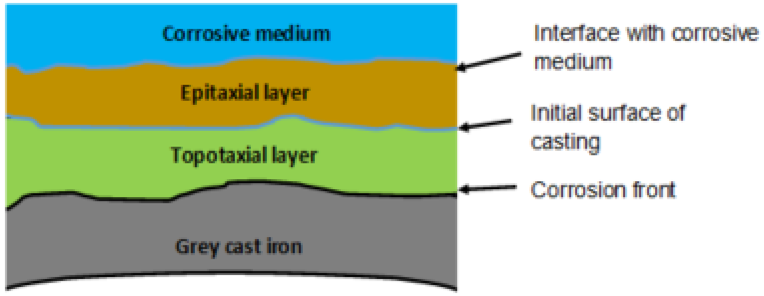
Corrosion current density shown to not decrease with time exposed to low conductivity electrolyte.

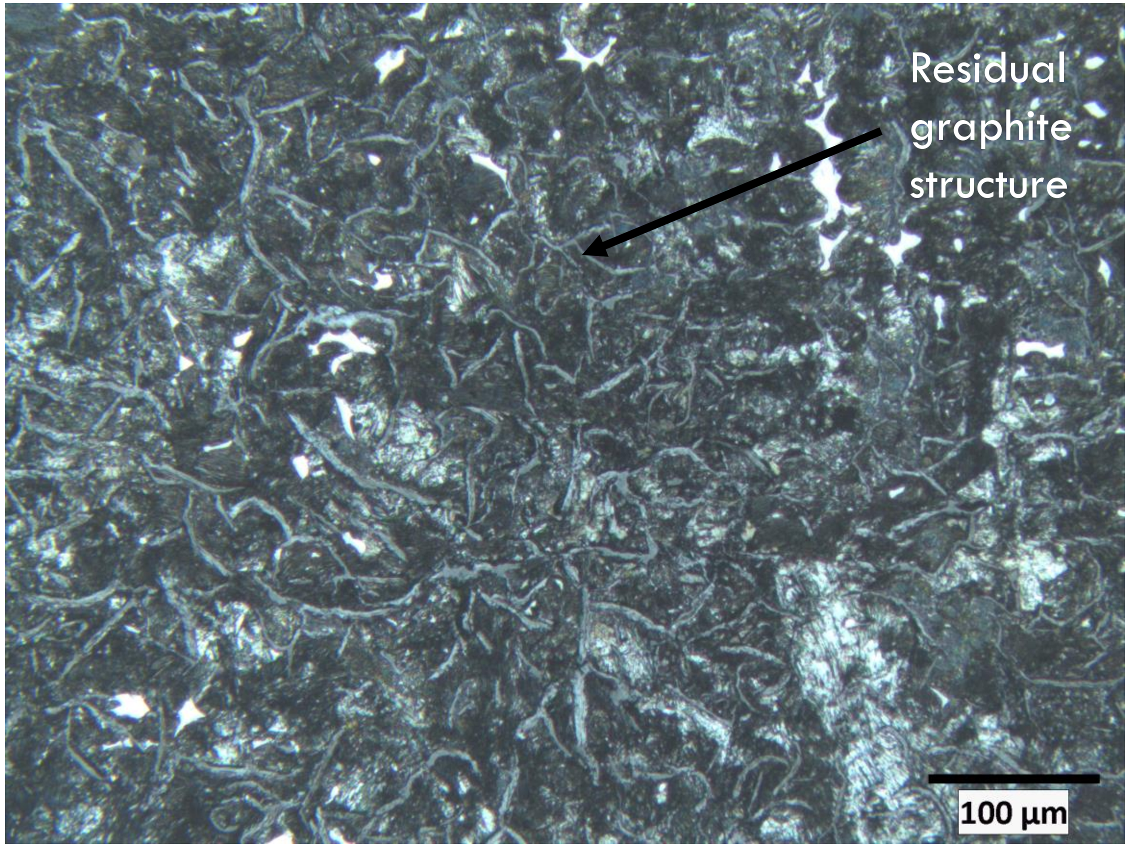


CORROSION

Ferrite phases are corroded away first, followed by the ferritic layers of the pearlite, leaving behind a graphitic structure - topotaxial layer

Corrosion products can be caught in graphitic structure, forming a product layer that can restrict oxygen diffusion to the front, and provide additional mechanical resistance to applied stresses





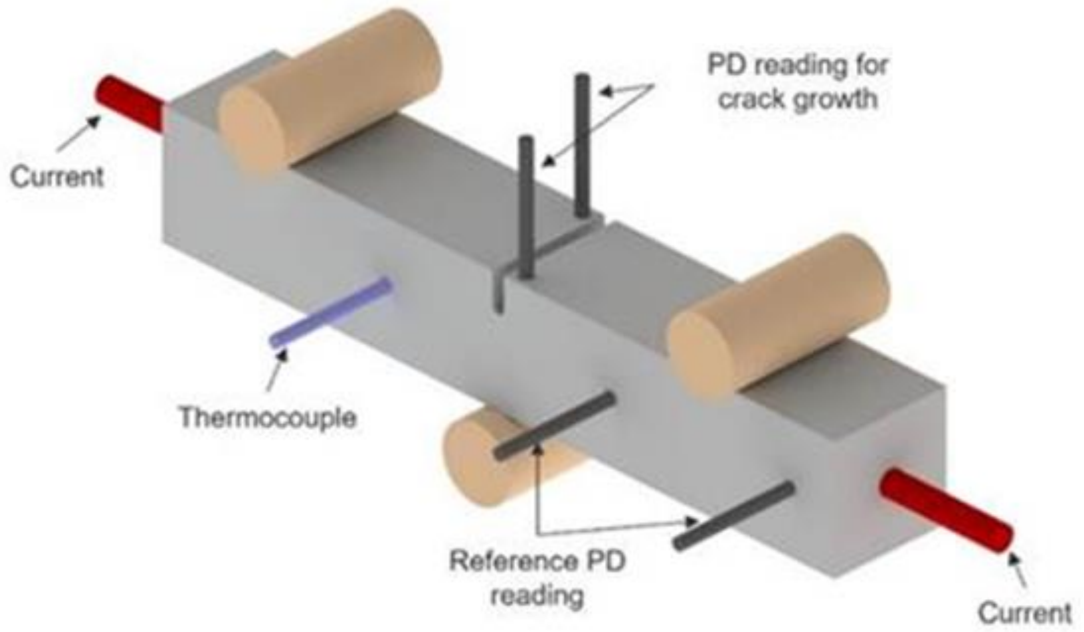
MECHANICAL – CRACK GROWTH

Three successful damage tolerant tests carried out, all at starting ΔK 8

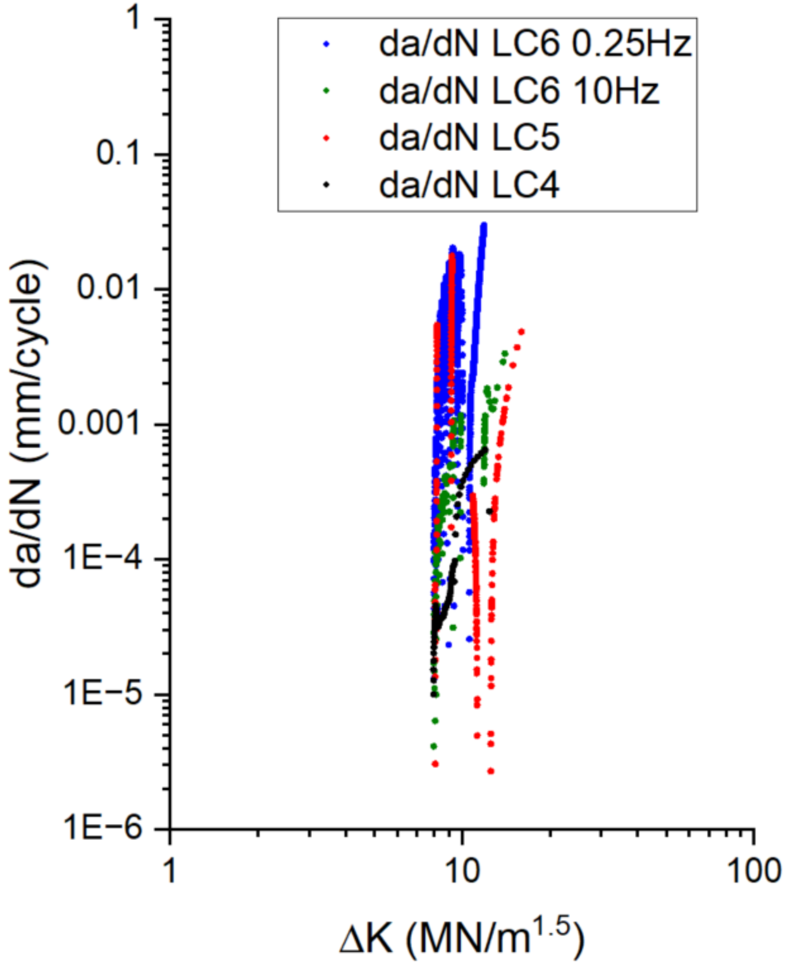
Experimental set-up same as the lifetime tests; notched samples used

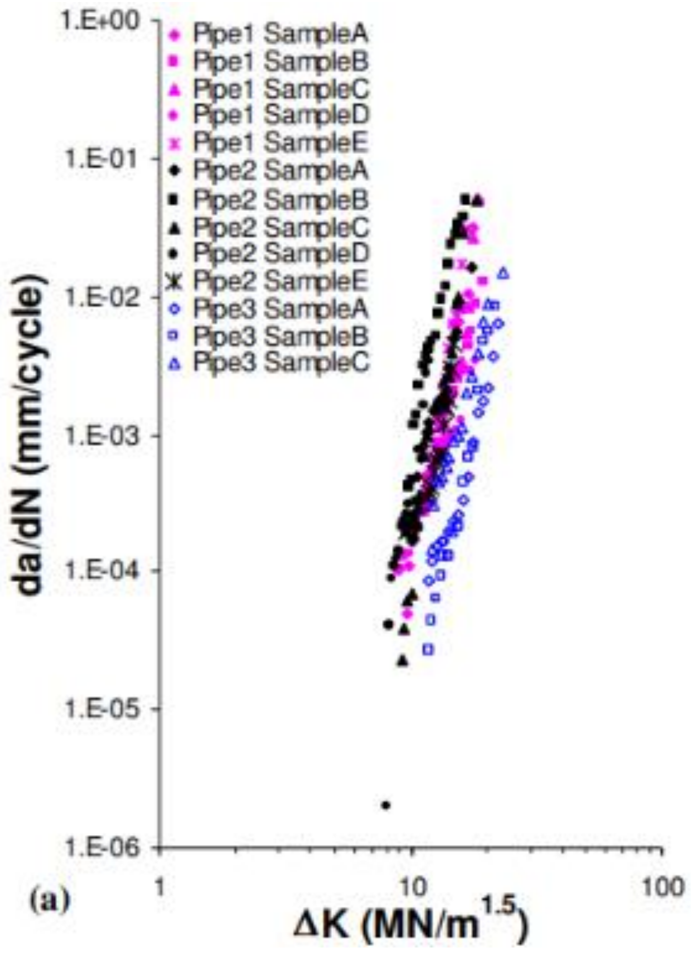
DCPD used to monitor crack growth through sample

Current passed through the sample (red/black) with the p.d. change monitored at the notch (brown) and at the reference point (blue)

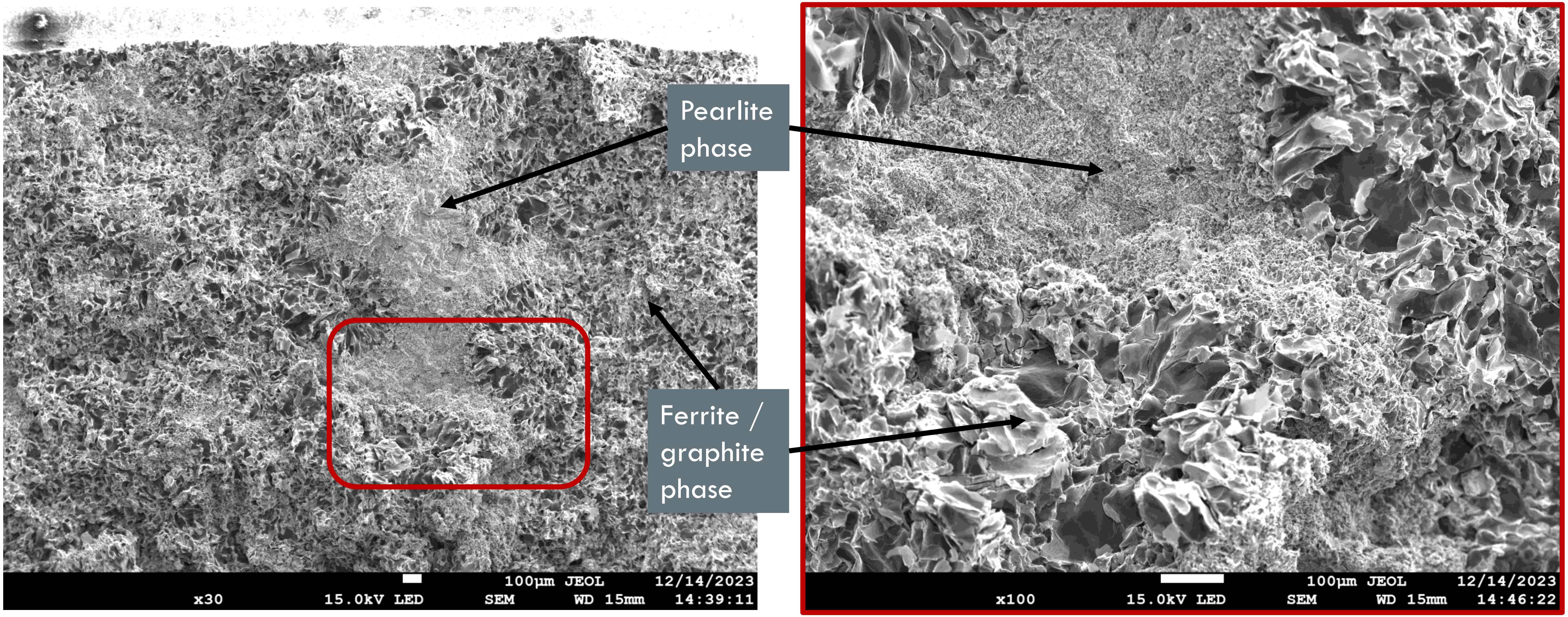


MECHANICAL – CRACK GROWTH





CRACK GROWTH / FAILURE MECHANISM

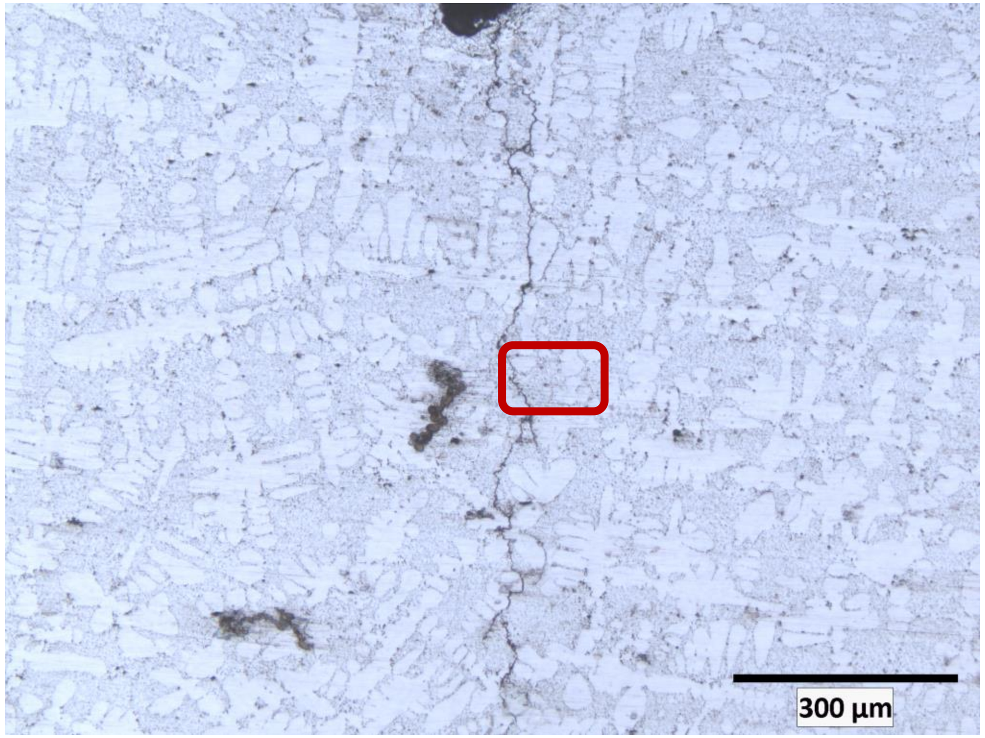


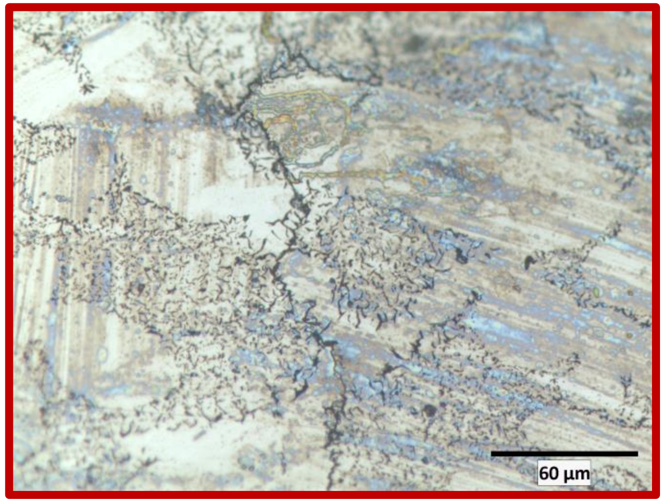
MECHANICAL - CRACK GROWTH

Cracks shown to grow primarily along boundaries of graphite flakes and matrix; crack path direction deviates significantly

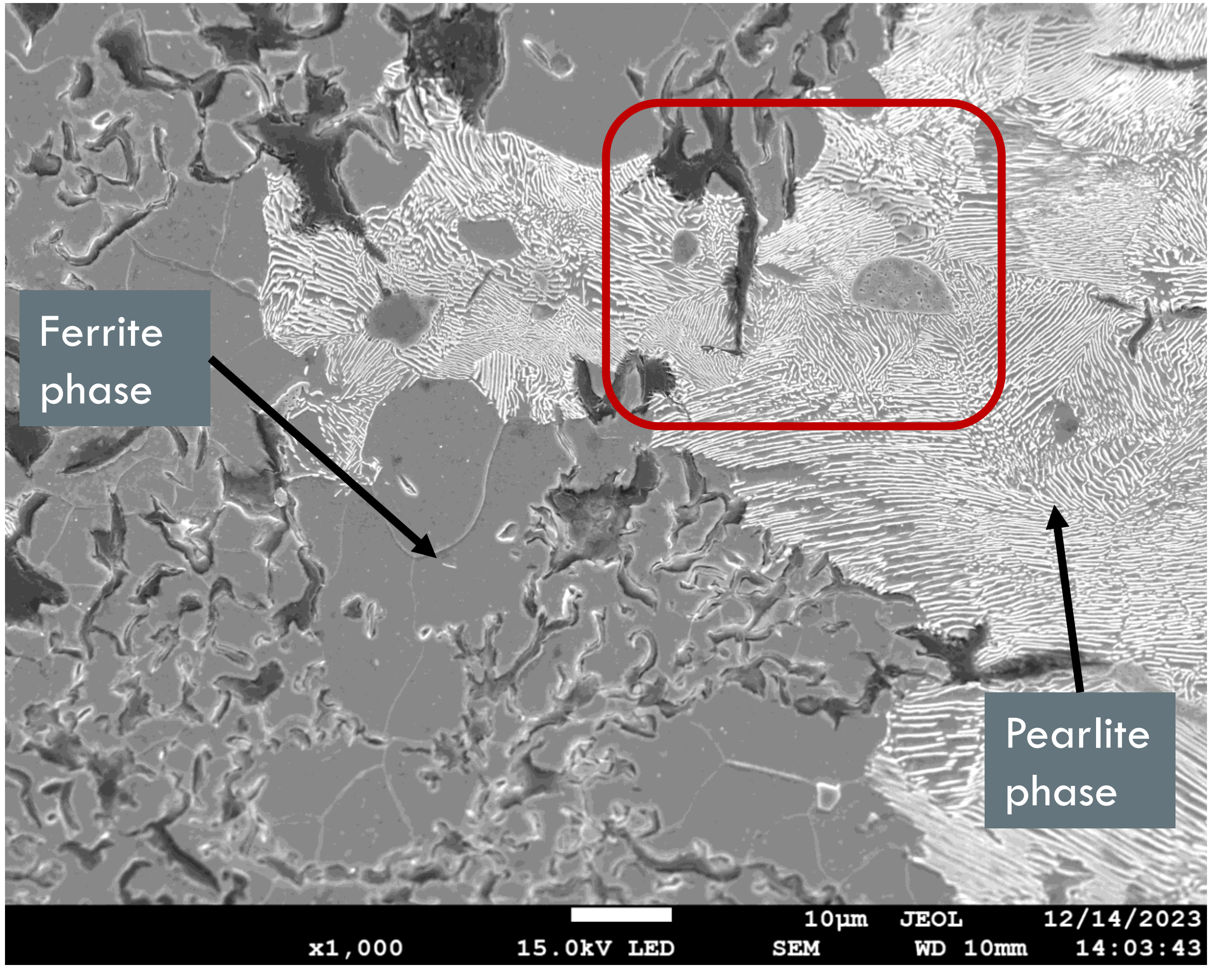
Alternating frequency testing shows spikes in crack growth rate at low frequencies; sample overloaded during frequency change

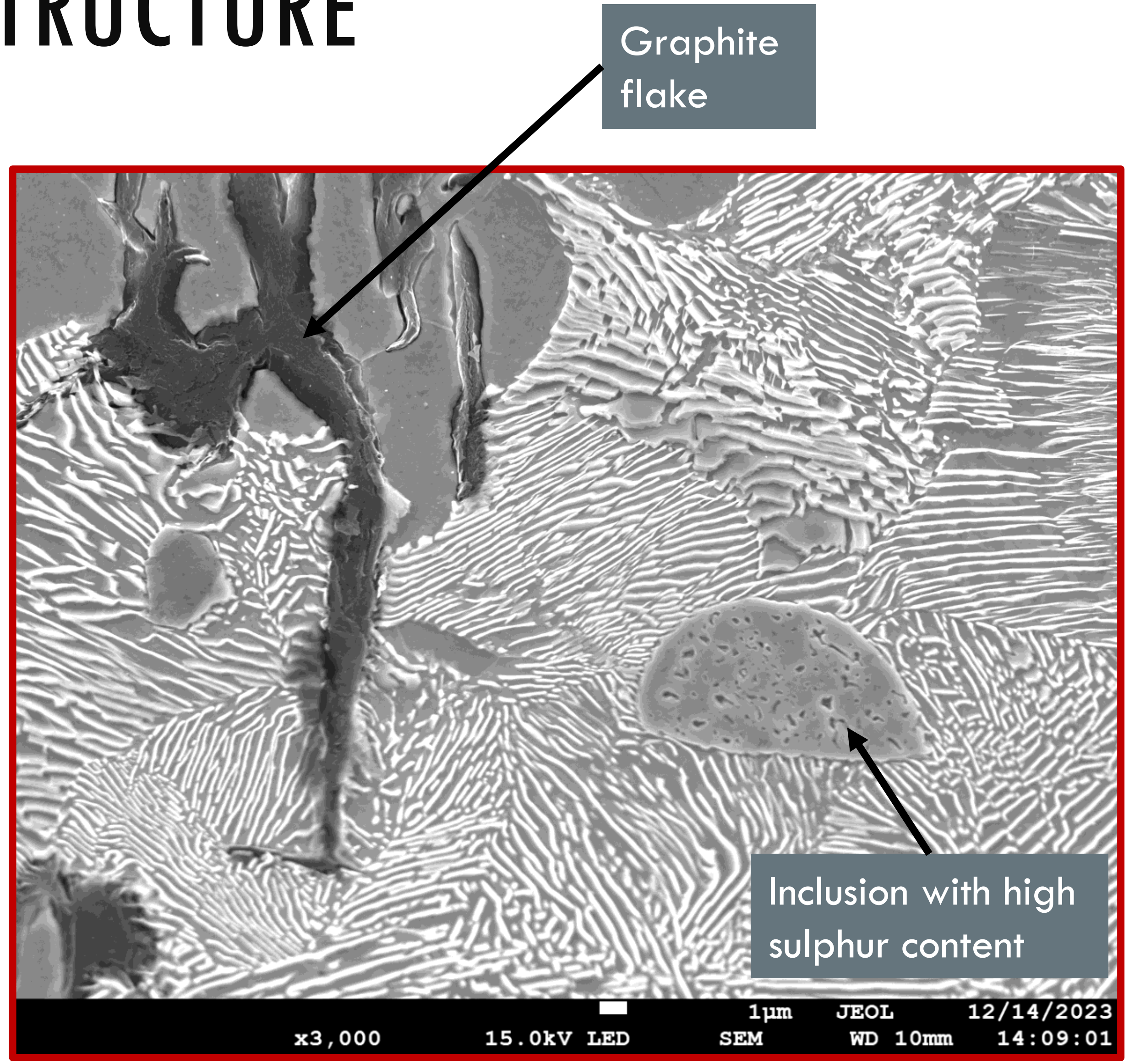
Cracks grow across the sample at an angle, with failure occurring very quickly once the crack completes growth across the sample and becomes a true long crack





LOCAL EFFECT OF MICROSTRUCTURE





CONCLUSIONS

Boundaries between the graphite flakes and the matrix are the crucial factor in defining the mechanical characteristics of the material

- Flakes act as cathodes, with ferrite as the primary anodes, allowing the initiation of micro-galvanic cells
- Structurally, the flakes act as voids adding very little strength to the material, but acting as sharp stress concentrations encouraging the initiation of micro-cracks

Pearlite phases scattered through the material provide the majority of the mechanical strength, forming a network through the material holding it together

Pit morphology determined primarily by variation of microstructure and the formation of corrosion product layers that restrict the supply of oxygen to the corrosion front

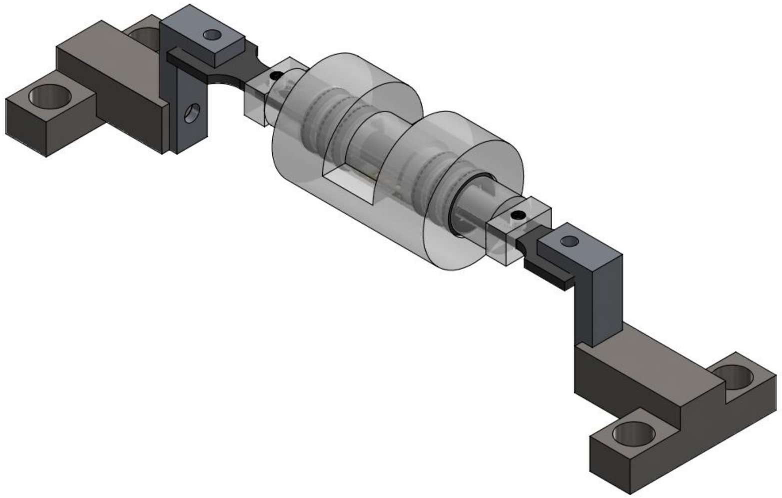
FUTURE WORK

Further investigation of frequency effects on crack growth

Staircase testing of corroded samples – investigating effect of corrosion product film and surface roughness on mechanical performance

Mechanical testing of in-situ micro-tensile samples – effects of active corrosion on crack initiation, X-ray CT scanning to observe crack growth

X-ray CT scanning to provide detailed information of the three-dimensional microstructure, before, during and after testing



YOUR QUESTIONS