The effect of inconsistent casting on the mechanical performance of cast iron wind turbine components

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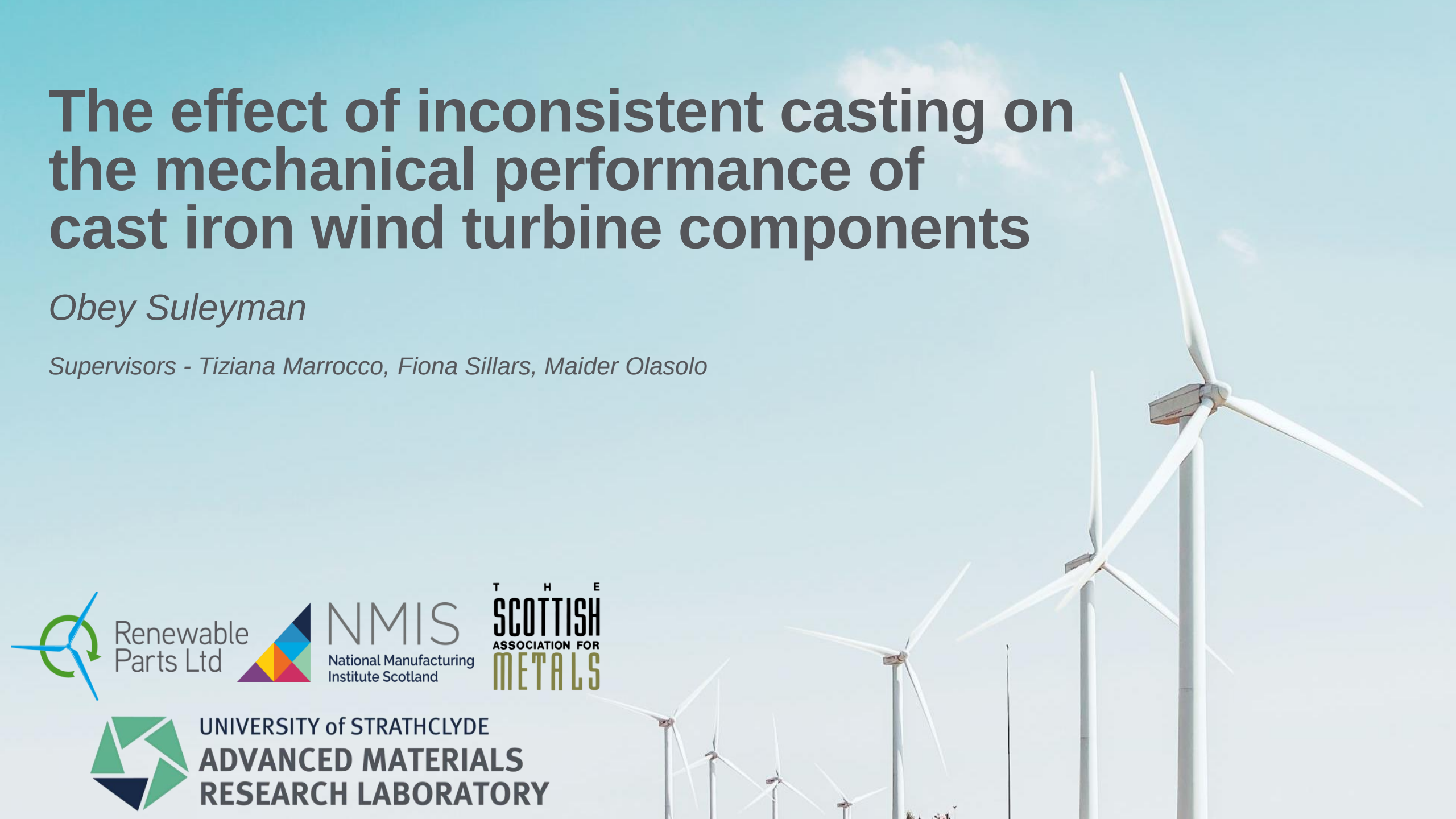

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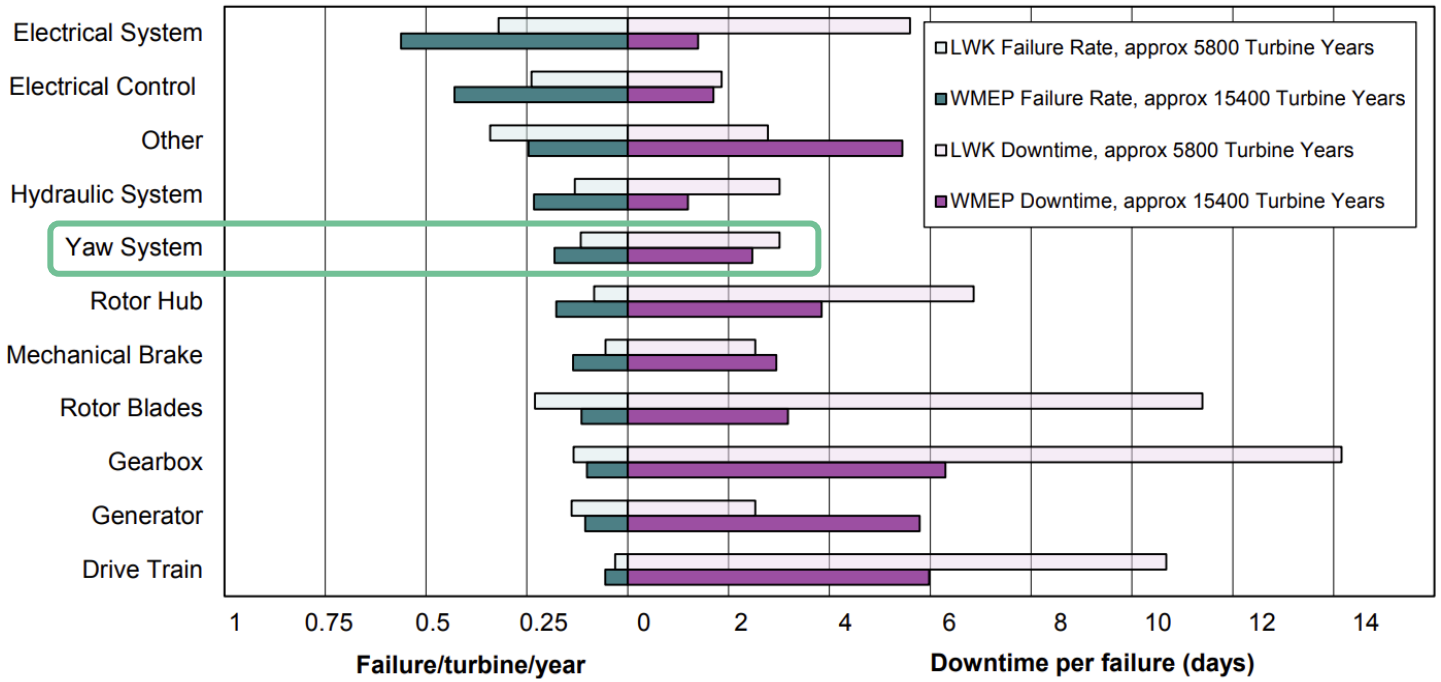
- Wind turbine components under consideration
- Mechanical testing
- Compositional analysis
- Microstructural characterisation
- Issues regarding the current casting & cooling procedure
- Conclusions

Background

Scottish wind turbine facts [1]:

- Currently **≈80kt** of spheroidal graphite iron (SGI) offshore
- By 2050 ≈500 turbines decommissioned → **≈17kt** of SGI
- By 2050 **>1500kt** of SGI required

Manufacturing processes must be improved to effectively deal with upcoming demands!



Component failure rates & downtimes depend on turbine type:

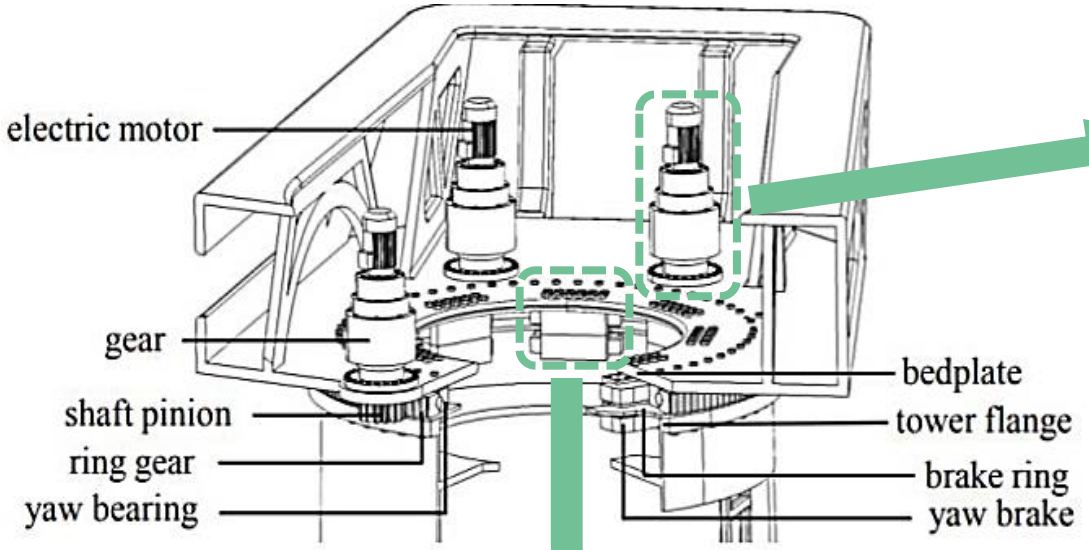
WMEP yaw system: ≈0.2 failures/year → ≈2.5 downtime days/year

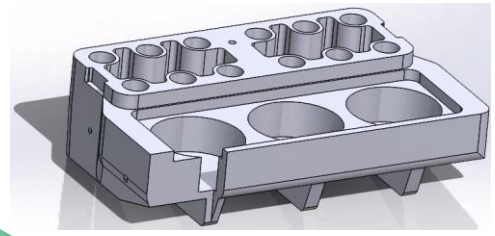
This equates to ≈63 days over the average turbine lifespan [2]

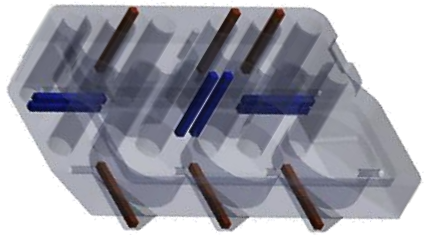
[1] D. C. Stamper, D. A. Velenturf and D. J. Millward-Hopkins, "End of life materials mapping for offshore wind in Scotland," Catapult offshore renewable energy, 2022.
[2] Tavner, P. (2011), How Are We Going to Make Offshore Wind Farms More Reliable?, presented at the 2011 SUPERGEN Wind General Assembly, March 20, Durham University, United Kingdom

What wind turbine components?

- The yaw system is housed between the tower and nacelle







What materials?

- Cast iron grades are defined by EN-1563-2018 ‘Spheroidal graphite cast irons’:

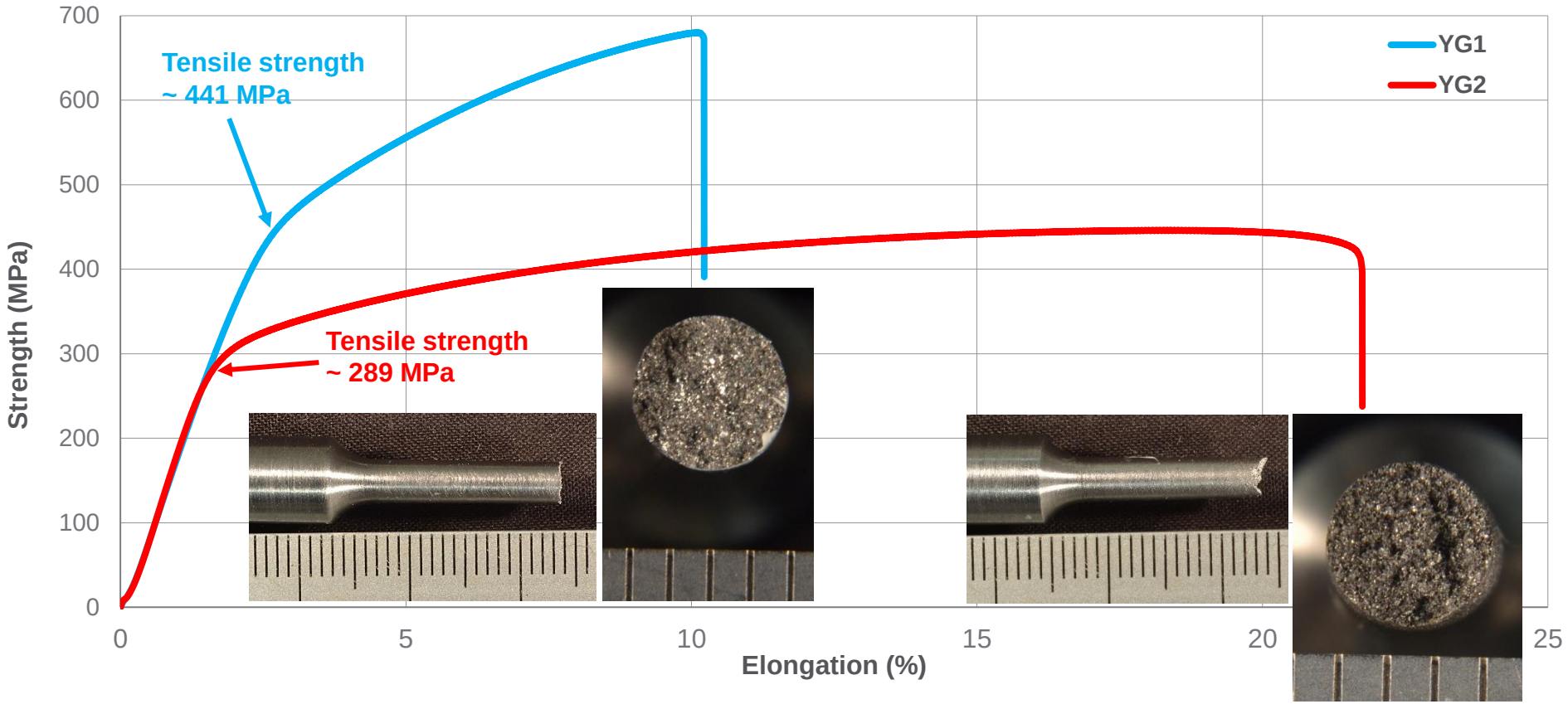
EN - GJS – TS – El

- GJS: G: Cast, J: Iron, S: Spheres
- TS: Tensile strength (MPa)
- El: Elongation (%)

- Little significance on composition and cooling treatments of the cast iron grade

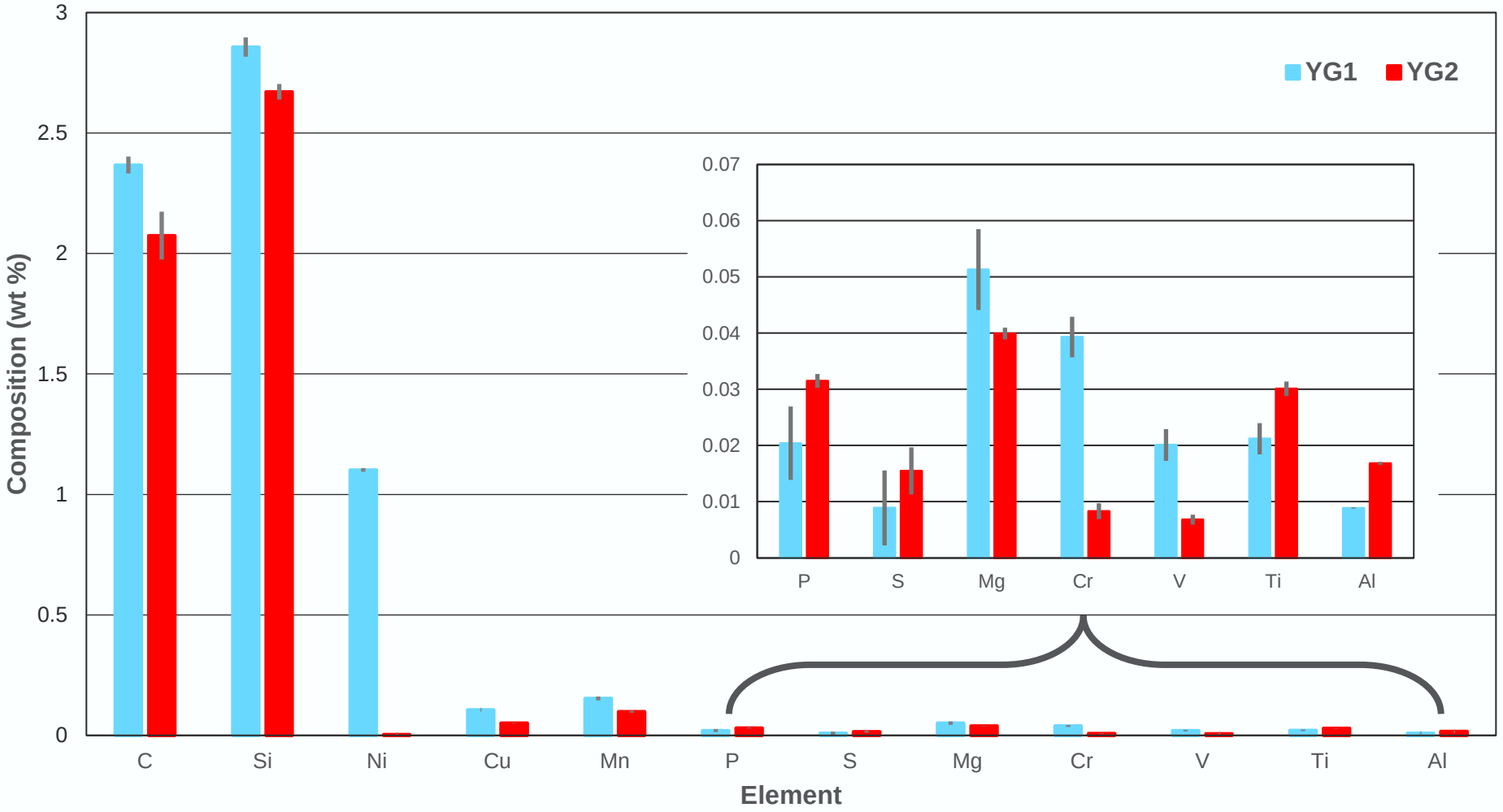
Sample	EN-1563-2018		Measured hardness, HV10
	Estimated grade	Hardness range, HV	
YG1	EN-GJS-450-10	160-210	175 ± 12
YG2	EN-GJS-400-18	130-175	150 ± 9
YBC1	EN-GJS-500-7	170-230	201 ± 15
YBC2	EN-GJS-500-7	170-230	194 ± 10

Yaw Gears – Defining strength & elongation



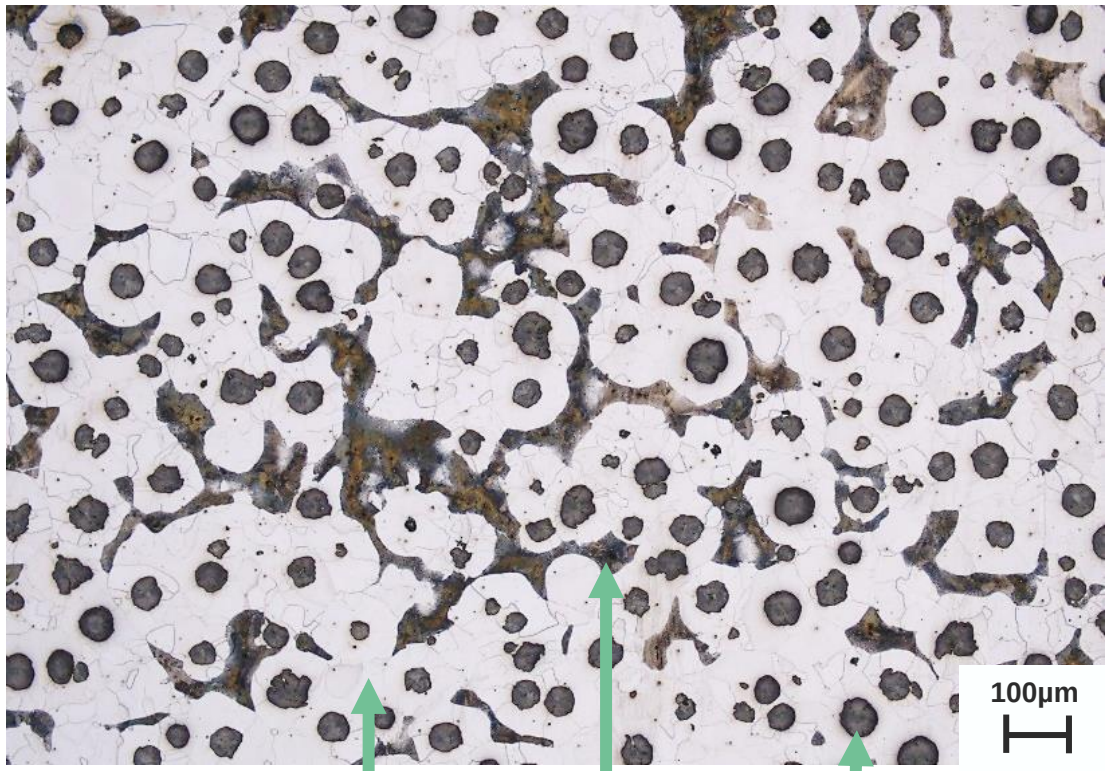
- Significant difference between yaw gears – both in tensile strength & elongation
- Brittle failure apparent in YG1, some necking apparent in YG2

Yaw Gears – Chemical composition



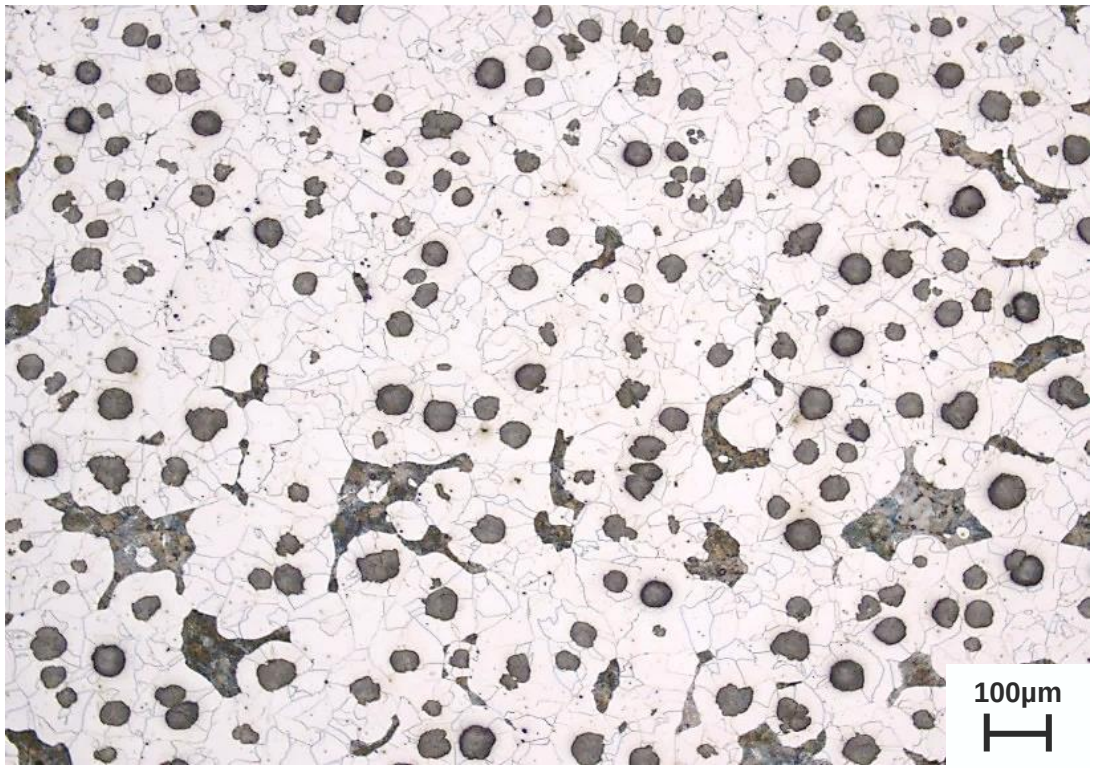
- Significant compositional differences between yaw gears – mainly Ni; but also Cu, Mn & Cr

Yaw Gears – Phases volume fraction



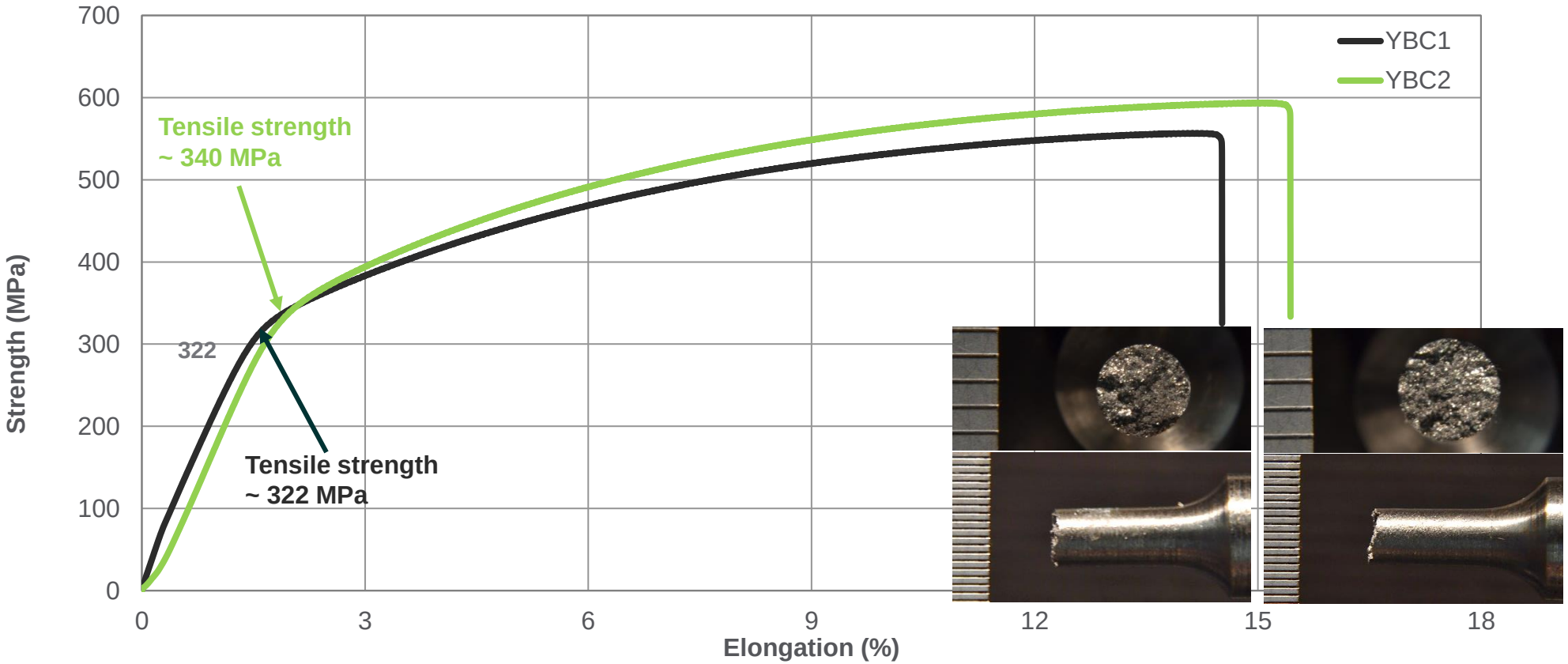
YG1	
Ferrite	62.2 ± 1.7
Pearlite	27.4 ± 1.9
Graphite	10.4 ± 0.2

Ferrite Pearlite Graphite



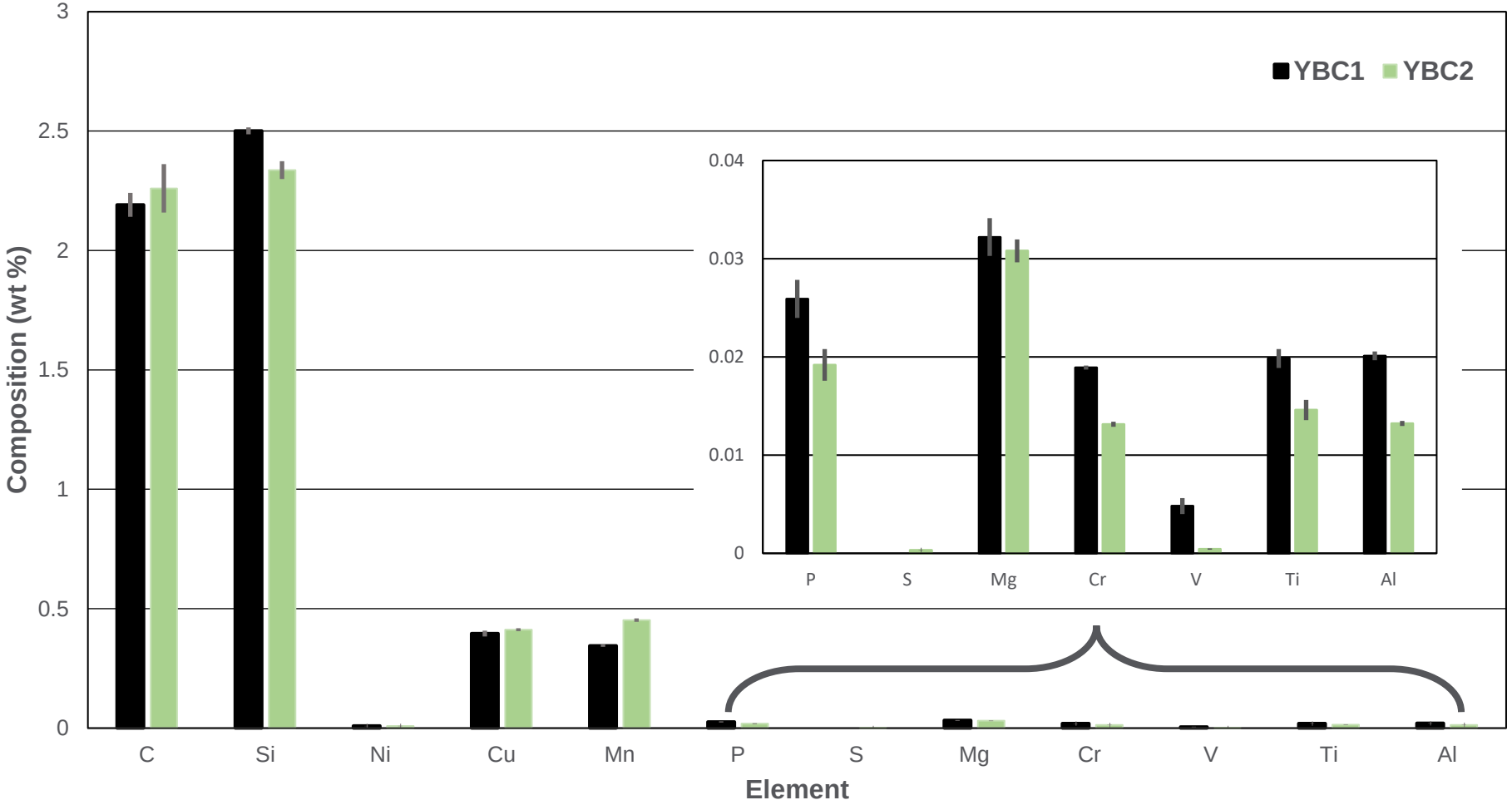
YG2	
Ferrite	69.5 ± 1.8
Pearlite	20.3 ± 1.7
Graphite	10.2 ± 0.1

Yaw Callipers – Defining strength & elongation



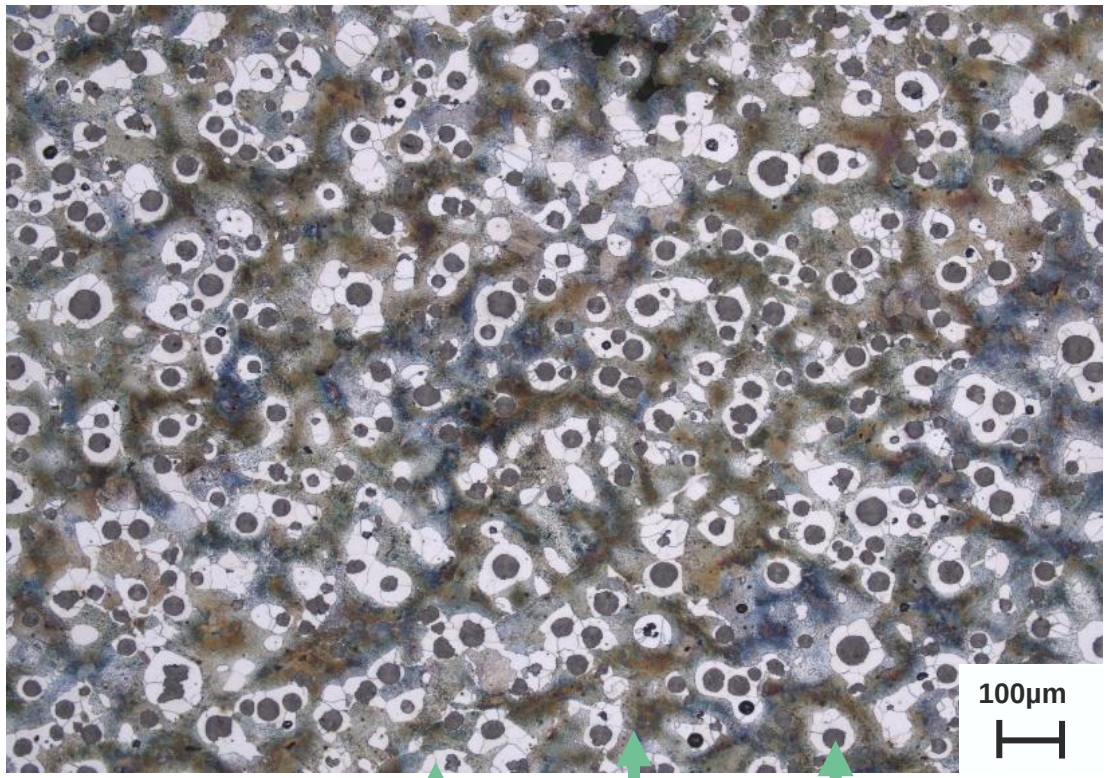
- Similar tensile strength and elongation between callipers
- Brittle failure apparent in both callipers

Yaw Callipers – Chemical composition



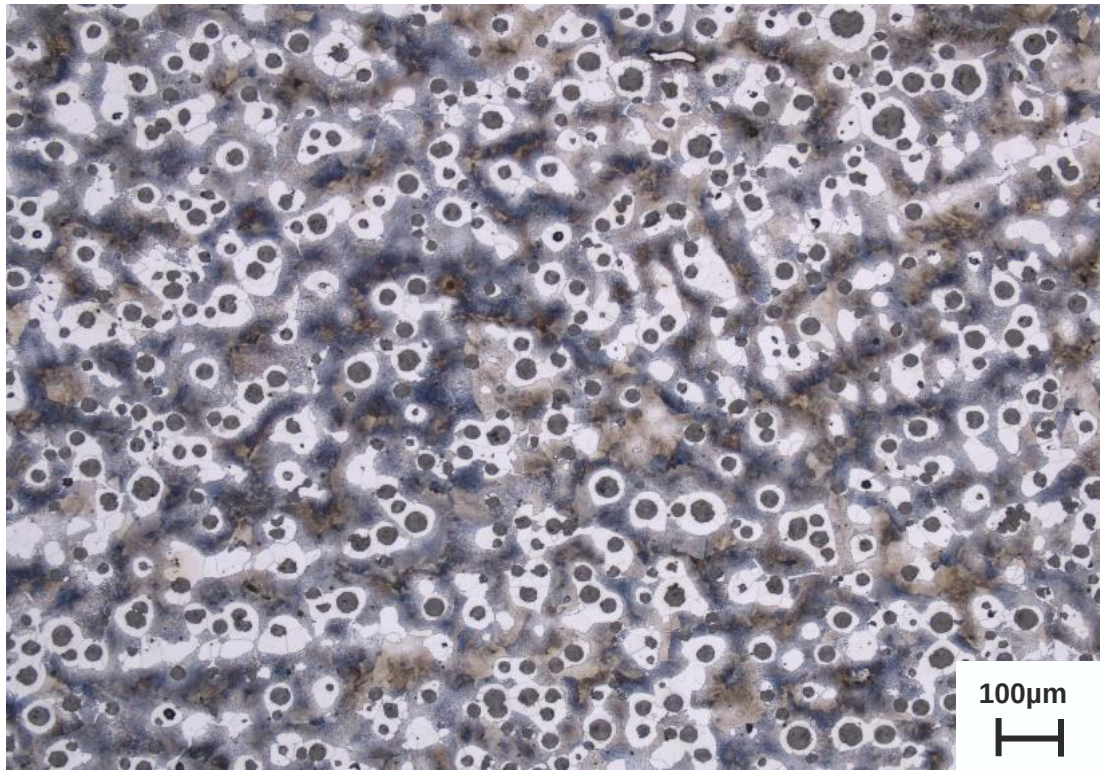
- Composition across YBCs similar
- Differences in ‘impurity’ elements which could hinder fatigue life

Yaw Callipers – Phases volume fraction



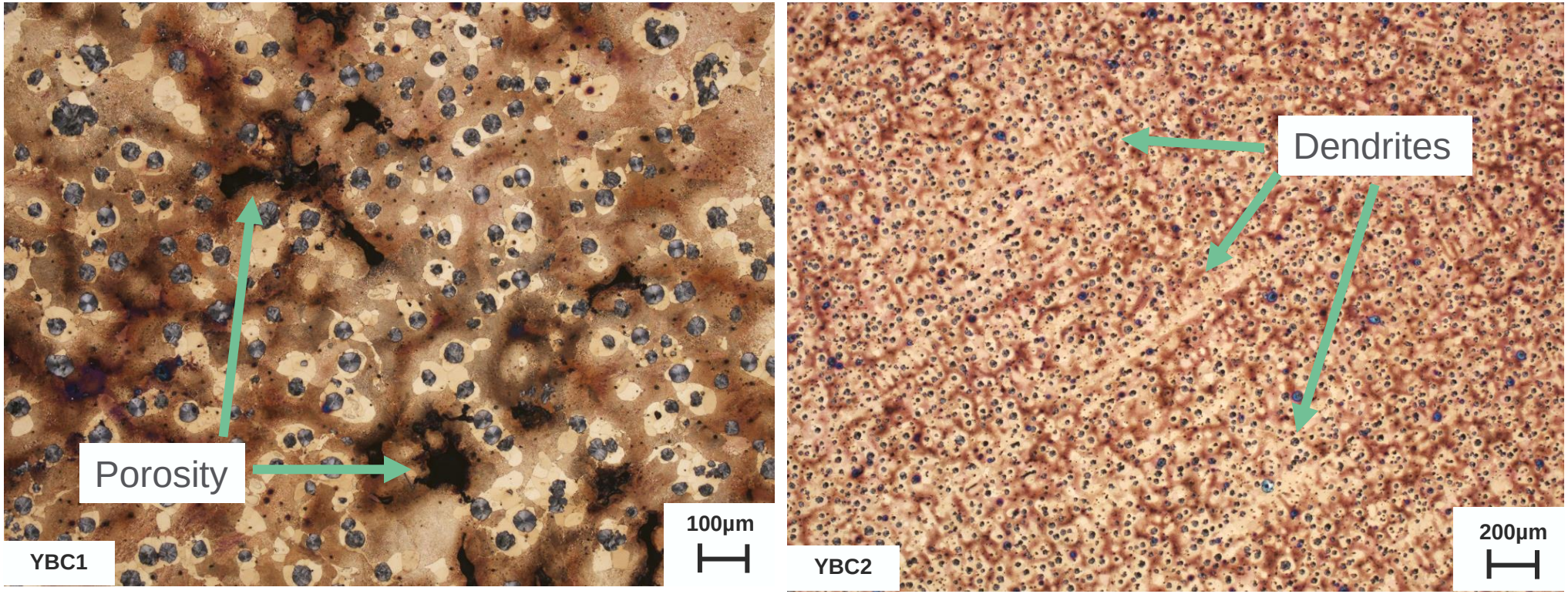
YBC1	
Ferrite	29.7 ± 1.2
Pearlite	60.9 ± 1.5
Graphite	9.4 ± 0.4

Ferrite Pearlite Graphite



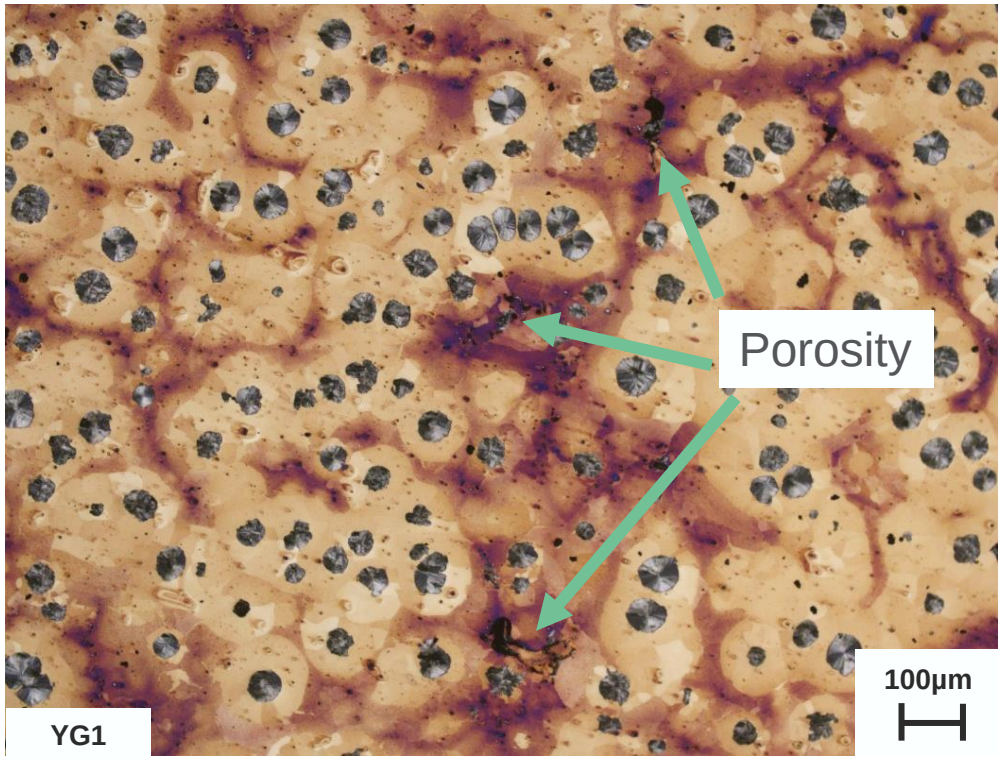
YBC2	
Ferrite	32.7 ± 1.5
Pearlite	58.2 ± 2.0
Graphite	9.1 ± 0.6

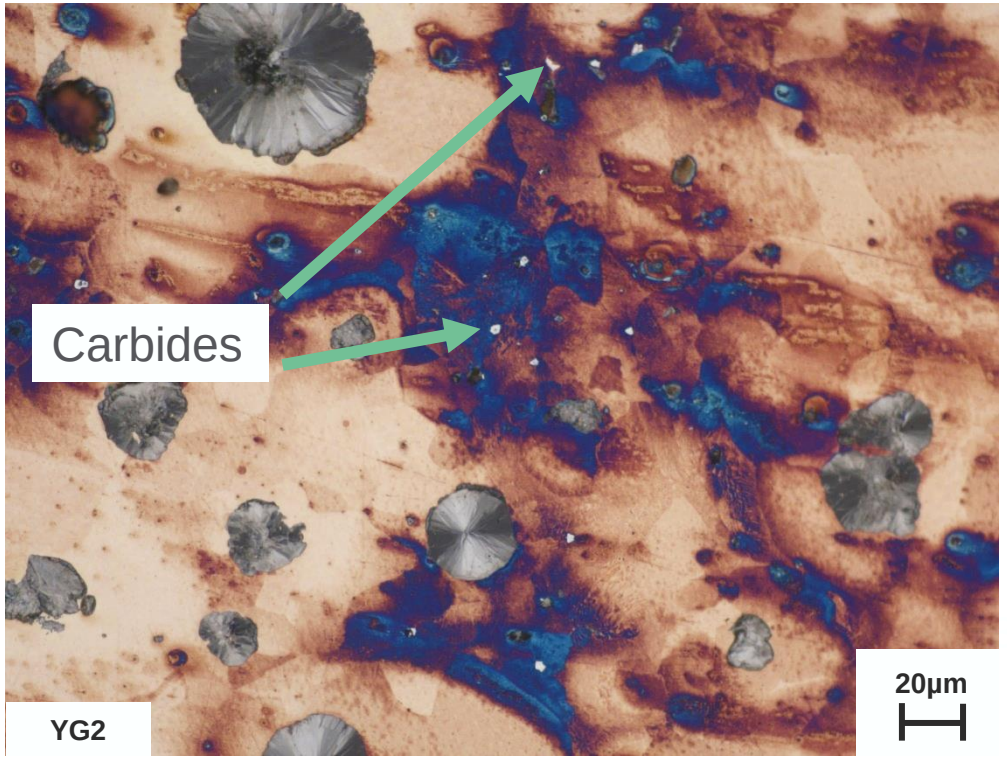
Yaw Callipers – Effect of casting



- Chains of carbides and macro shrinkage porosity hinder mechanical properties
- Heavily dendritic microstructure evident in YBC2

Yaw Gears – Effect of casting





- ‘Dark’ zones highlight issues attributed to cooling
- Elements with lower melting points segregate and solidify together
- Chains of macro shrinkage porosity and carbides generate areas of weakness

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Conclusions

- Yaw gears produced stark differences when tensile tested, mostly due to Ni → differences in microstructure
- Yaw break callipers showed relatively little difference when tensile tested → similar composition & microstructure
- YBC2 was found to have a heavily dendritic structure → potential hindrance to fatigue life
- Inconsistent casting control can generate significantly different materials

Future work

- Comprehensive microstructural analysis on the effects of composition and casting on yaw gears and callipers properties – e.g. ferrite grain size measurements, pearlite interlamellar spacing measurements, graphite nodule analysis
- Fatigue testing to define SN curve

Questions ?