Wire + Arc Additive Manufacture of non-ferrous alloys – current status and material properties

Cranfield UNIVERSITY

Presented by Stewart Williams

Welding Engineering and Laser Processing Centre

www.waammat.com

www.cranfield.ac.uk

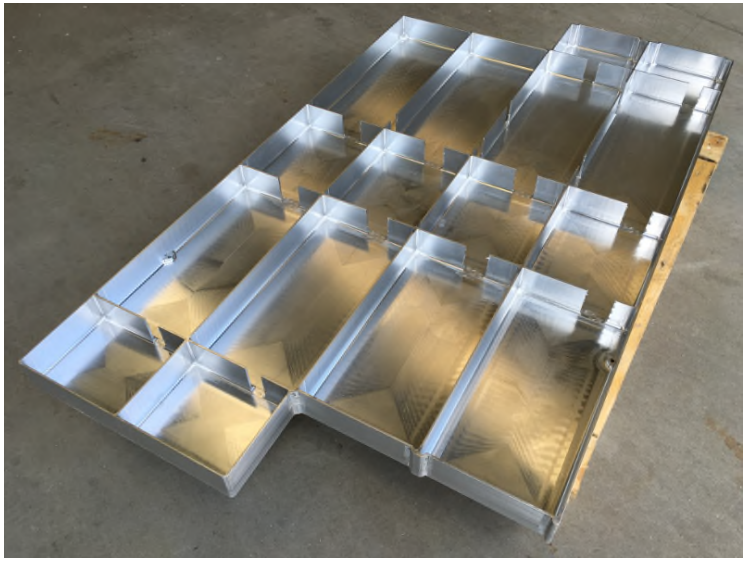
Topics

- Very brief summary of Wire + Arc Additive Manufacture
- WAAM non-ferrous materials
  - Titanium 64
  - Aluminium
  - Refractory metals
  - New and mixed materials
- Future prospects

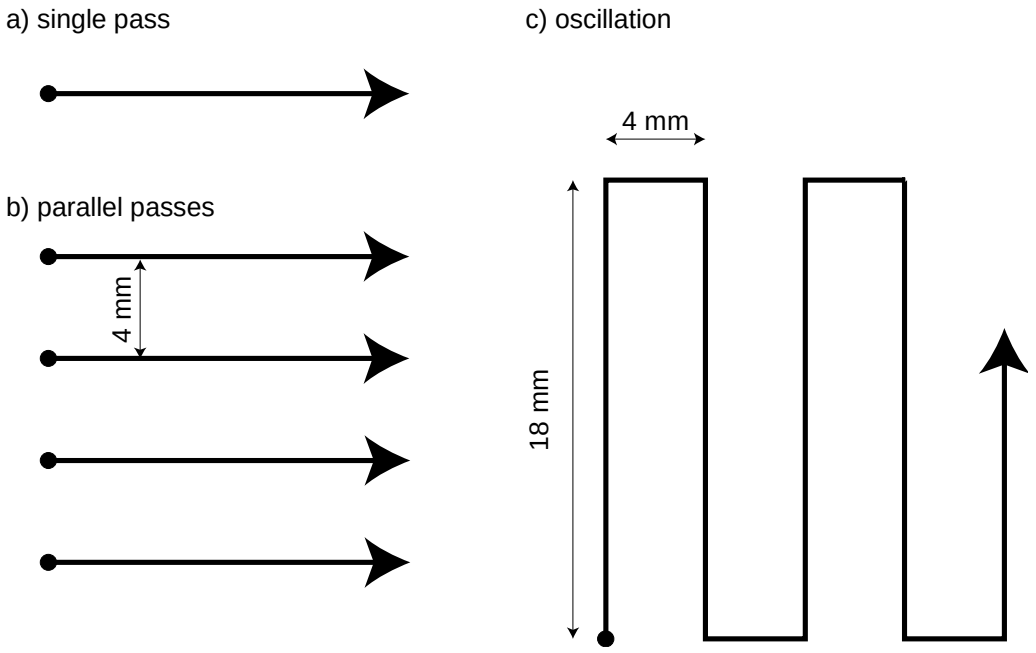
Key WAAM process features

- Build rates 0.5 - 4 kg/hour – **typical 1kg/hr titanium**
- Unlimited build volume
- Fully dense materials with excellent mechanical properties
- Minimum feature size 2 mm
- **No commercial systems available – yet**

Machined part

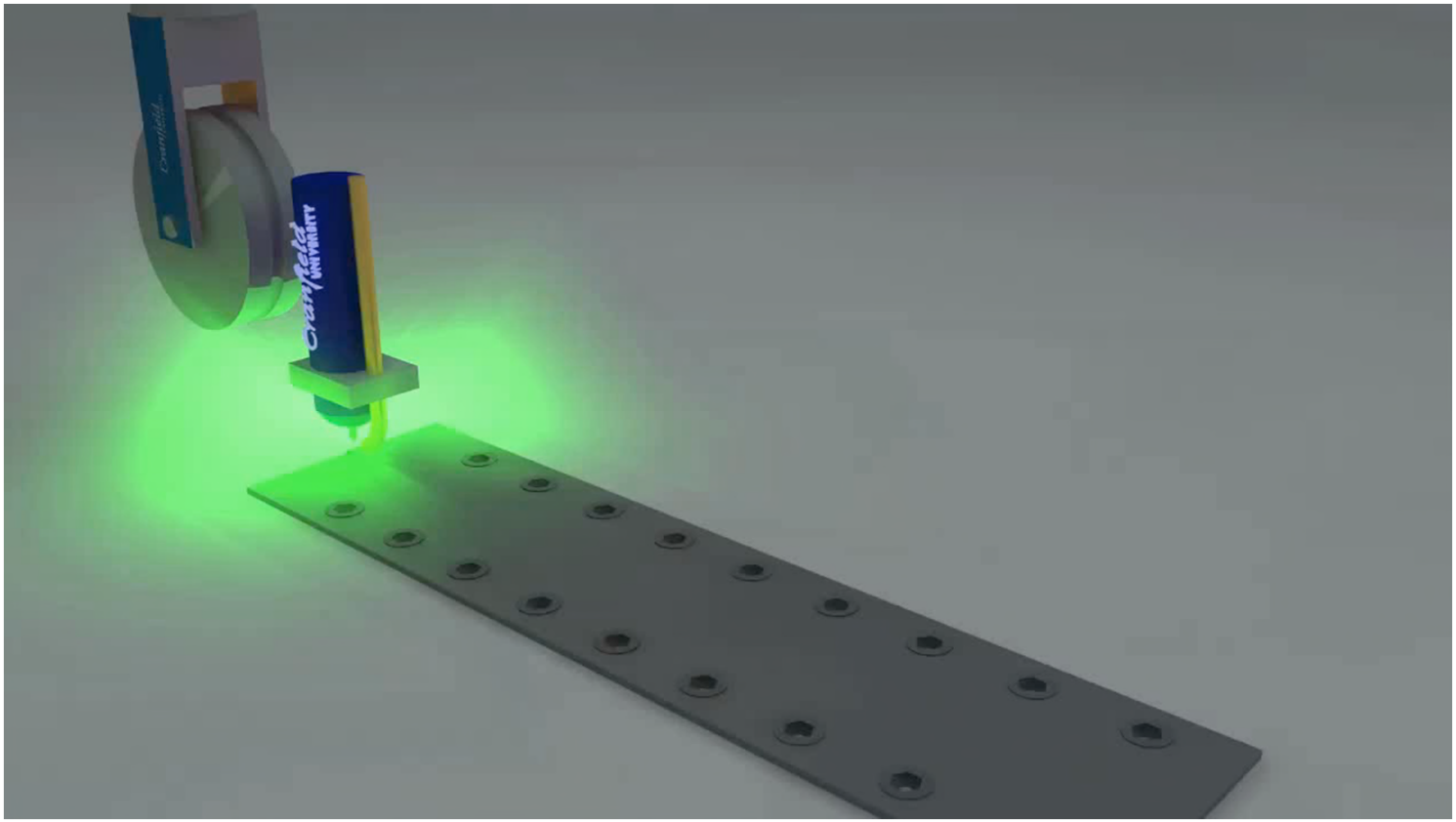


Effect of deposition strategy – Ti64



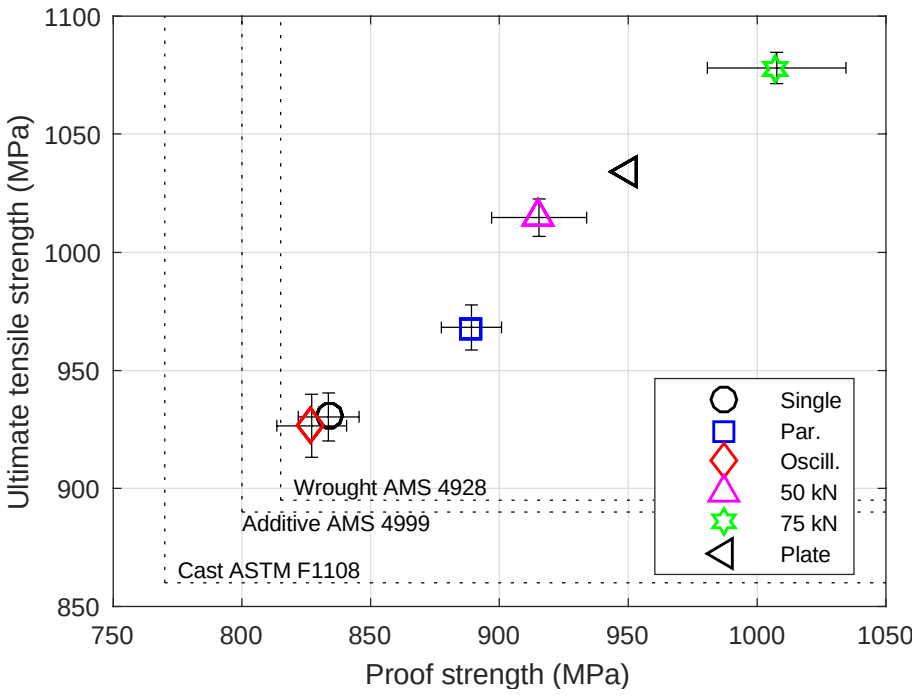
- Each will result in different cooling rates → different microstructures → different mechanical properties

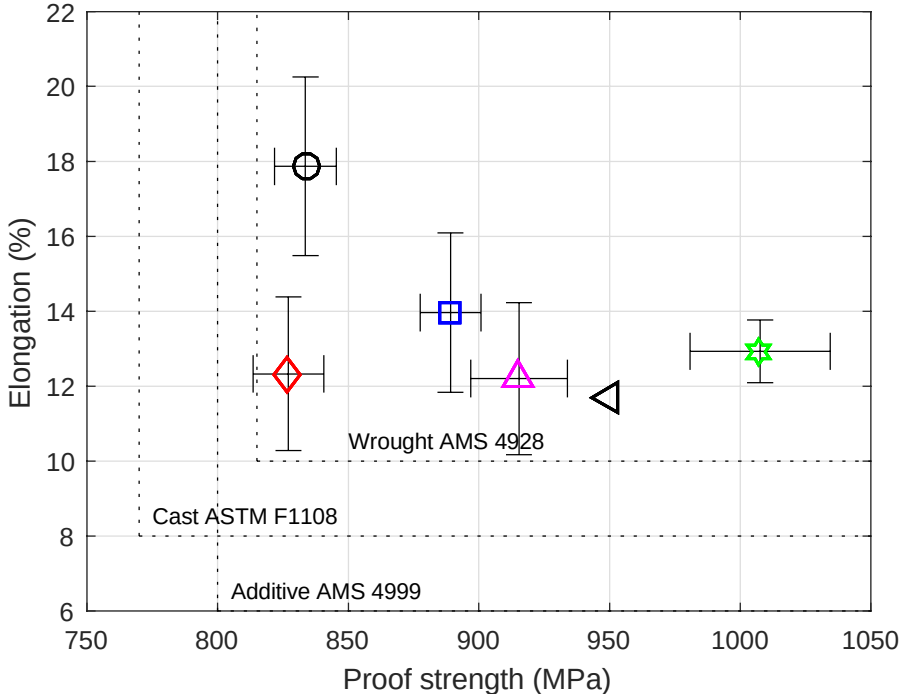
Unique features // High pressure rolling



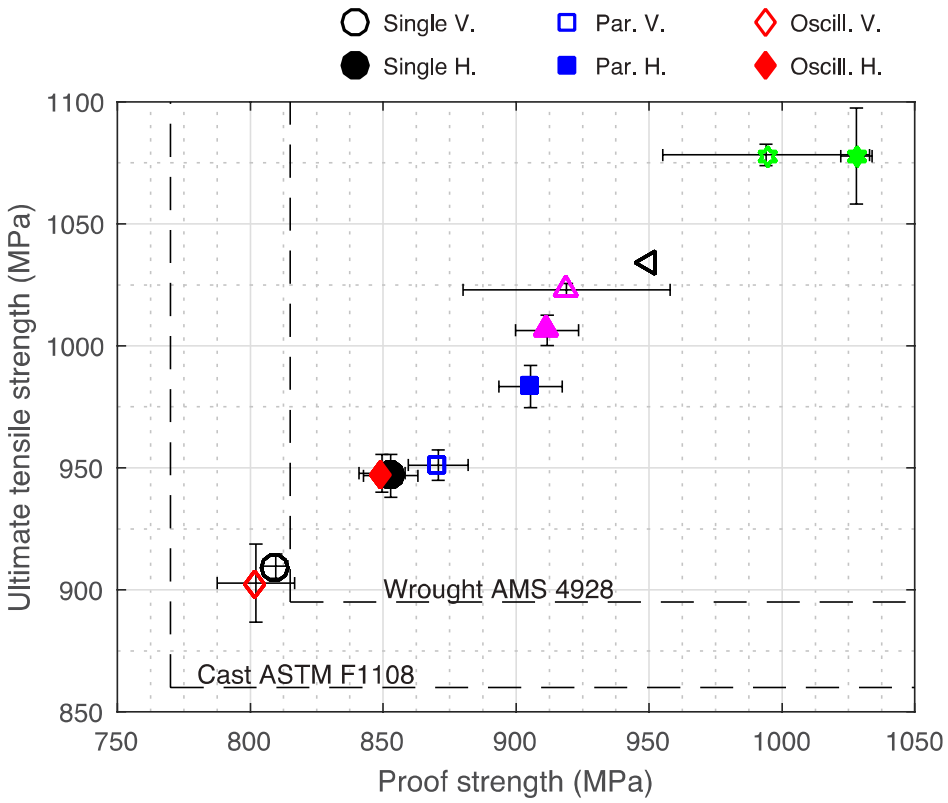
Ti64 // Microstructure with rolling

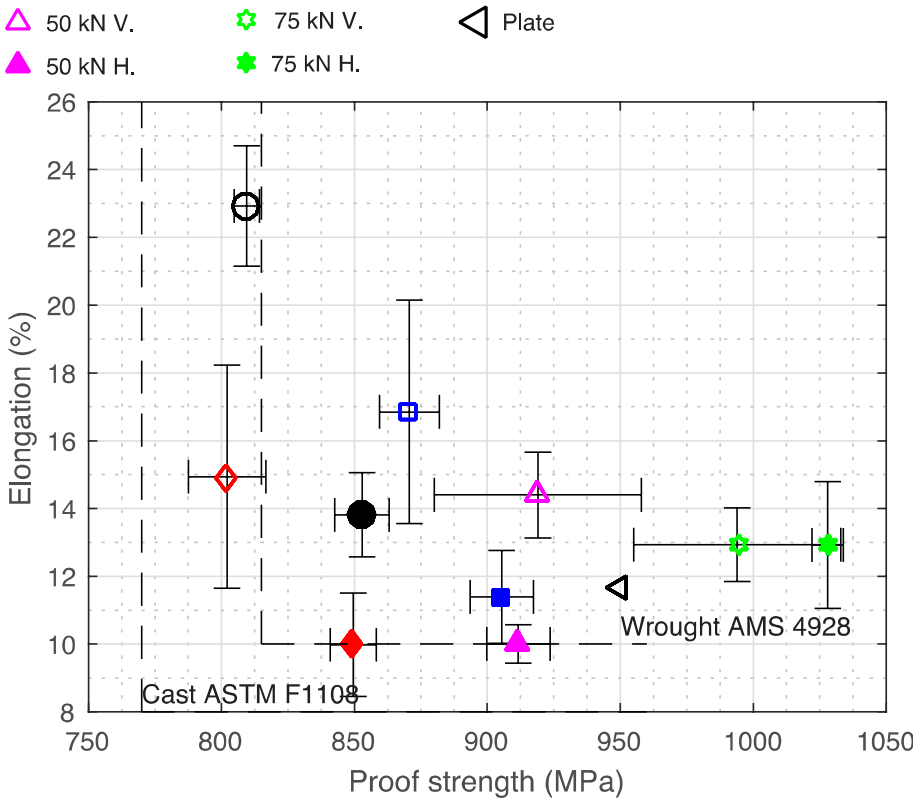
WAAM Ti64 without and with rolling (average)



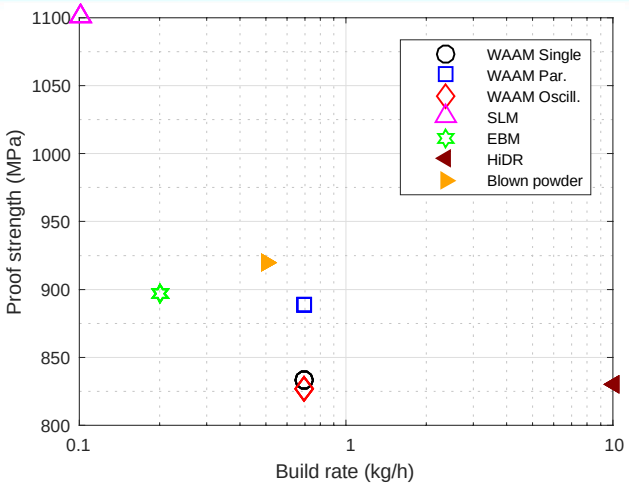


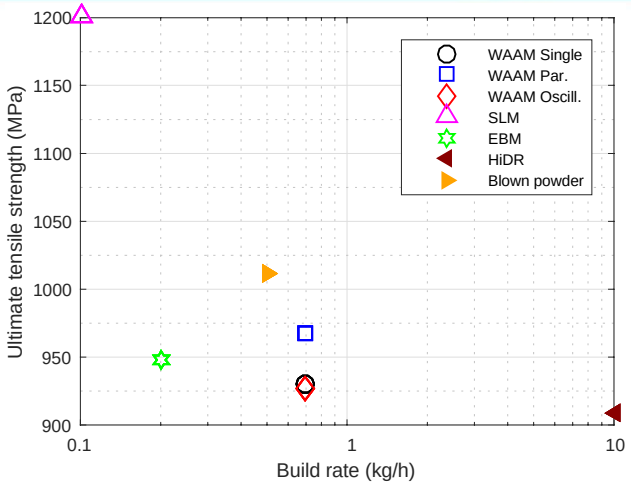
With rolling (direction)

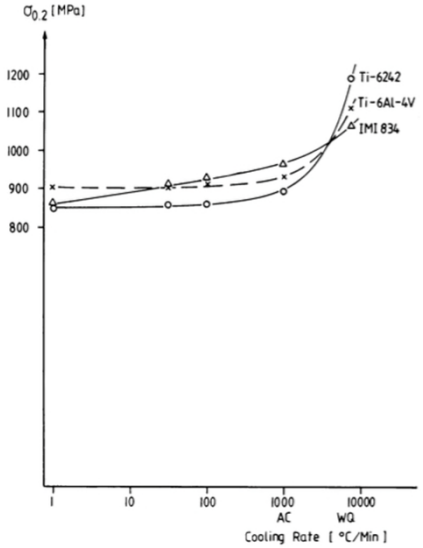


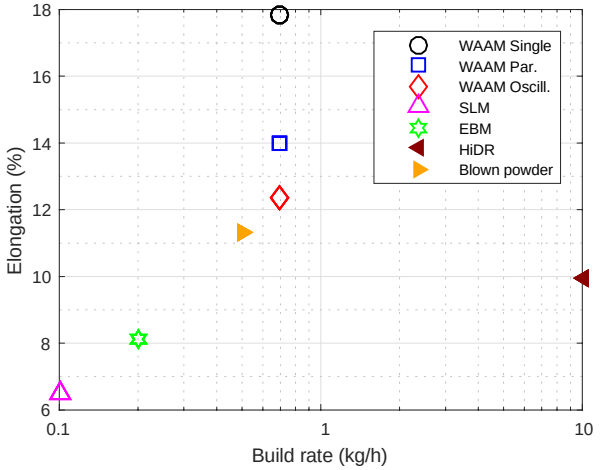


The effect of build/cooling rates









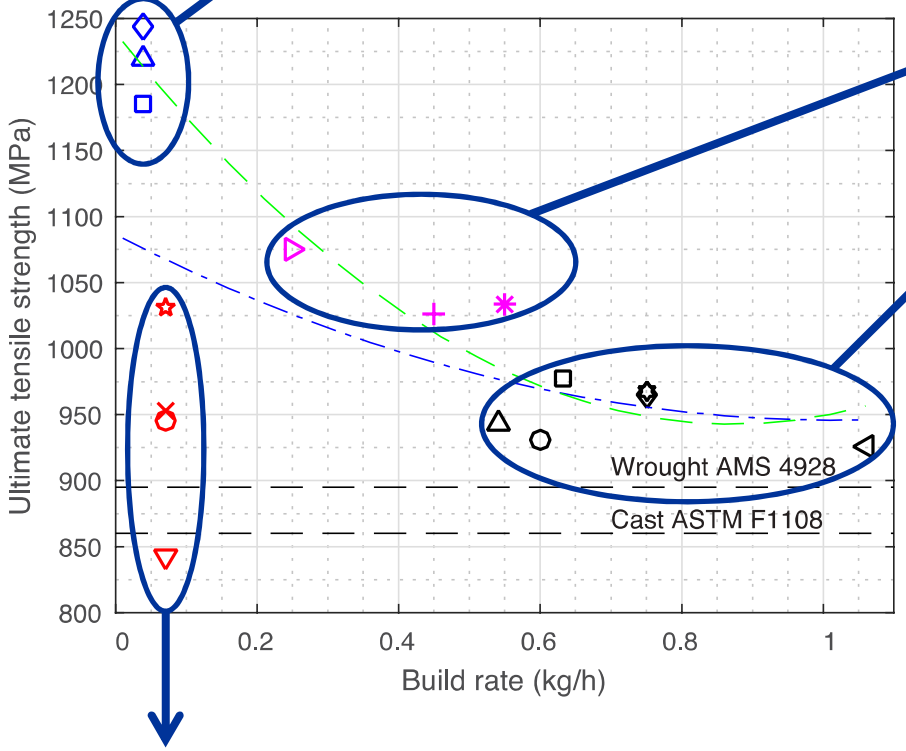
The effect of build/cooling rates

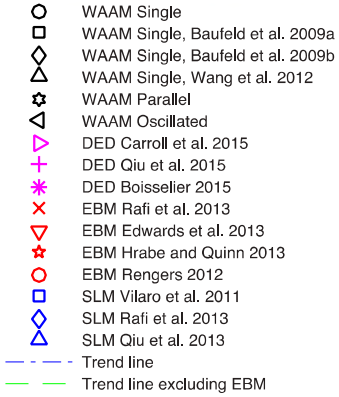
Laser powder bed

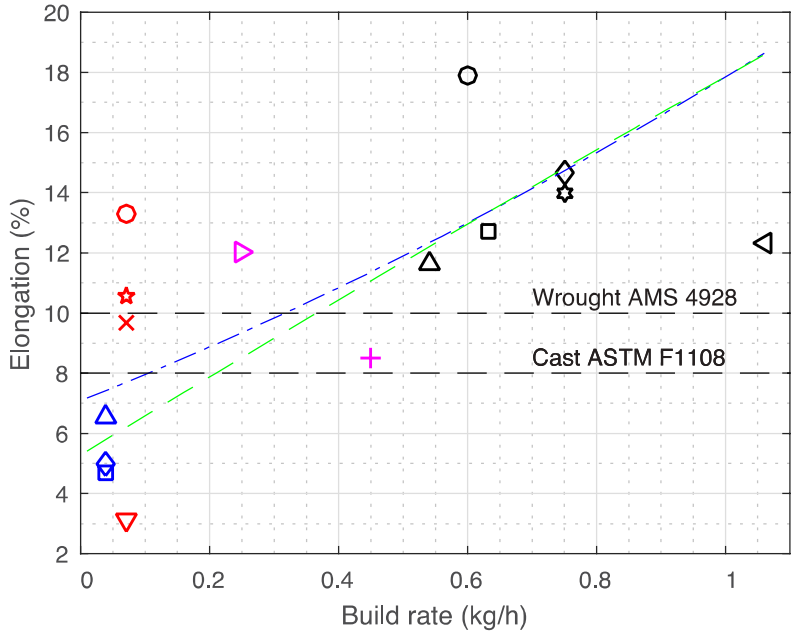
Laser blown powder

Arc +wire

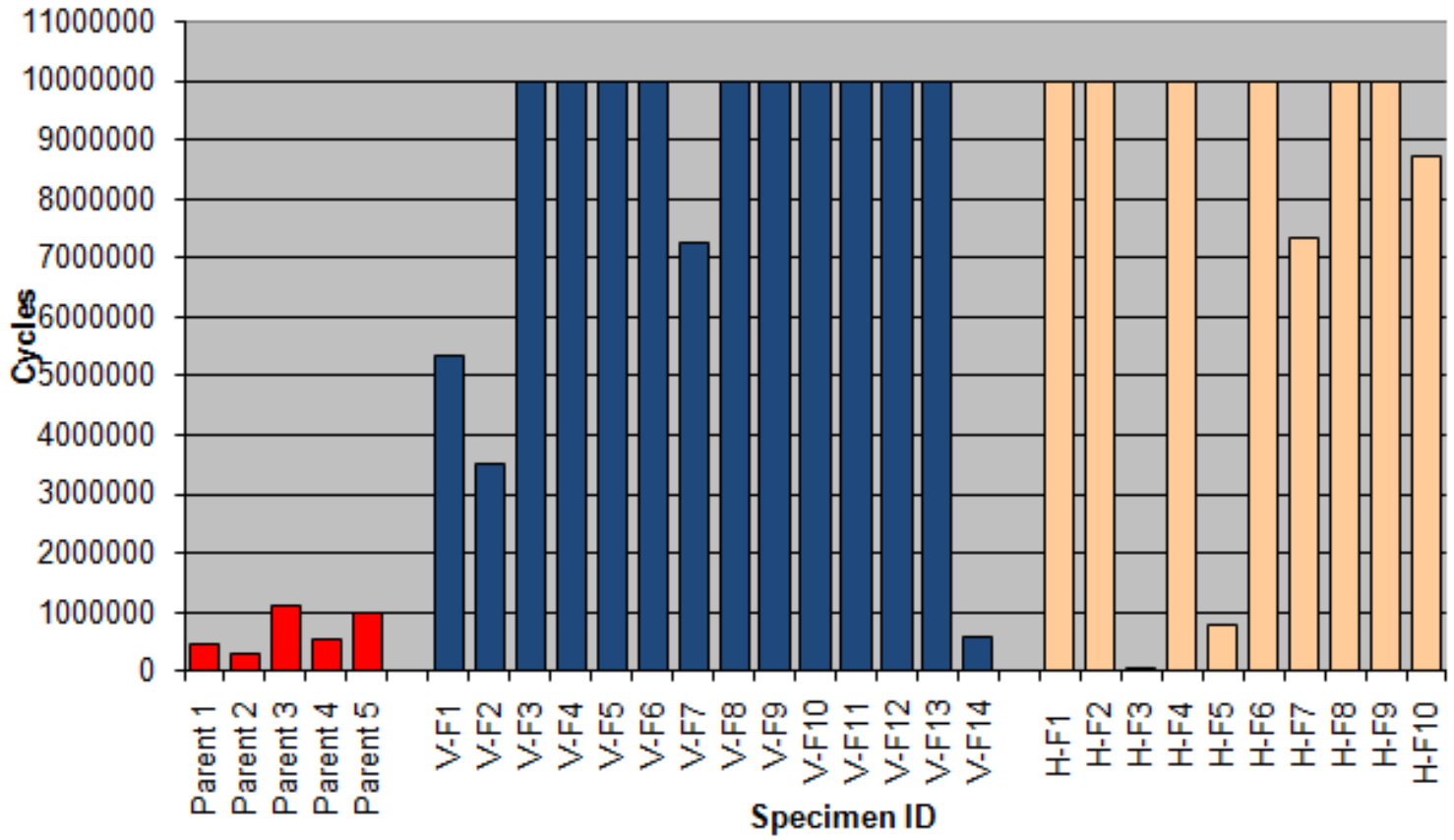
EB powder bed







Fatigue Vs Specimen direction



R-Ratio 0.1, σ_{max}=600MPa,Sinusoidal Waveform and 30Hz,

Improved fatigue performance

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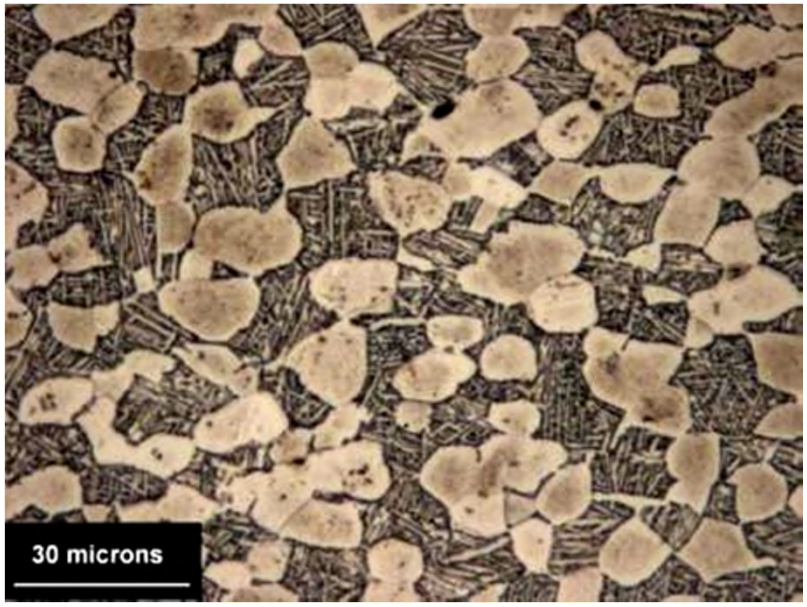
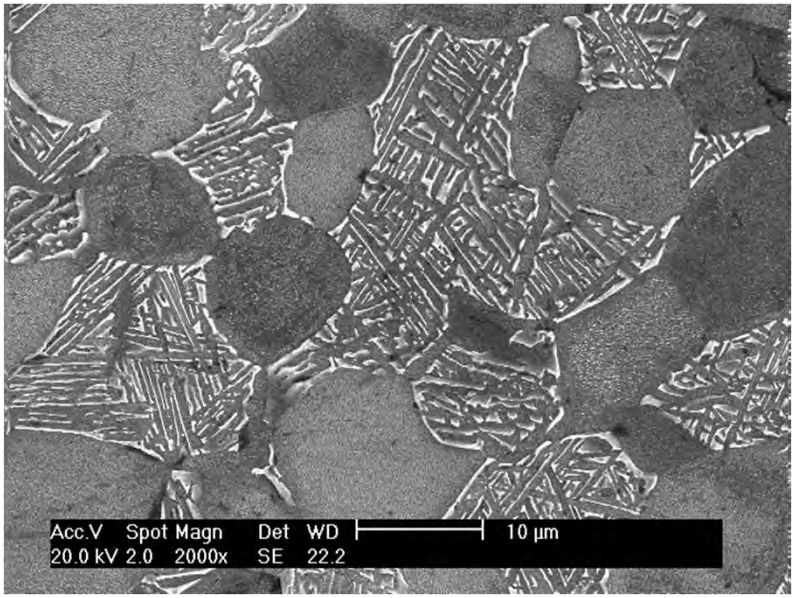
Wrought Ti64



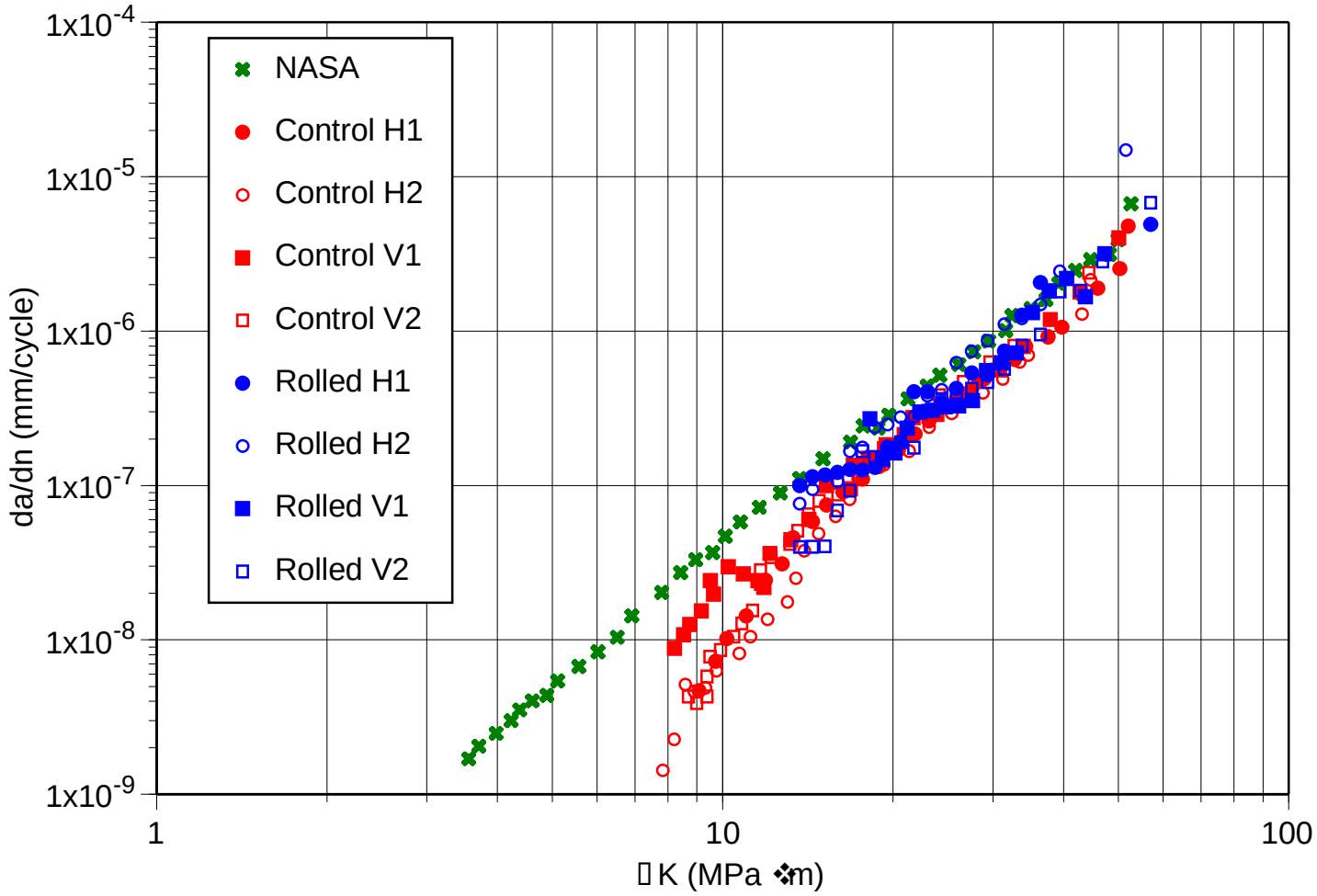


heterogeneous bi-modal (duplex) microstructure

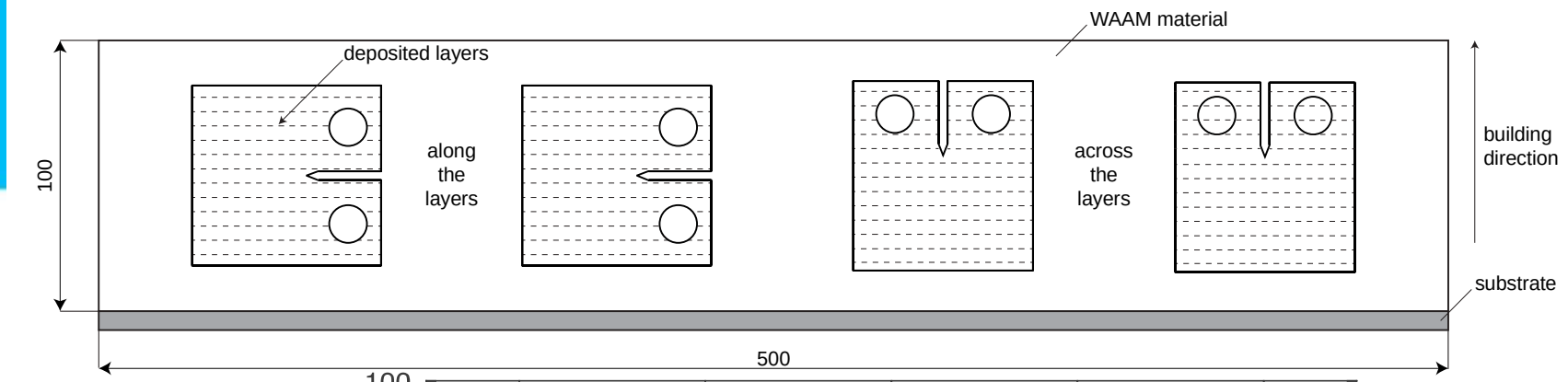
WAAM

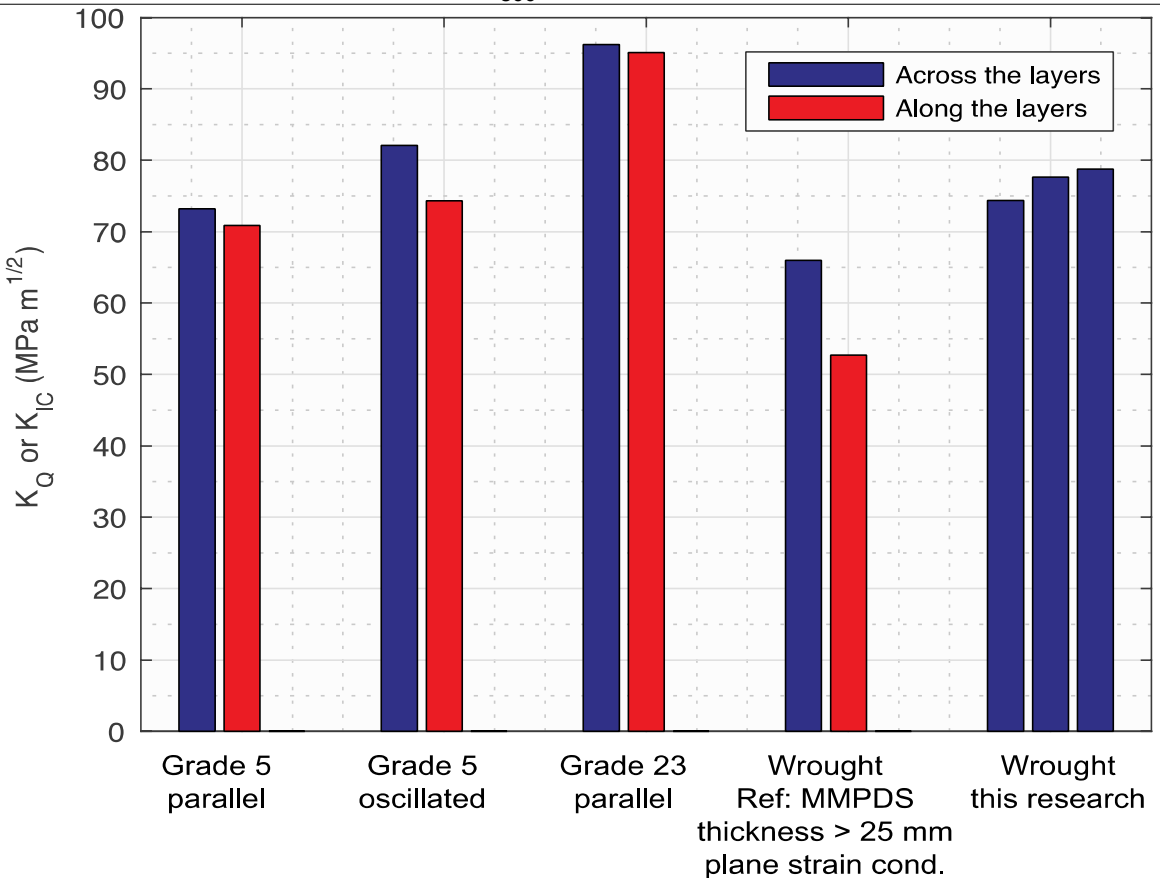
- **Wrought material initiates at primary α particle or casting pores**
- **WAAM material does not initiate (in this test) or initiates at very isolated pores due to wire contamination**

Ti64 // Rolling and FCGR of WAAM material unrolled and rolled



Ti64 // Fracture toughness





TI64 Crack growth trajectory at the interface

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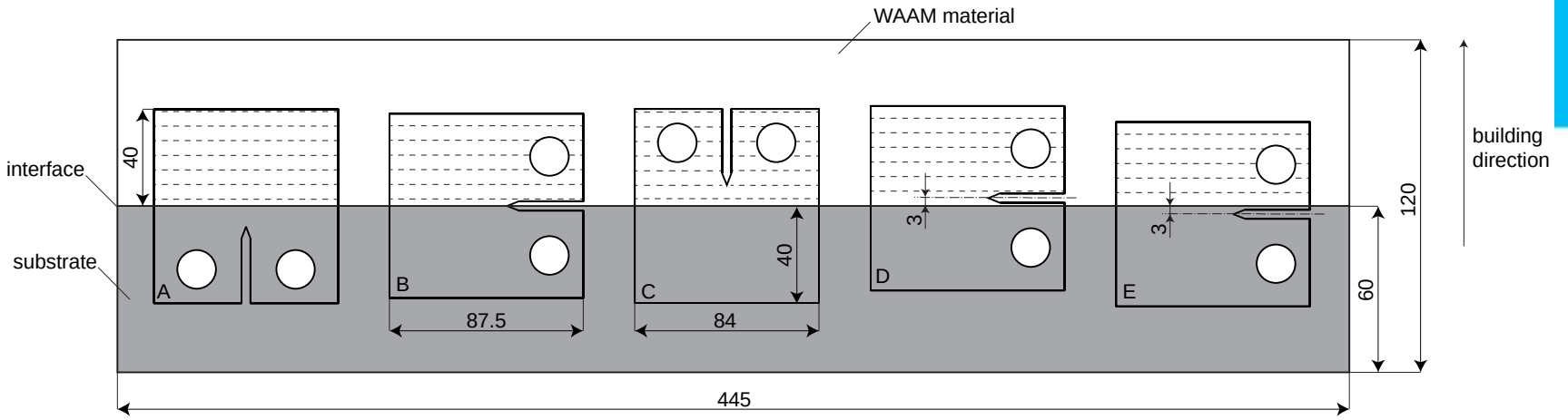
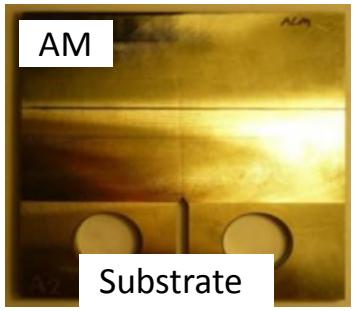
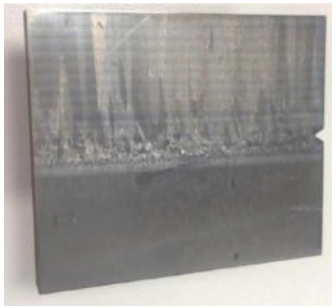
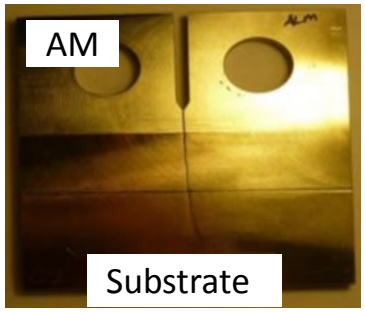
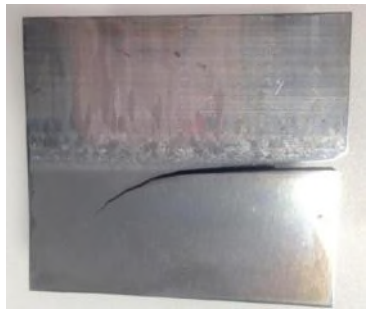






Crack trajectory maintains almost a straight line





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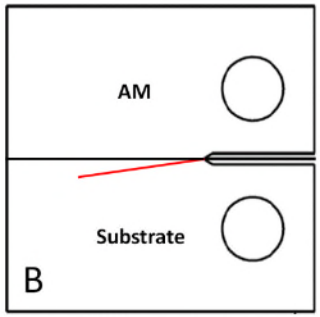
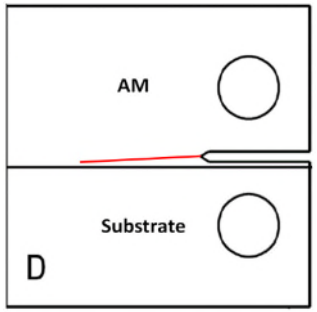
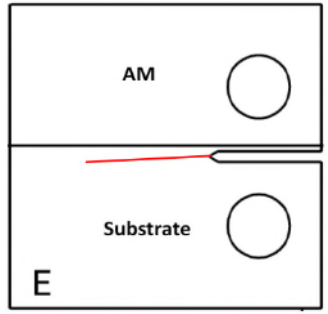
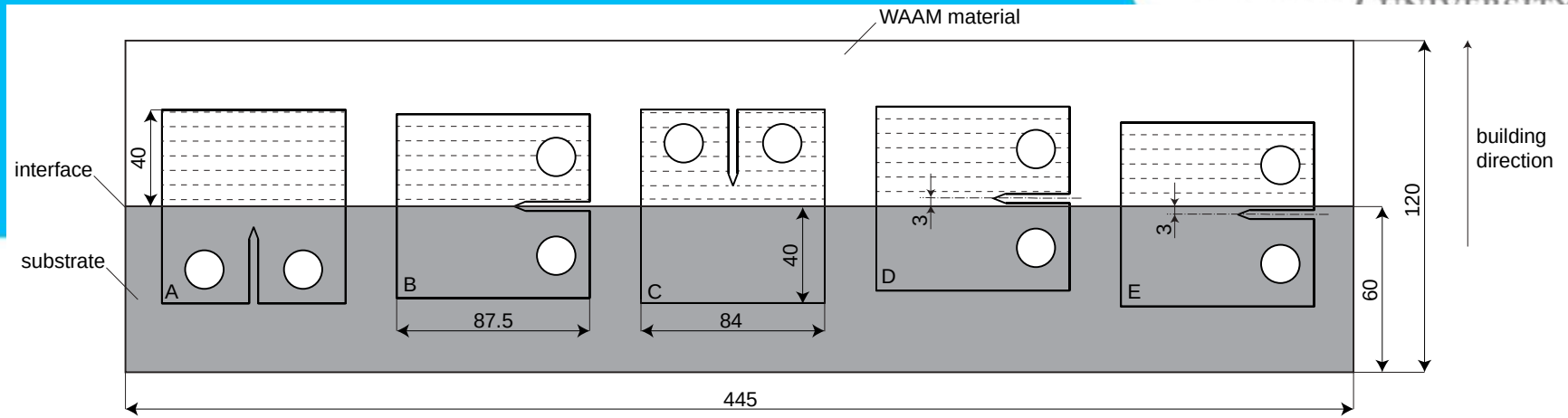
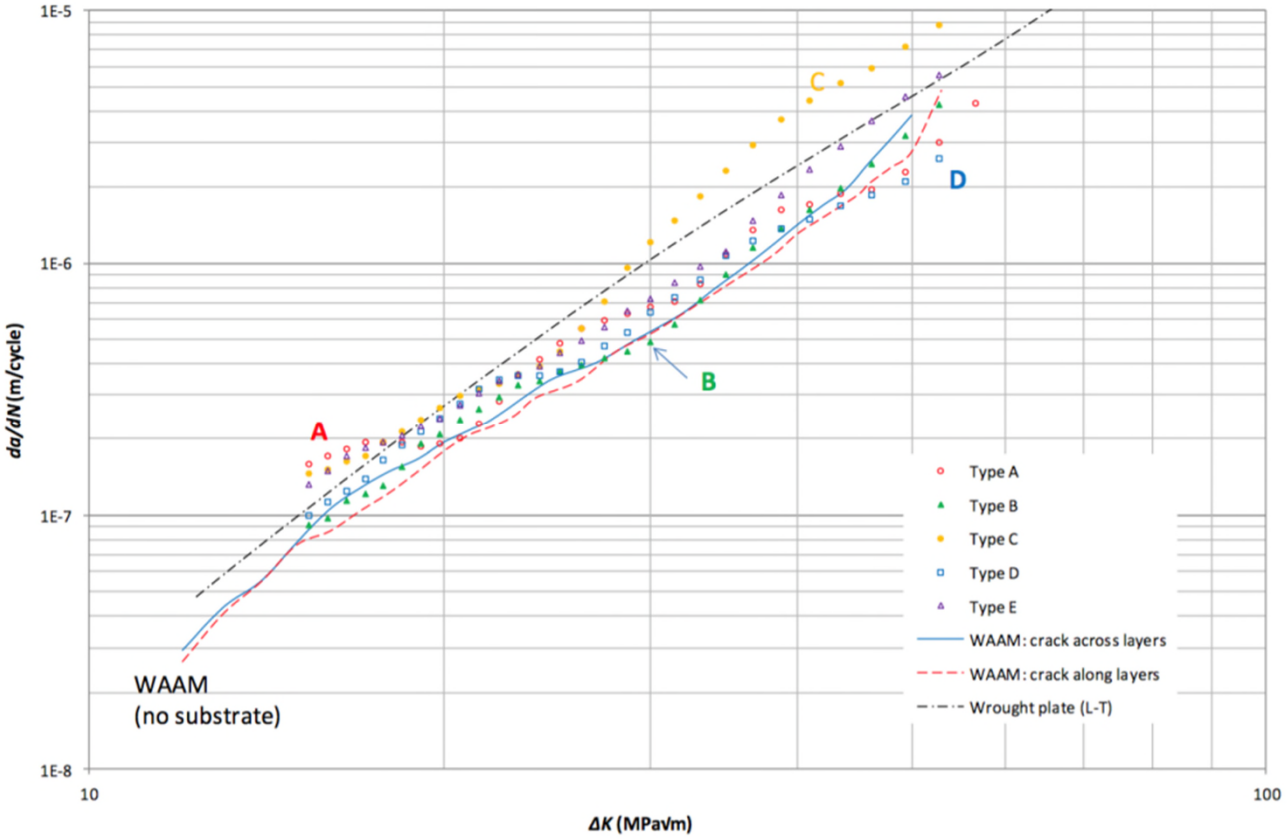






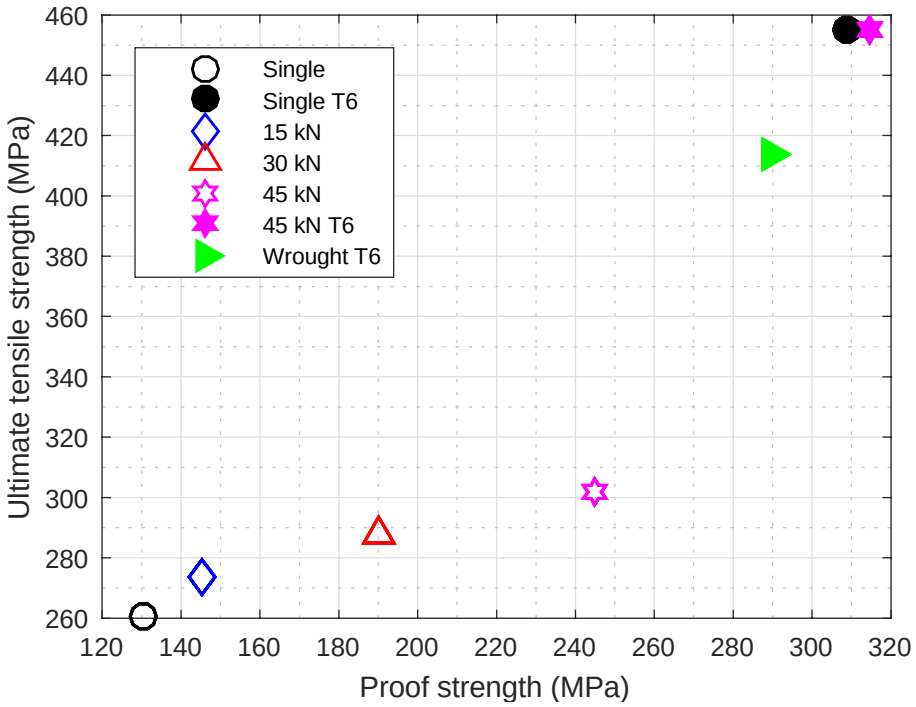
Ti64 // FCGR and interface

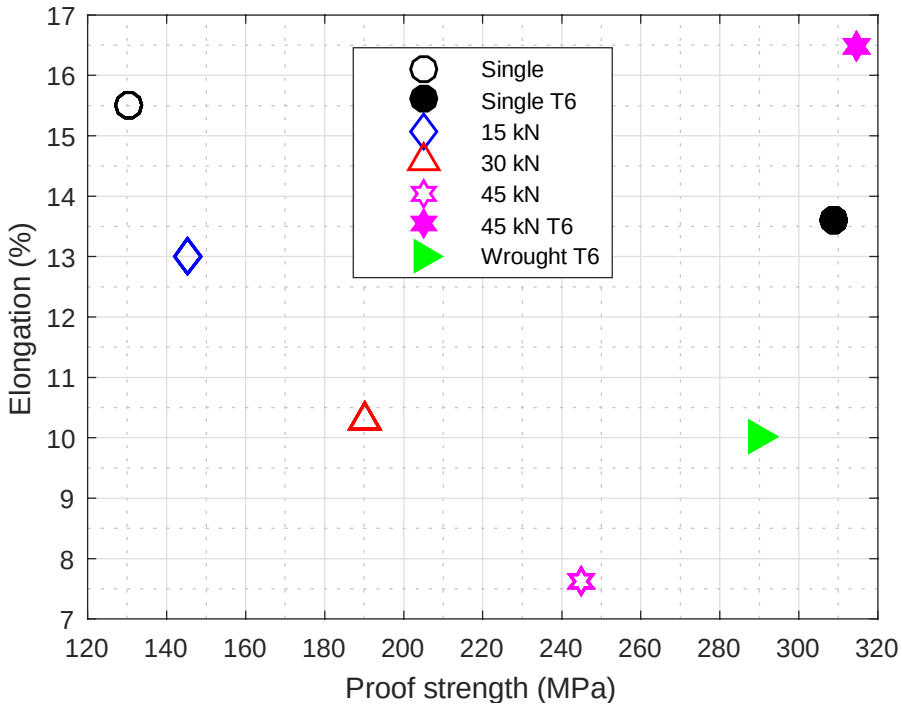




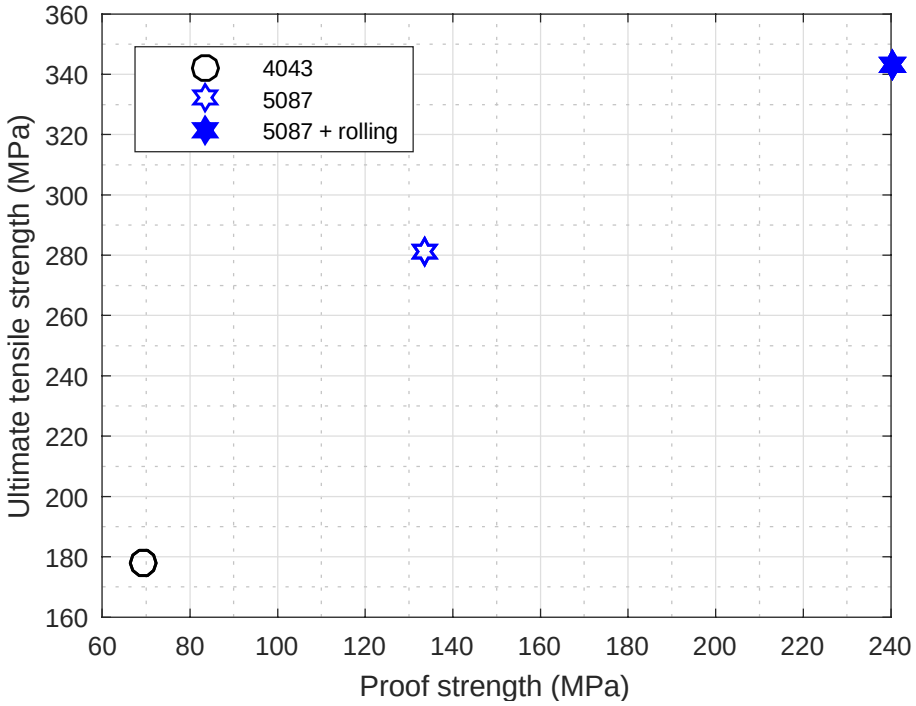
- C is 43-100% greater
- B is the best of this subset
- WAAM material has the slowest growth rate and is isotropic

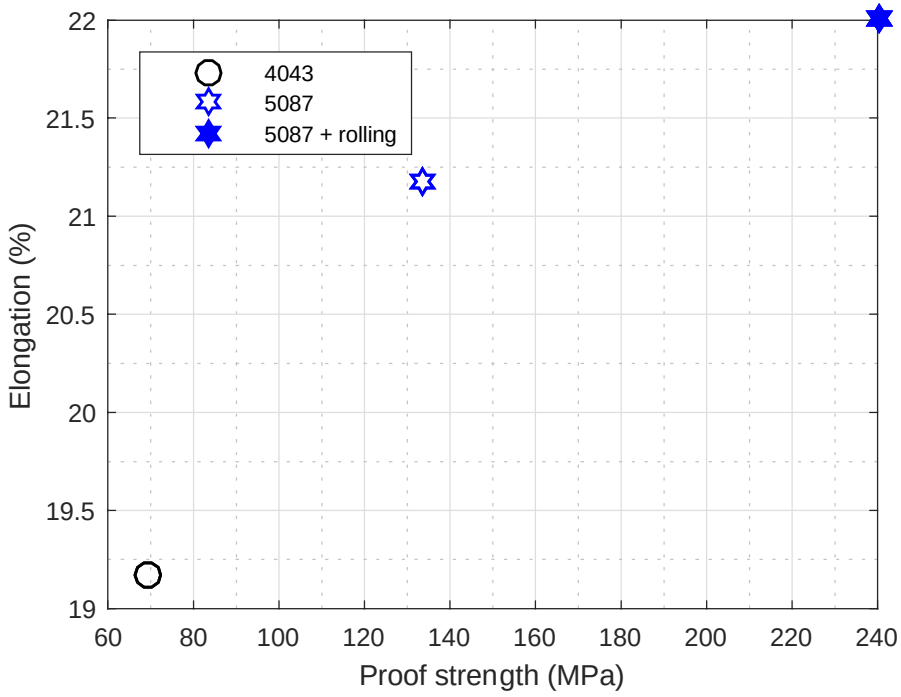
WAAM aluminium 2319





WAAM aluminium alloys 4043 and 5087

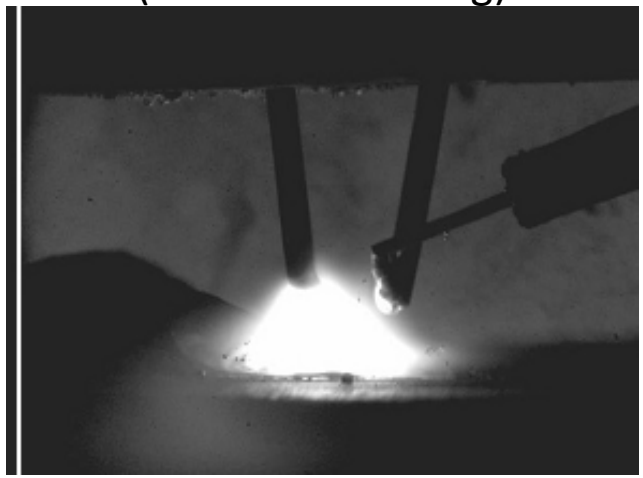




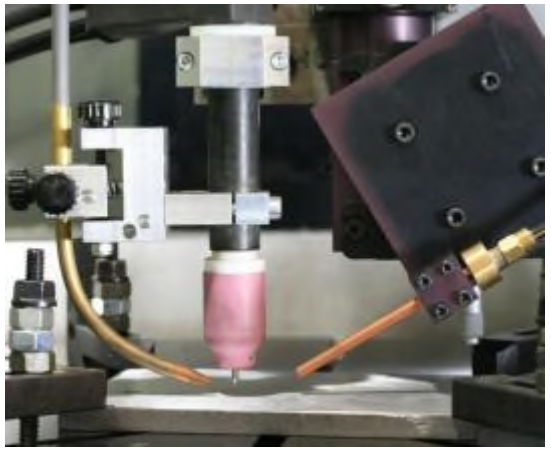
Composition control using multiple feeds

1 wire Al6%Cu– 100HV

2 wire (Al4.5%Cu1.5%Mg) – 120HV

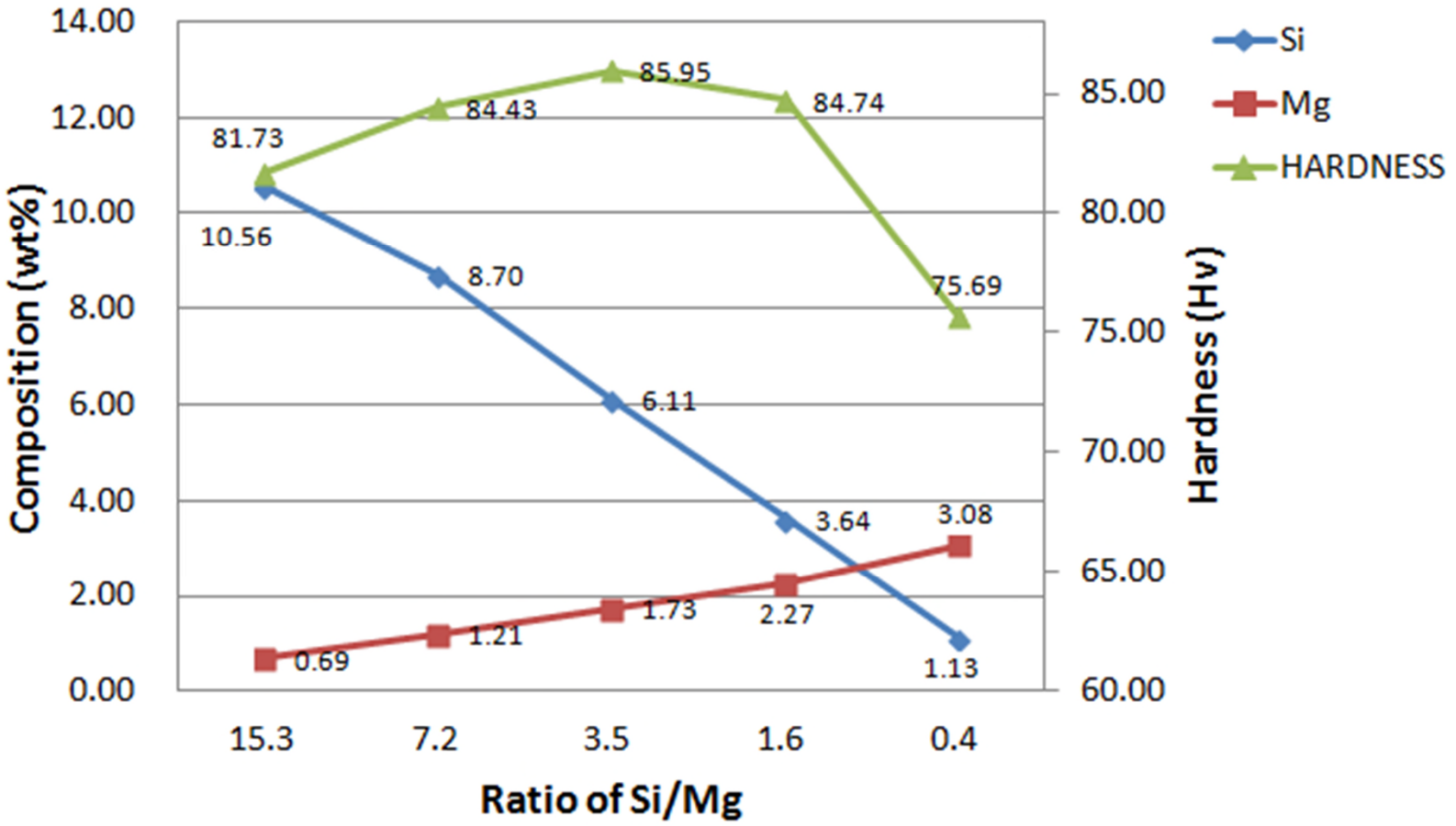


3 wire (Al8%Cu1.5%Mg – 140HV)

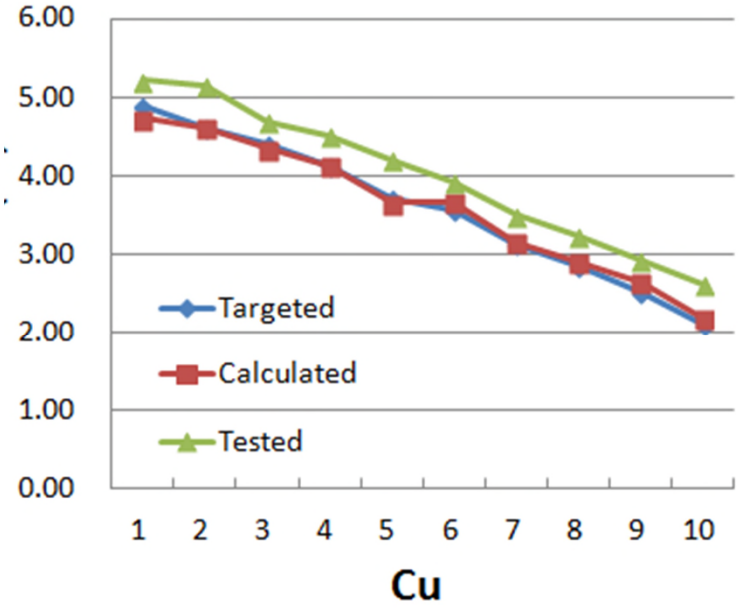


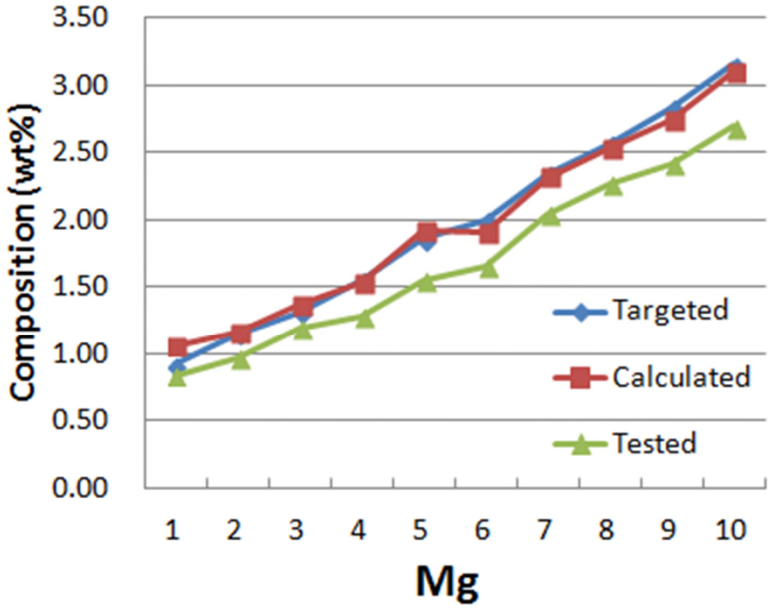
Wire + Powder

Aluminium alloy variable Si/Mg composition & hardness



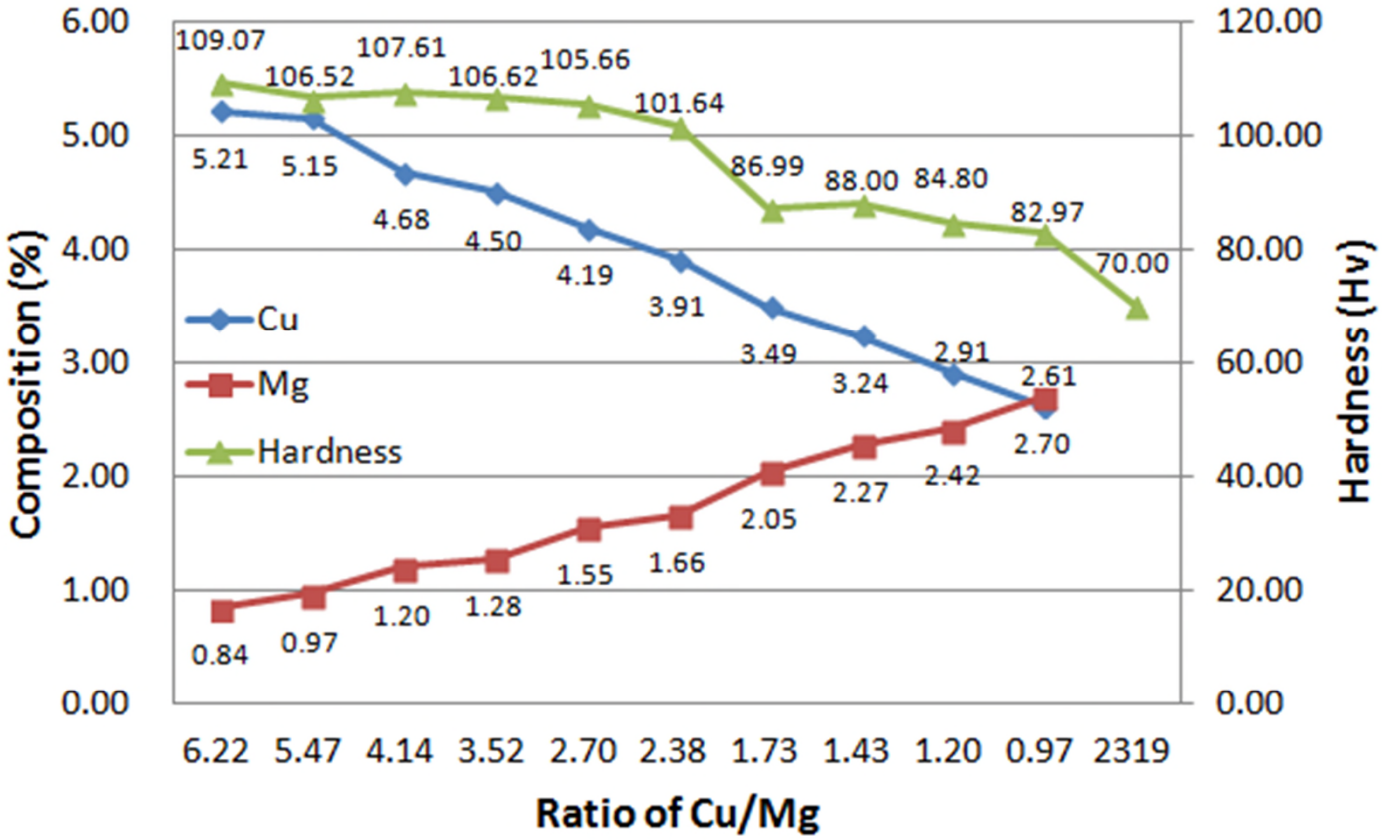
Aluminum alloy variable Cu/Mg composition



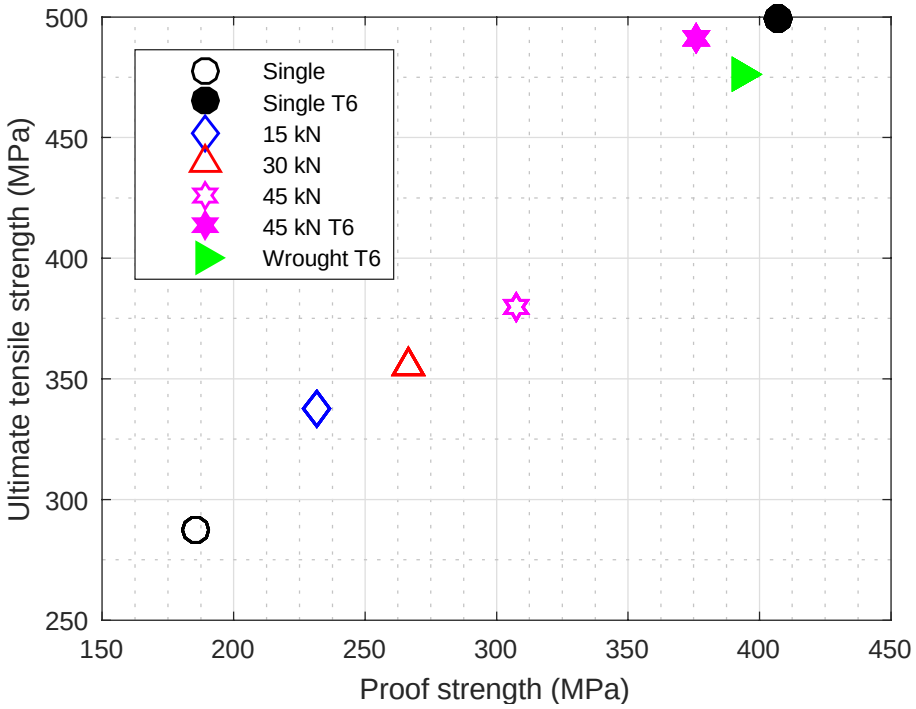


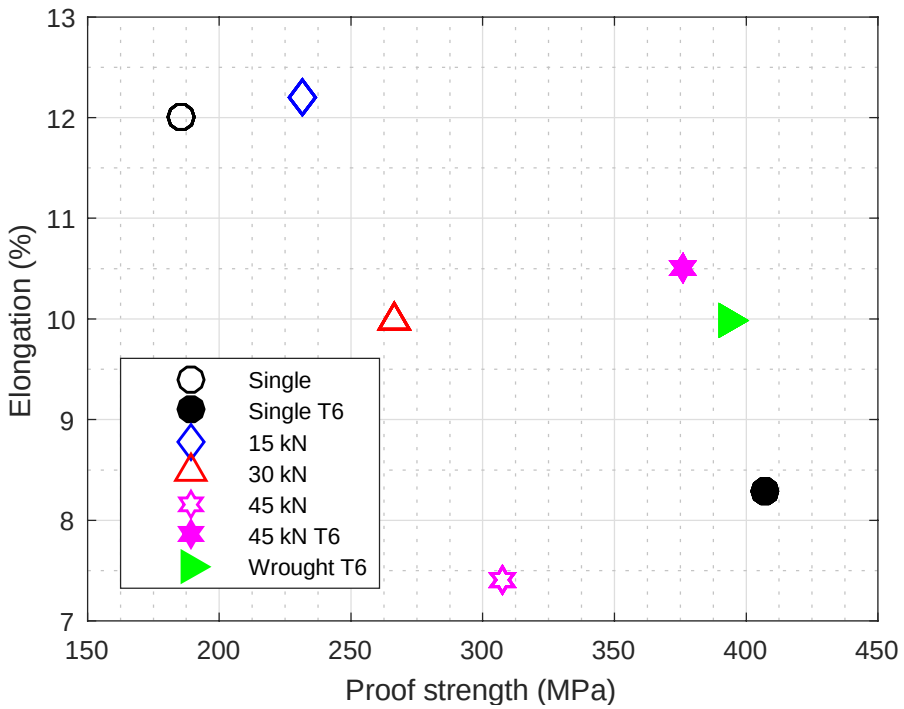
Wires: 2319+5087; Substrate: 2219

Tested Cu/Mg composition & hardness



WAAM aluminium 2024





Rolling + heat treatment porosity

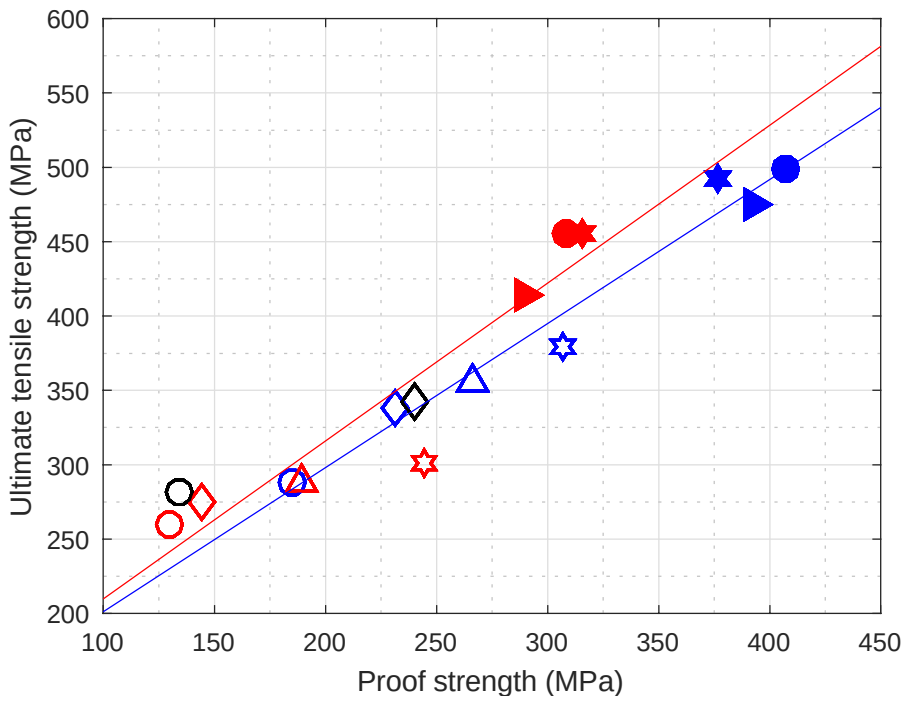
As deposited

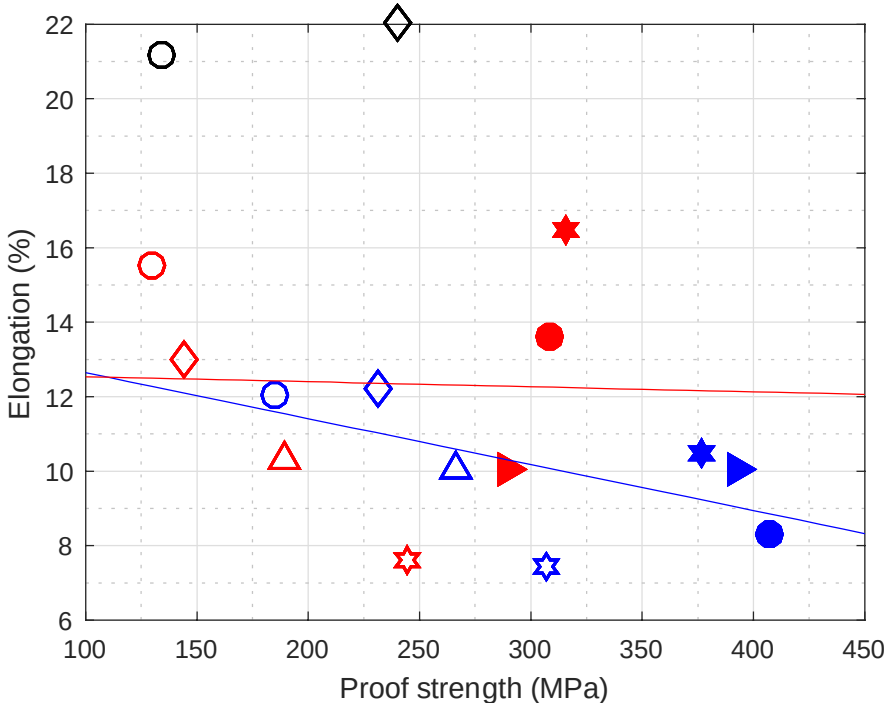
Heat treated ST+AA

Rolled + heat treated ST+AA

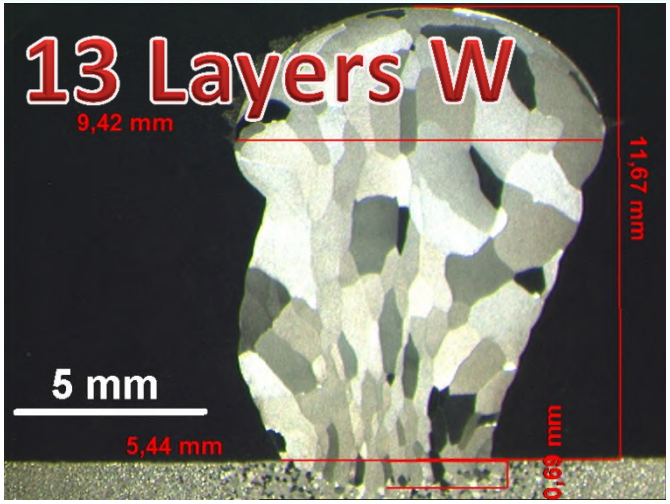
There is no porosity of the rolled + heat treated sample.

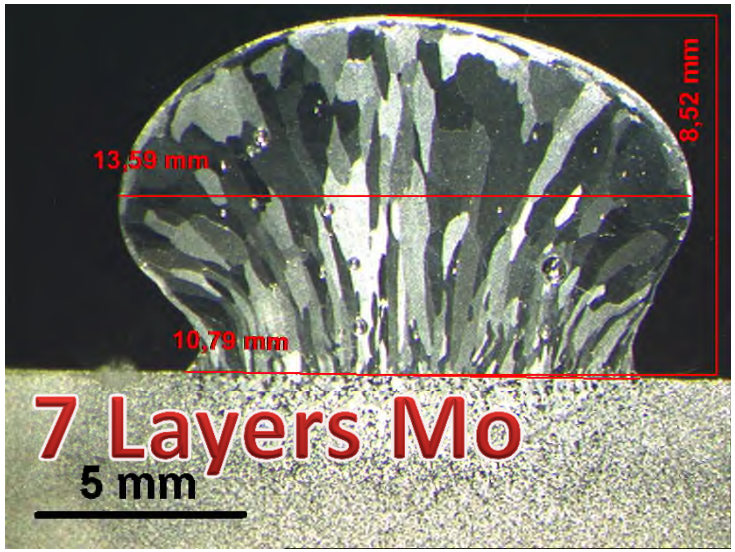
Aluminium properties (2024 – 2319 – 5087 (average))

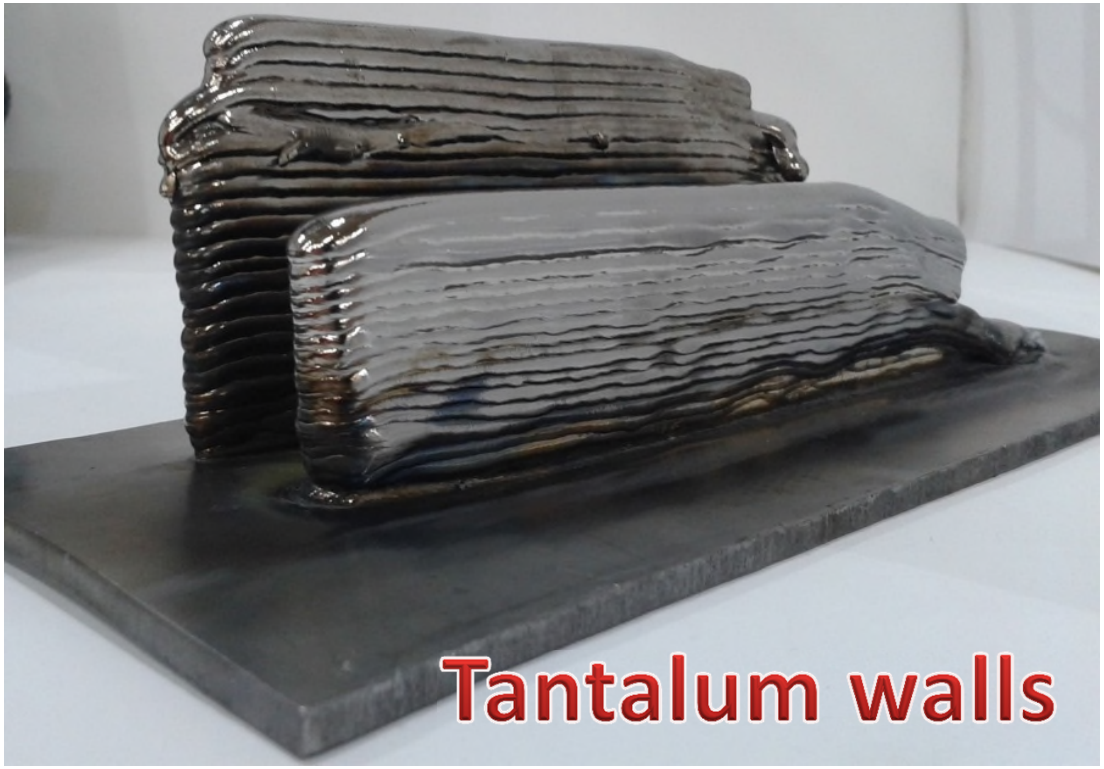




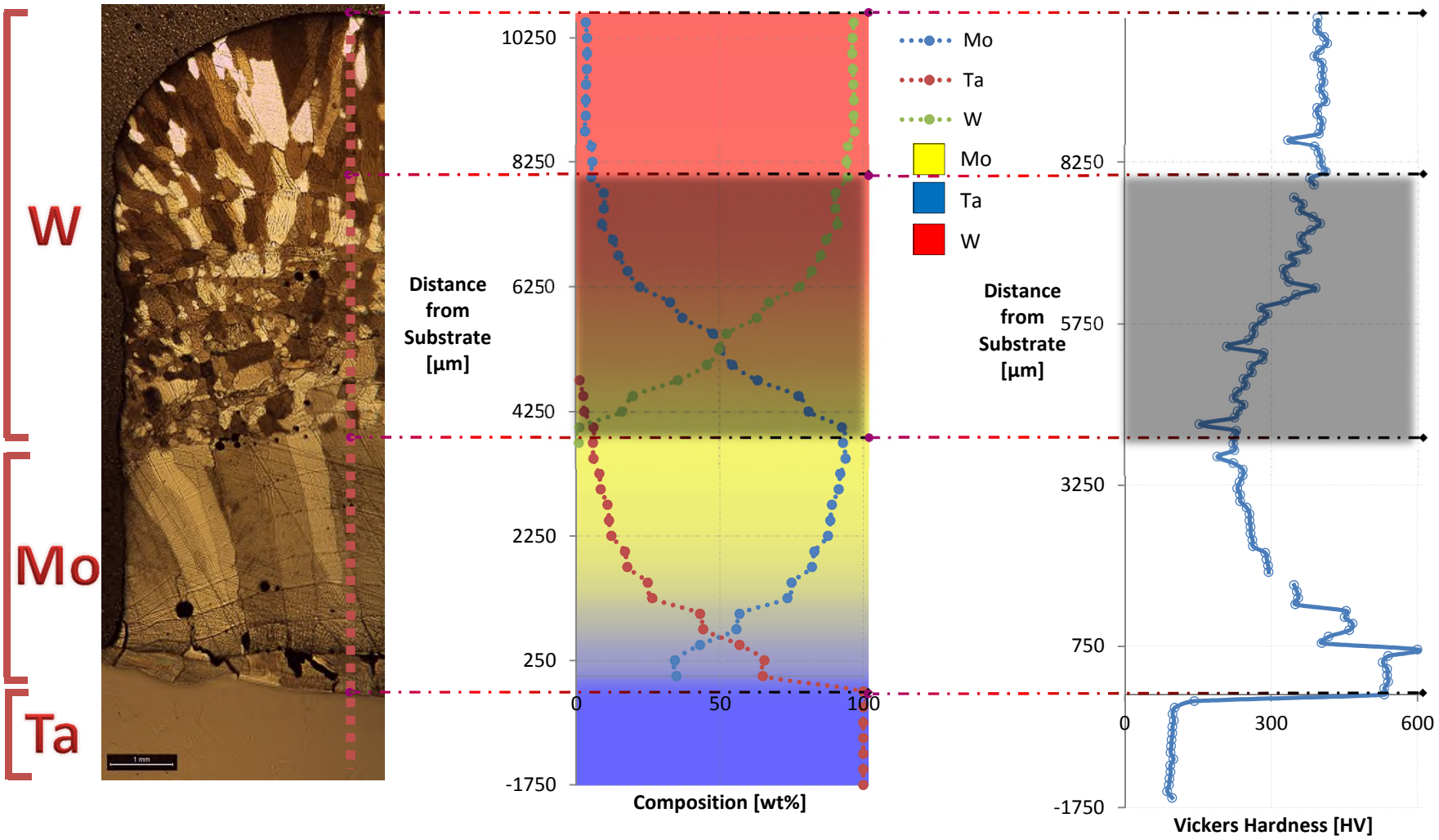
Refractory metal WAAM



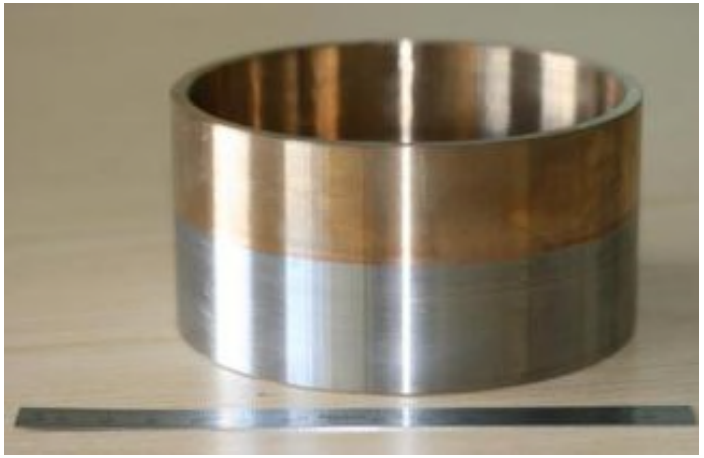


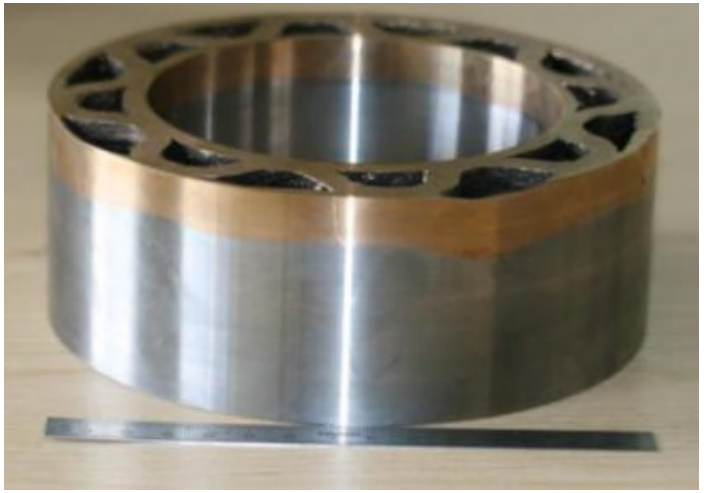


Graded Structure Ta/Mo/W (Chemical Analysis and Hardness)

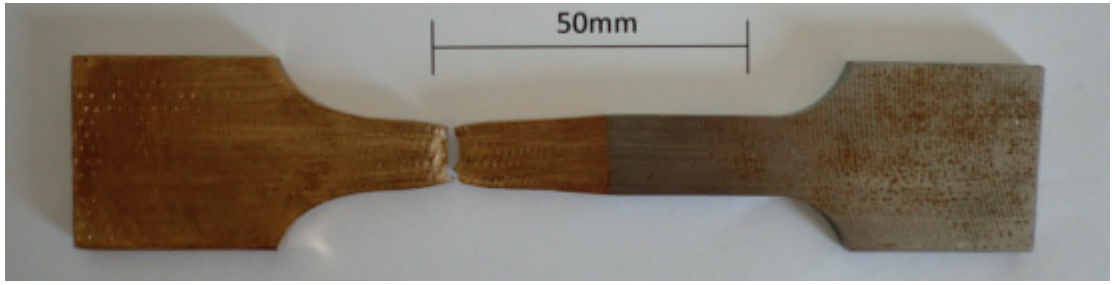


Mixed materials - copper and steel + WC





Steel/bronze (CuSi3%) parts



Yield 140 MPa, UTS 300 MPa, elongation 12%, failure in bronze

Copper on steel with WC ceramic added

Future Developments

- Commercial WAAM systems - both CNC and robotic
- Control and toolpath planning software to drive them
- Very large scale systems
- Parallel process systems (multi deposition, on-line NDT/metrology)

Summary

- WAAM is an excellent process for large scale additive manufacture of a wide range of materials
- Mechanical properties are excellent
- With cold work mechanical properties cam exceed those of forged materials

WAAMMat website

WAAMMat website www.waammat.com

THANK YOU FOR YOUR ATTENTION - ANY QUESTIONS ☺

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