



## Recap of mechanical properties

[waamm.com](http://waamm.com)

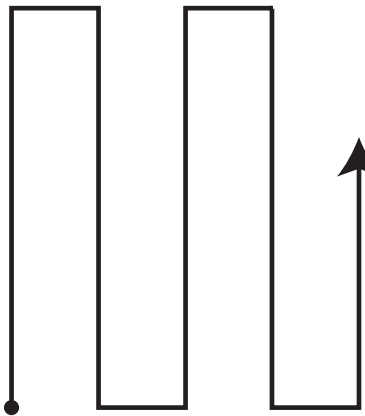
Updated 31<sup>st</sup> October 2019

[www.cranfield.ac.uk](http://www.cranfield.ac.uk)

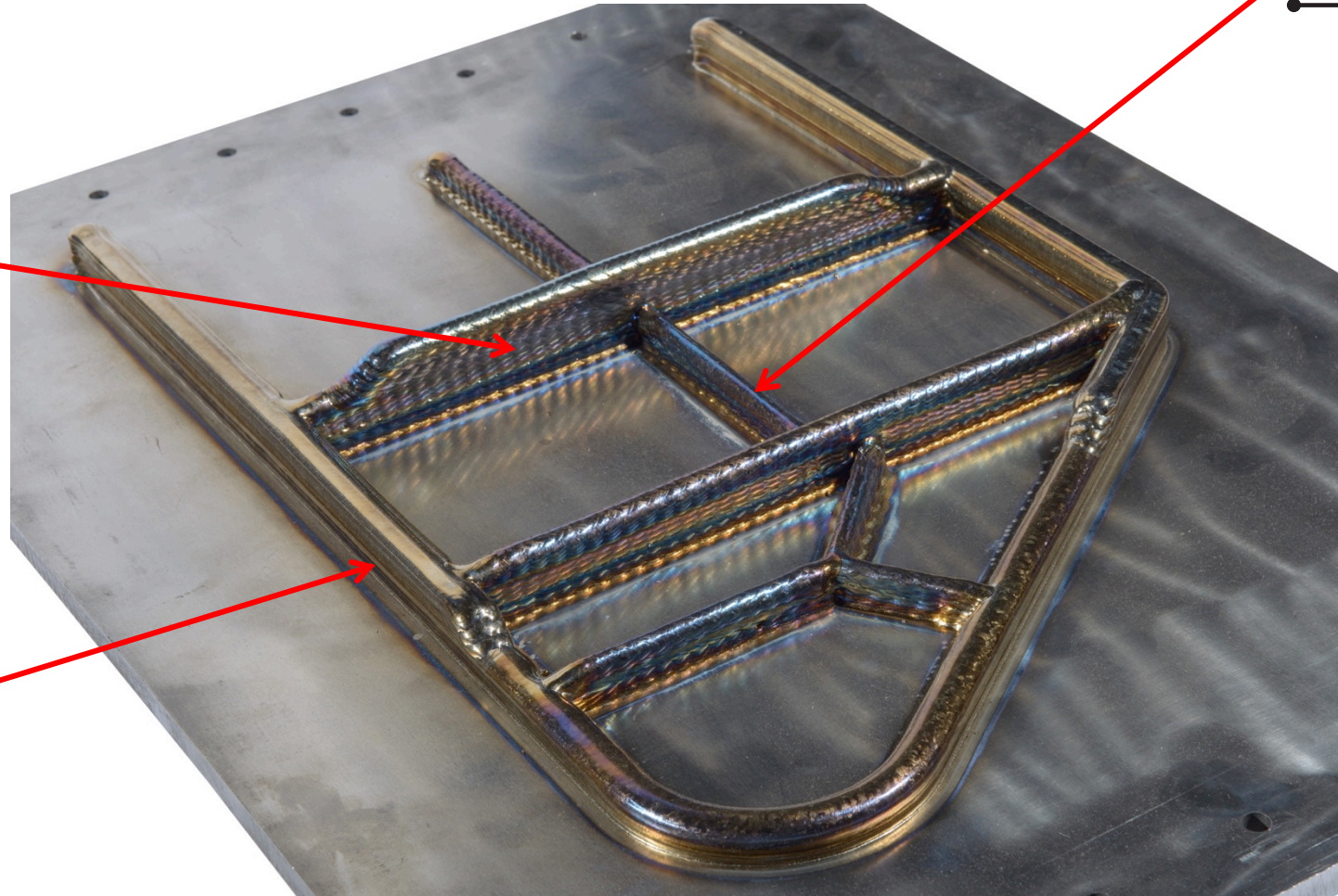
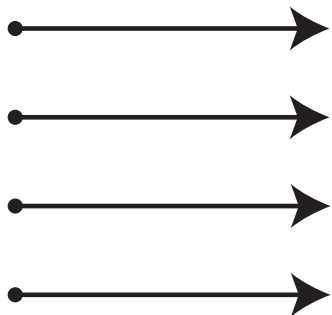
**WAAM**®

# The deposition strategies

Oscillation

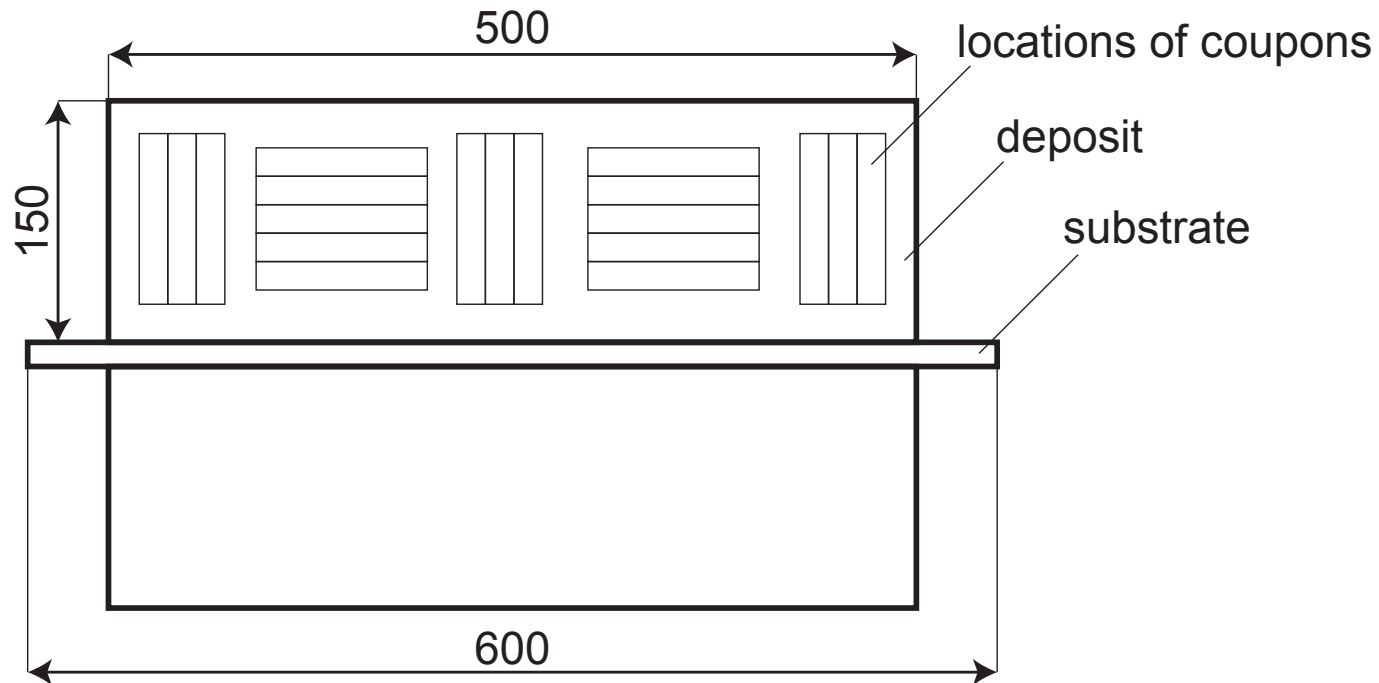
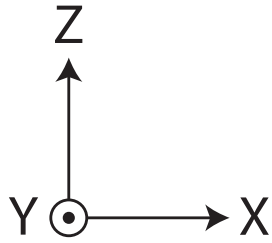


Parallel passes

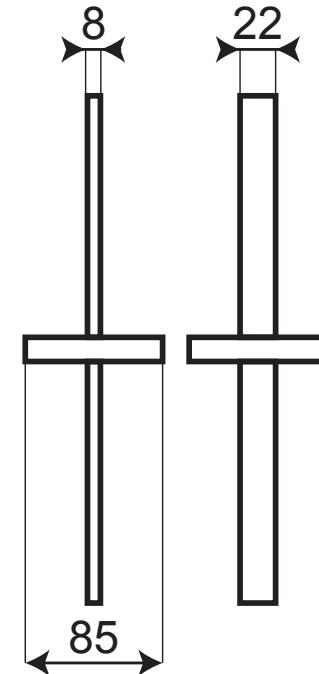
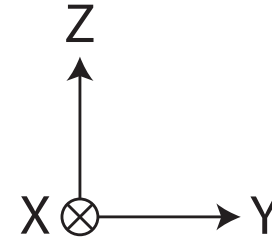


# Ti64 // Cutting plan for static properties

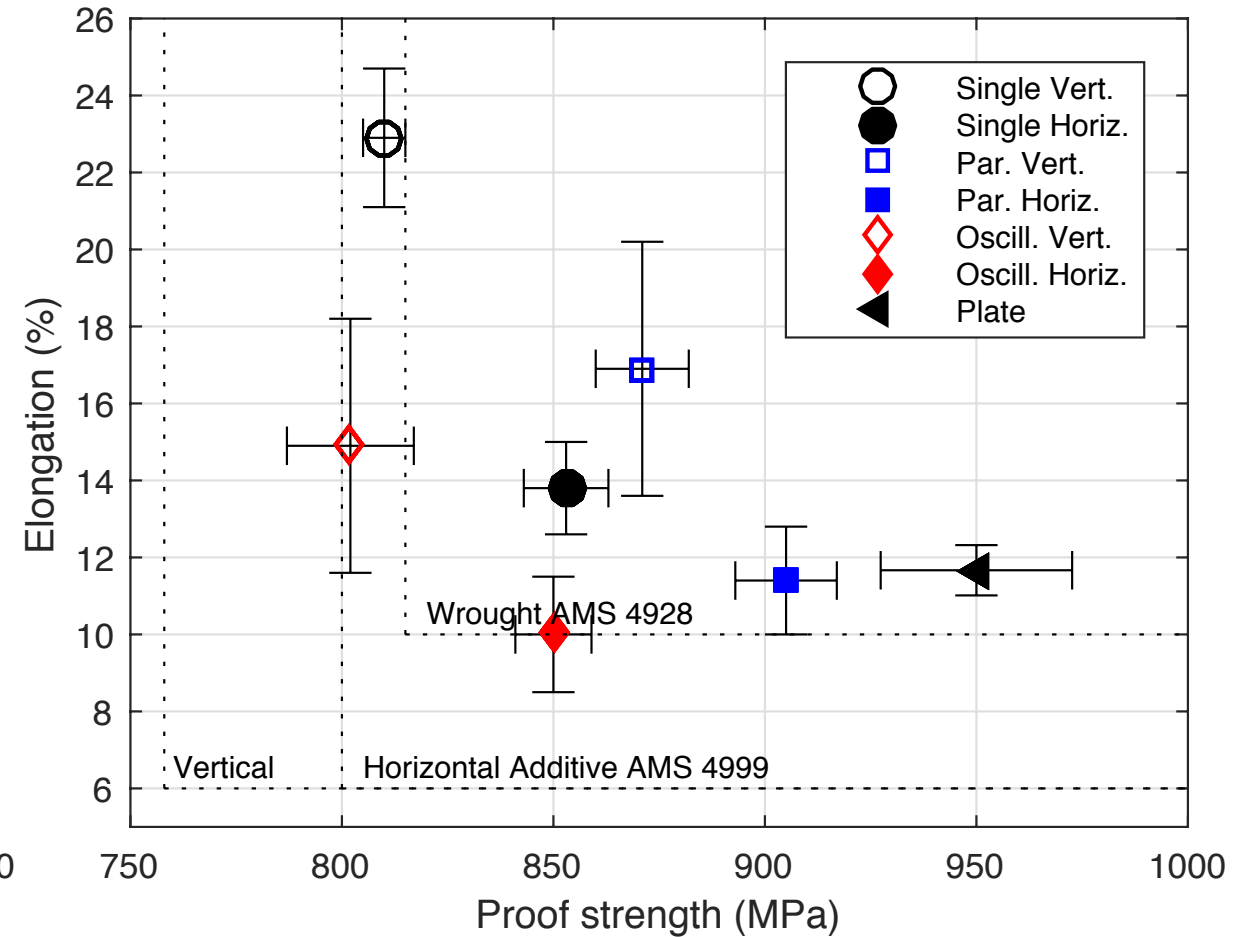
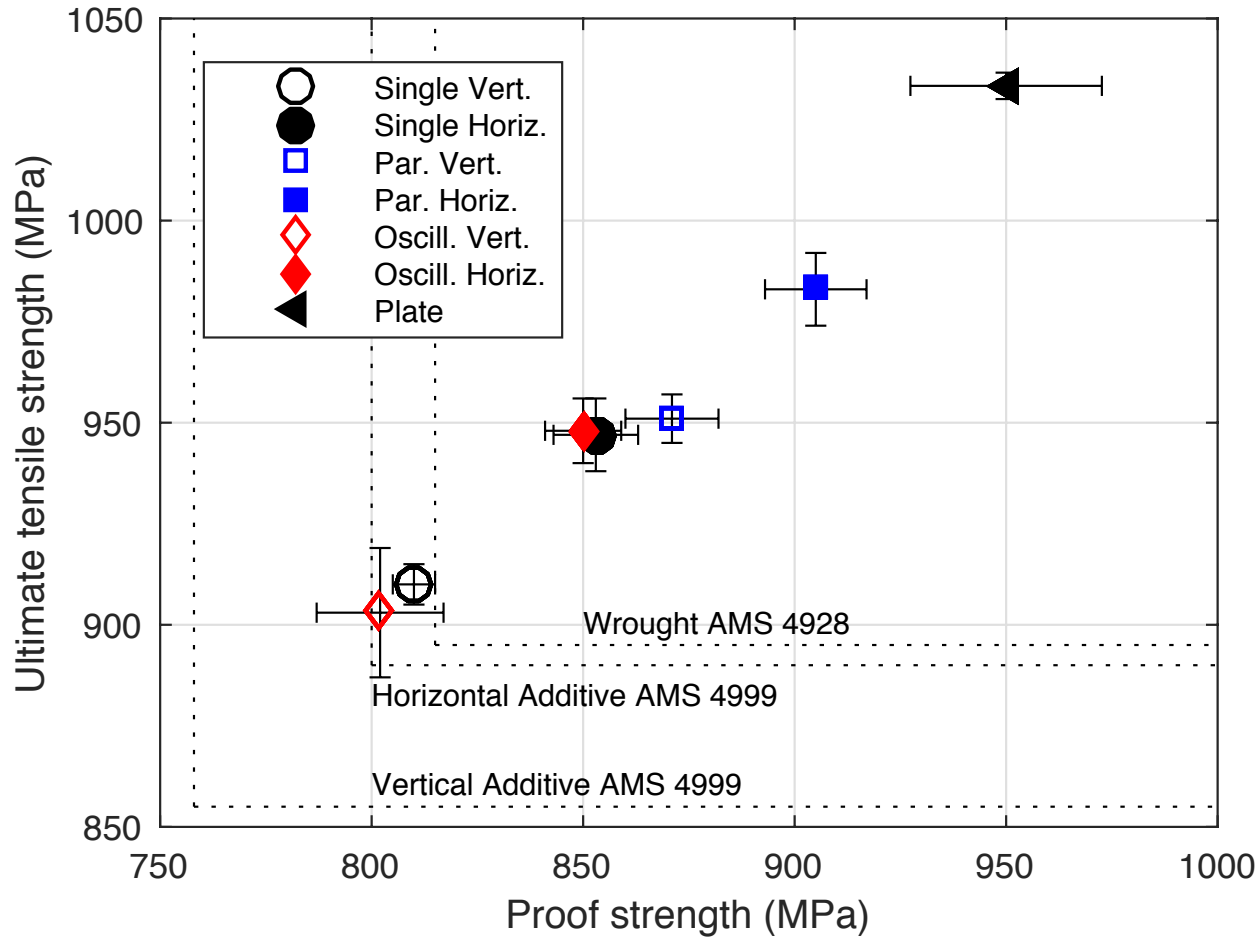
a)



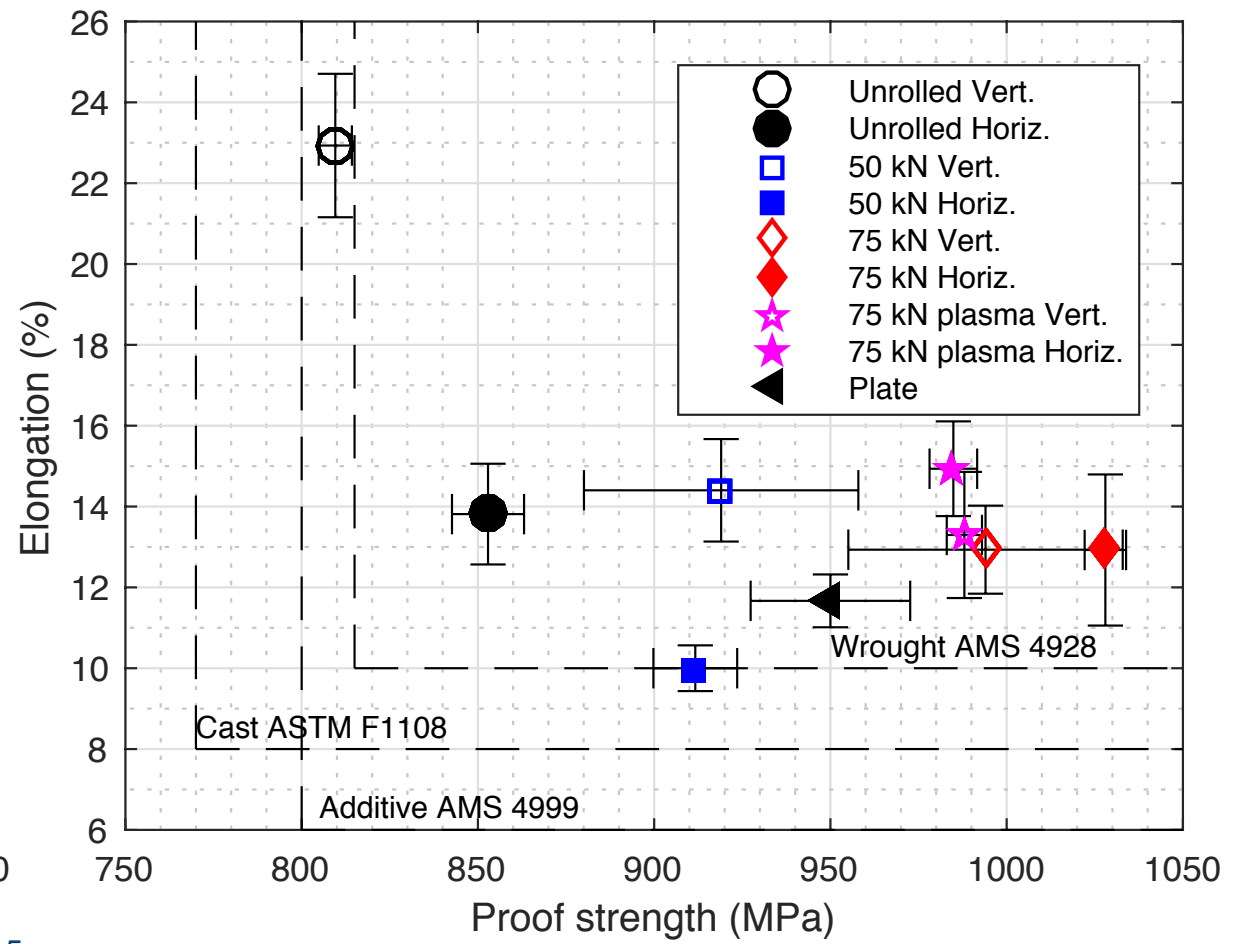
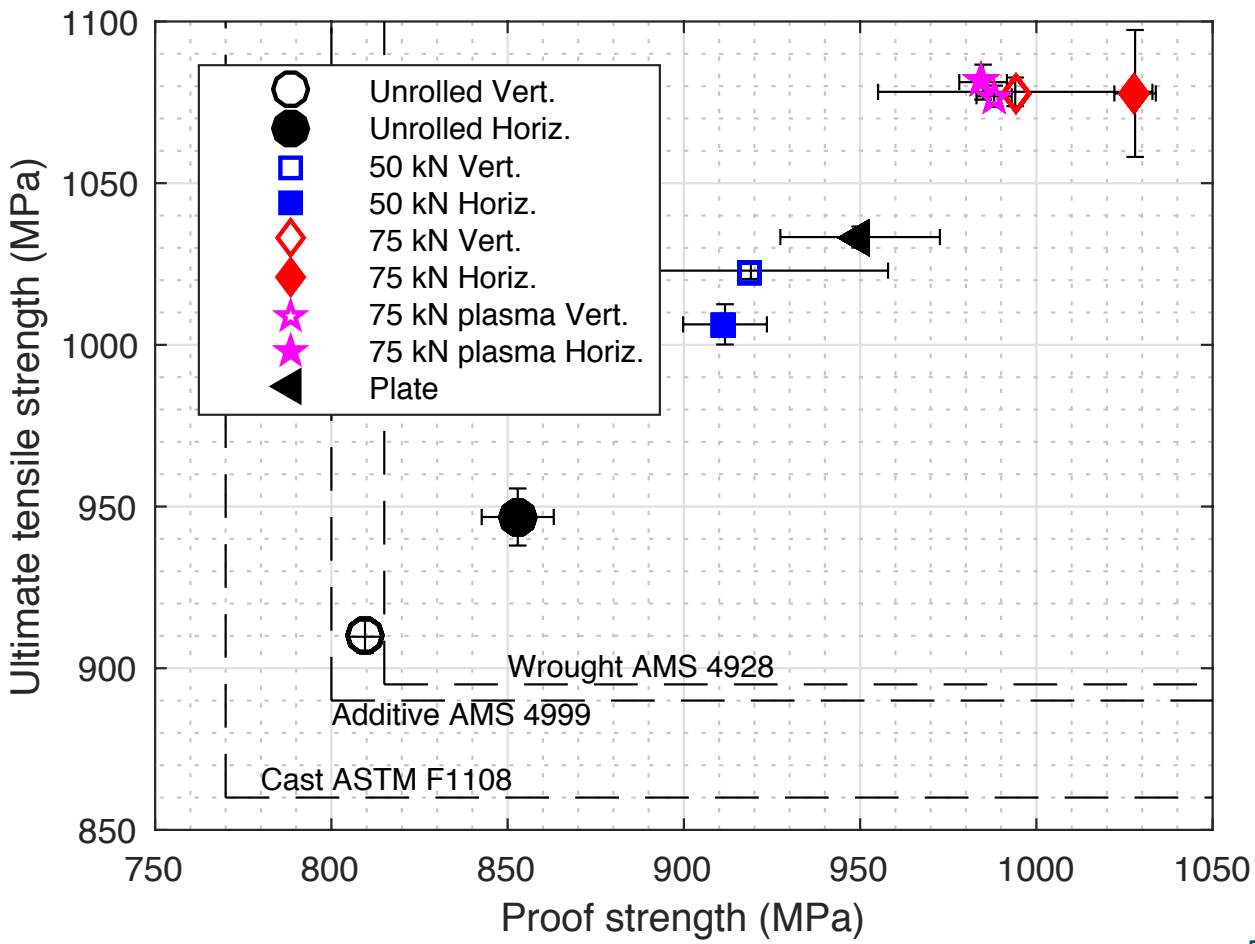
b)



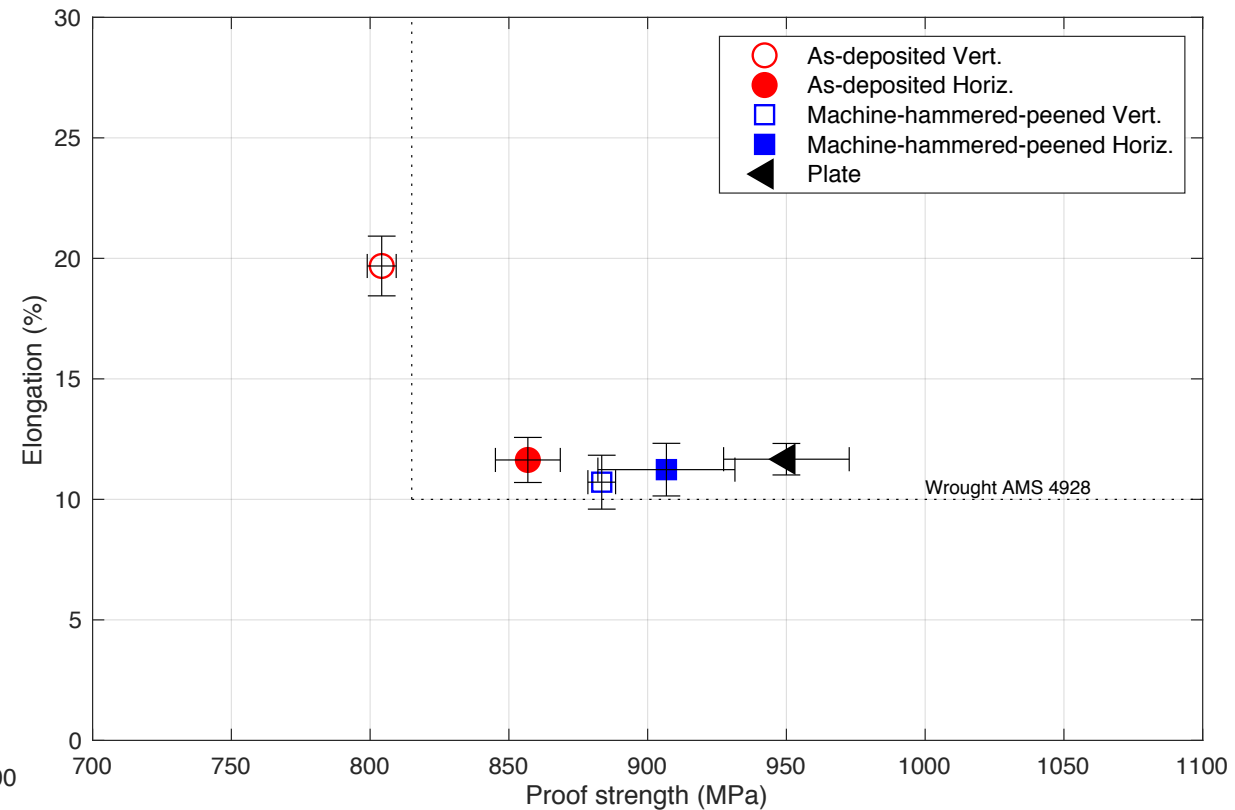
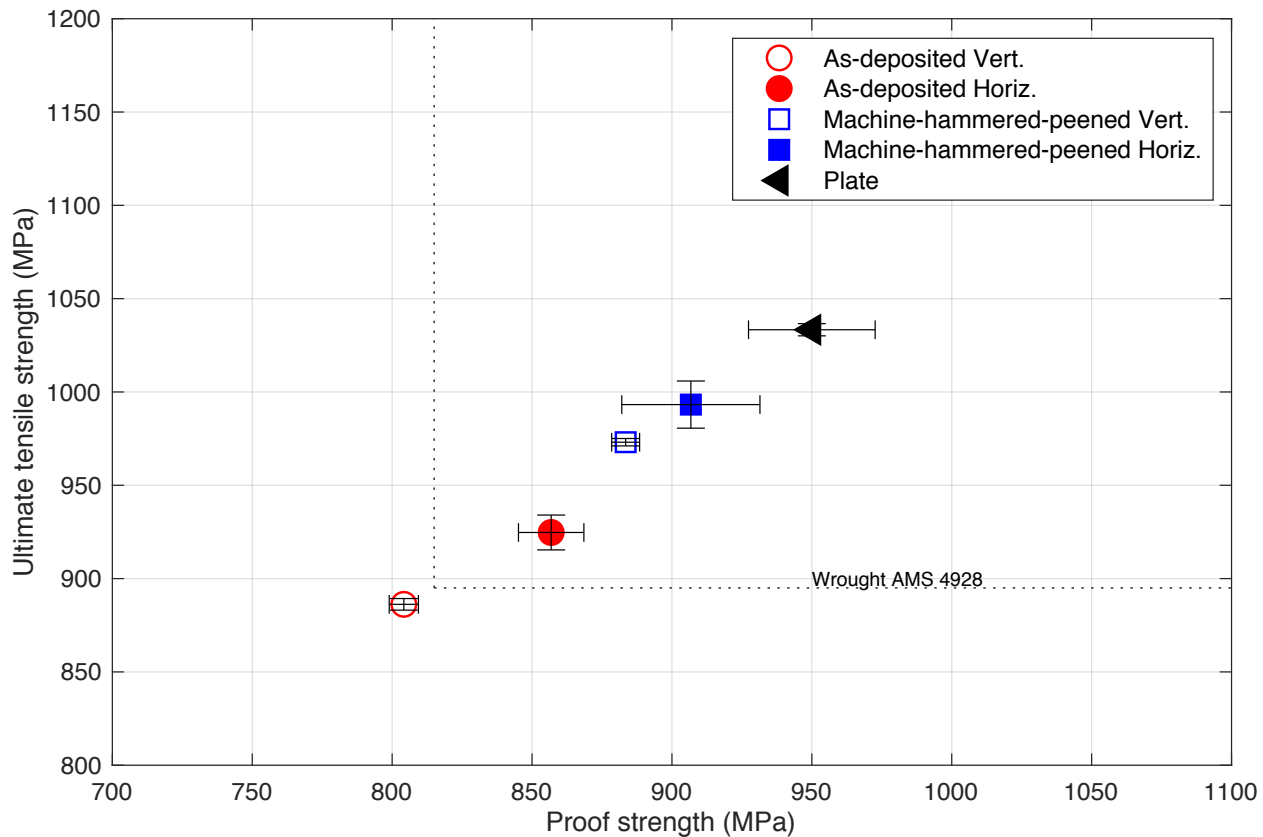
## Directionality



## Directionality

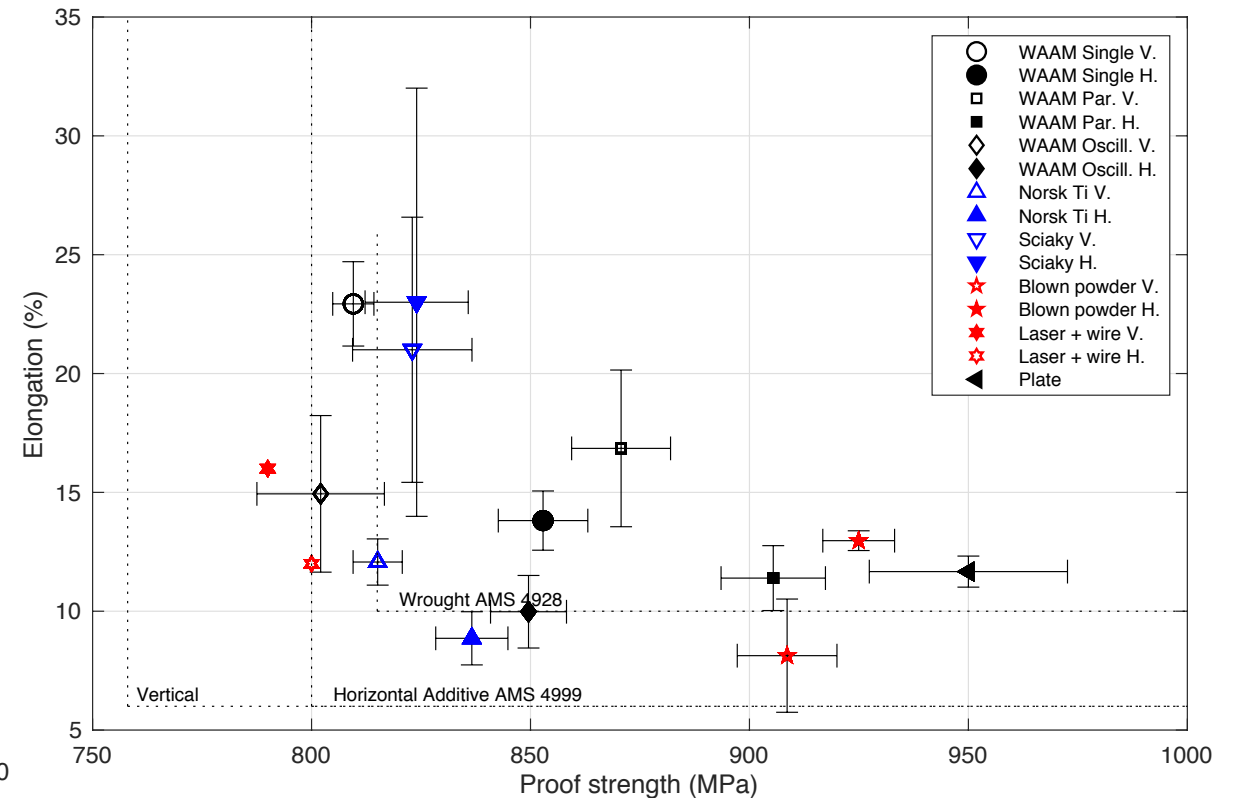
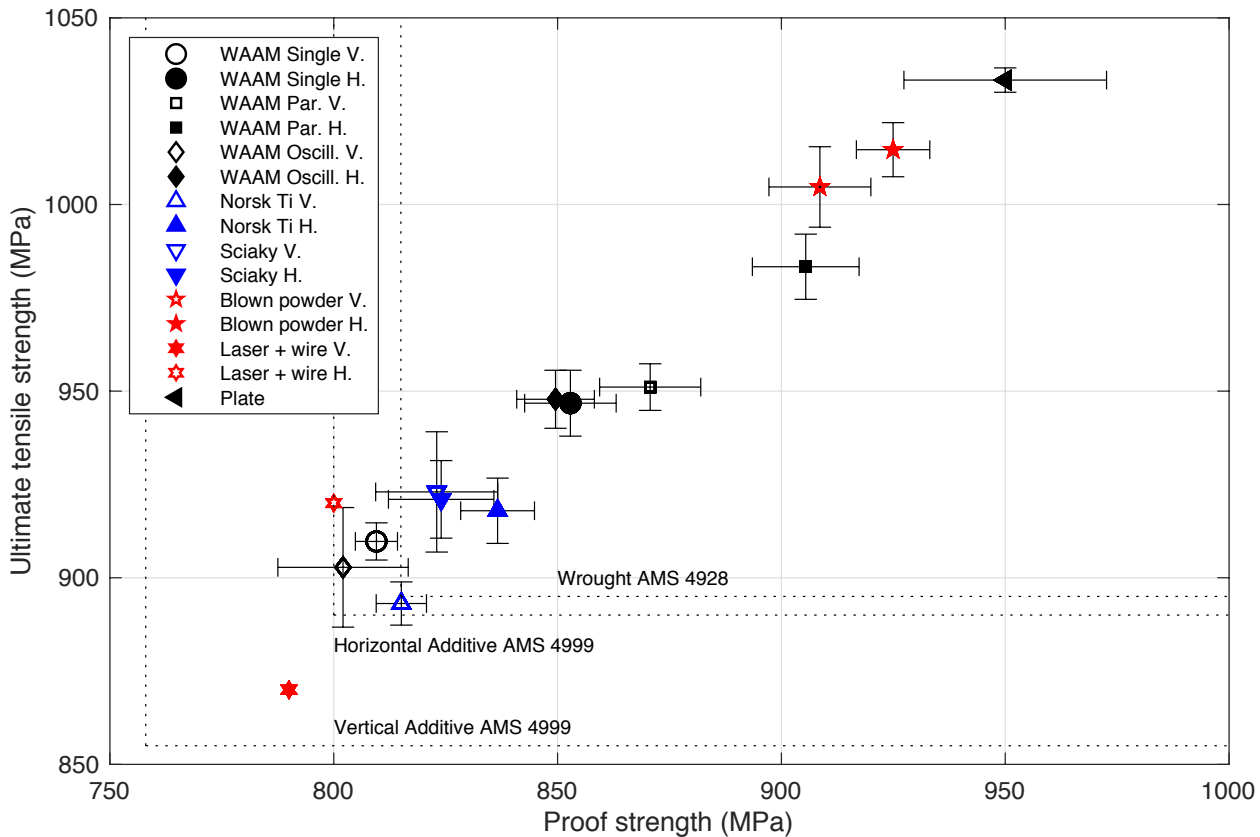


## Directionality

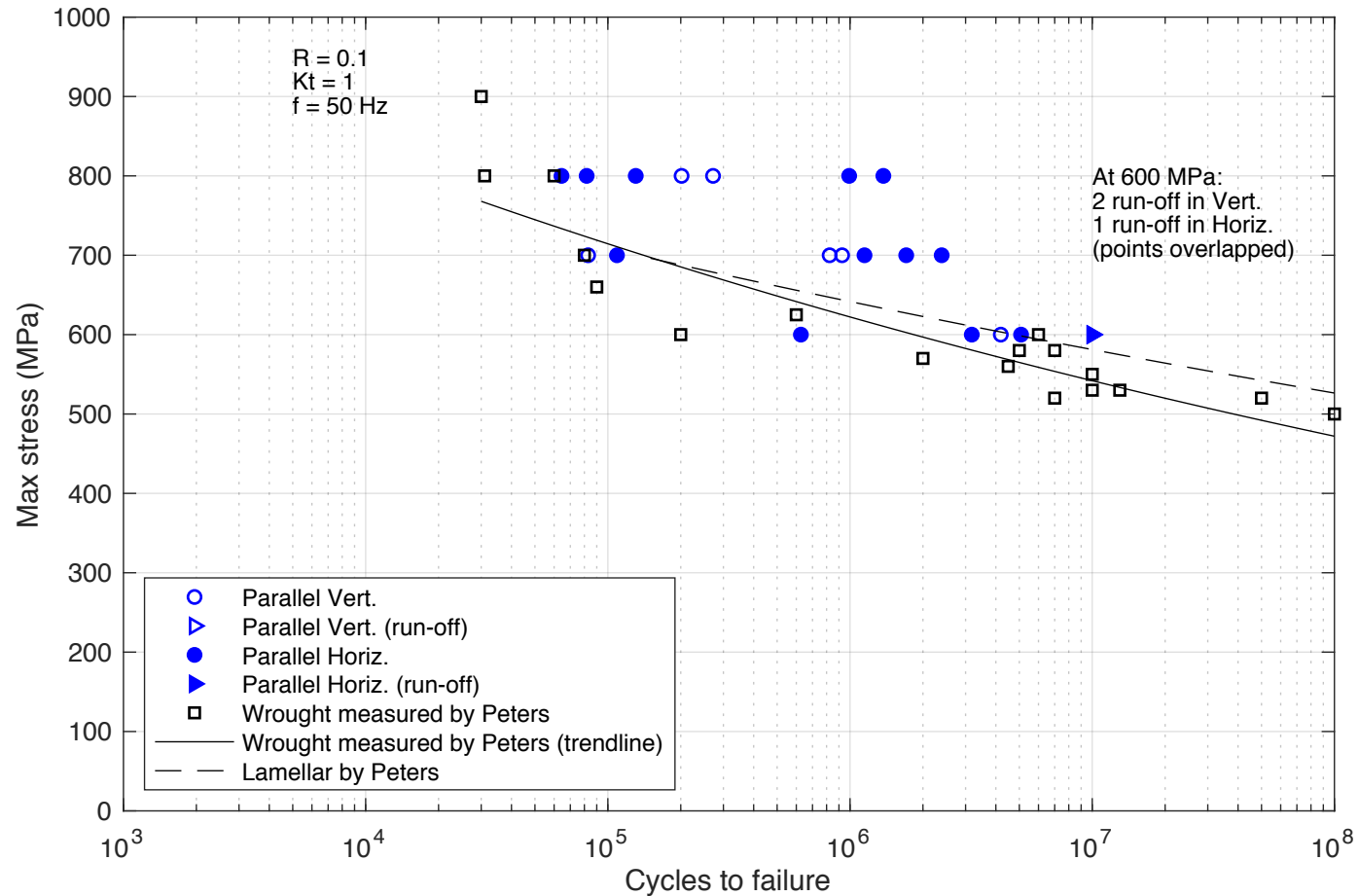


- Norsk Ti from norsktitanium.com; Sciaky from Structure-property correlations for additively manufactured Ti-6Al-4V components produced using directed energy deposition processes, 2016 Proceedings of the 13th World Conference on Titanium
- Blown-powder from IREPA lasers
- Laser + Wire from “Additive Manufacturing of Ti-6Al-4V: Relationship between Microstructure, Defects and Mechanical Properties”, Pia Akerfeldt, PhD Thesis, Lulea

## Directionality



## High cycle fatigue // Parallel strategy



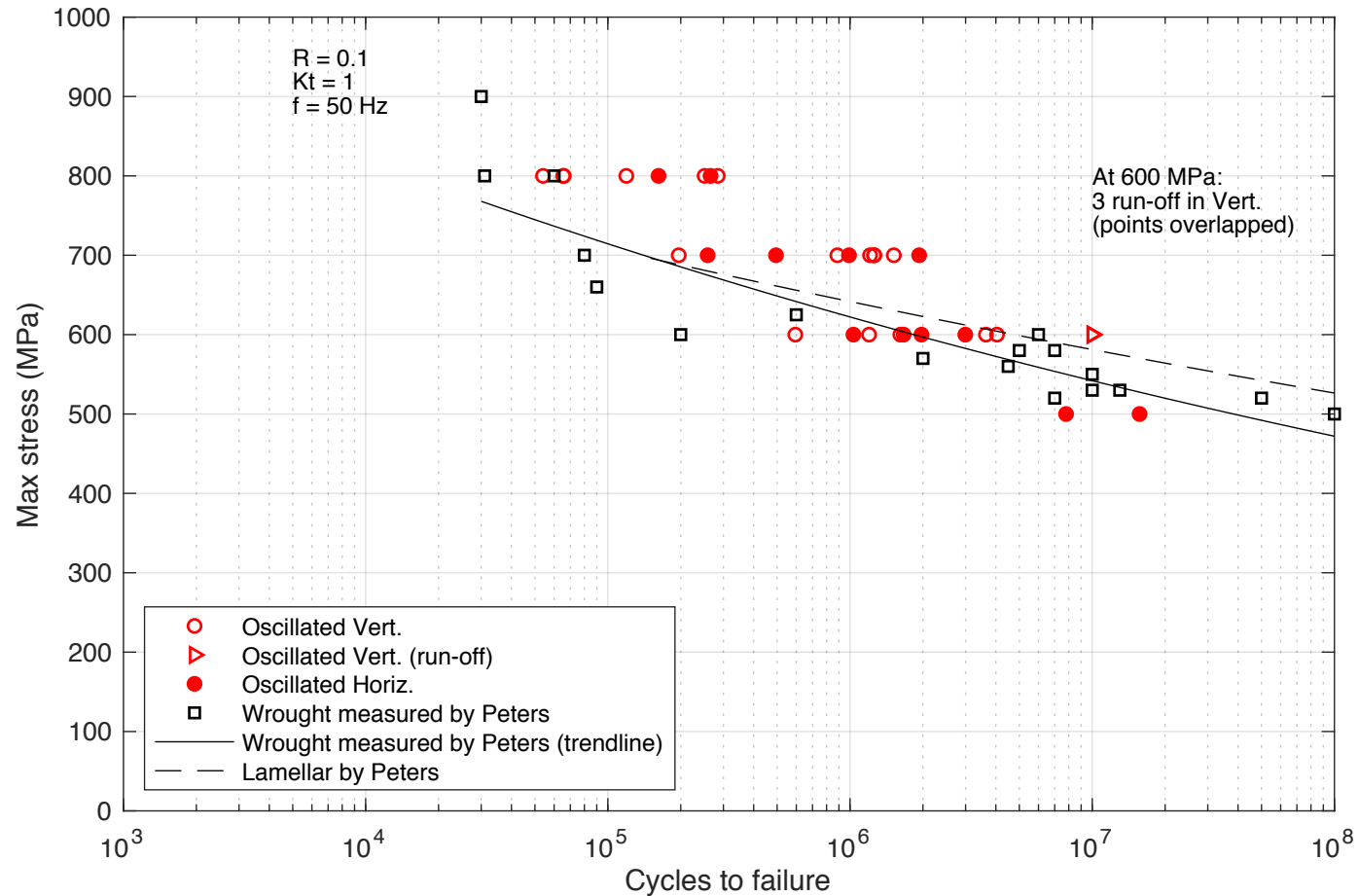




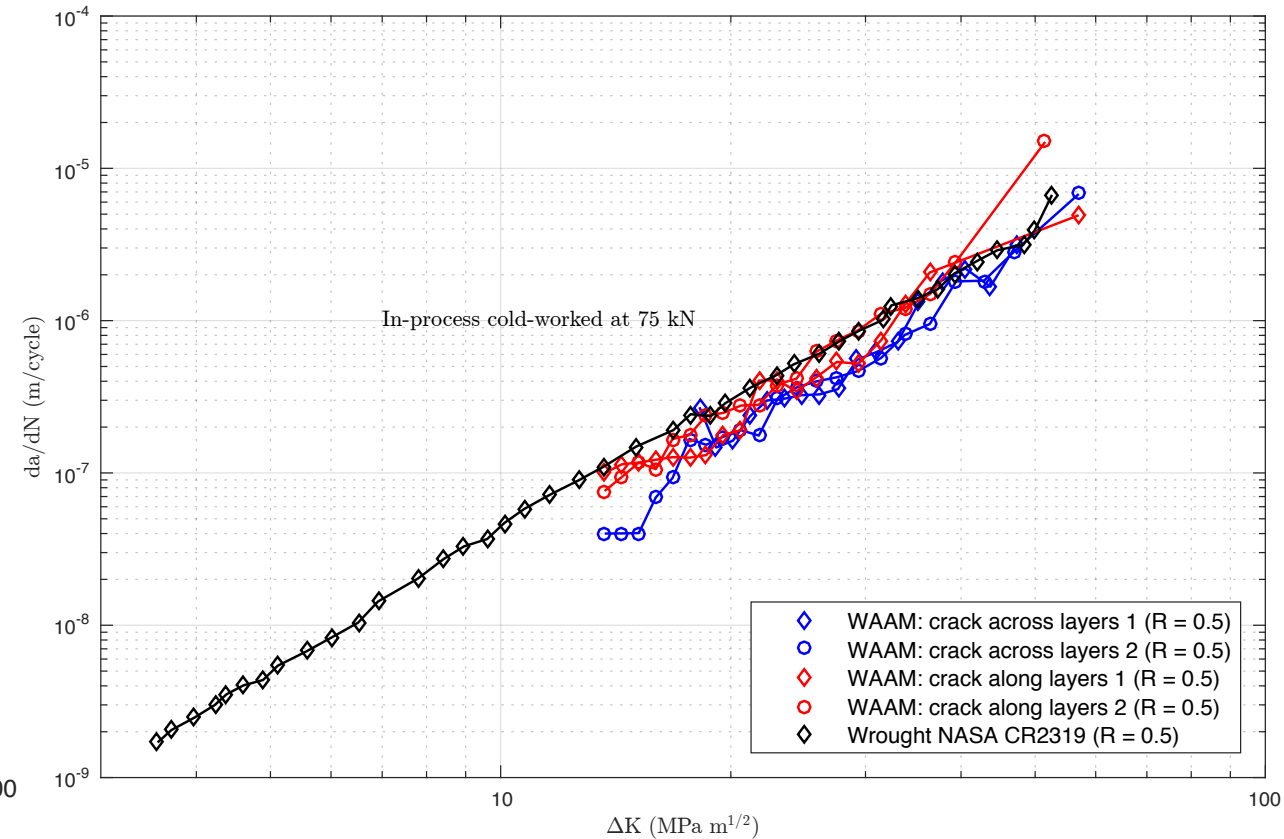
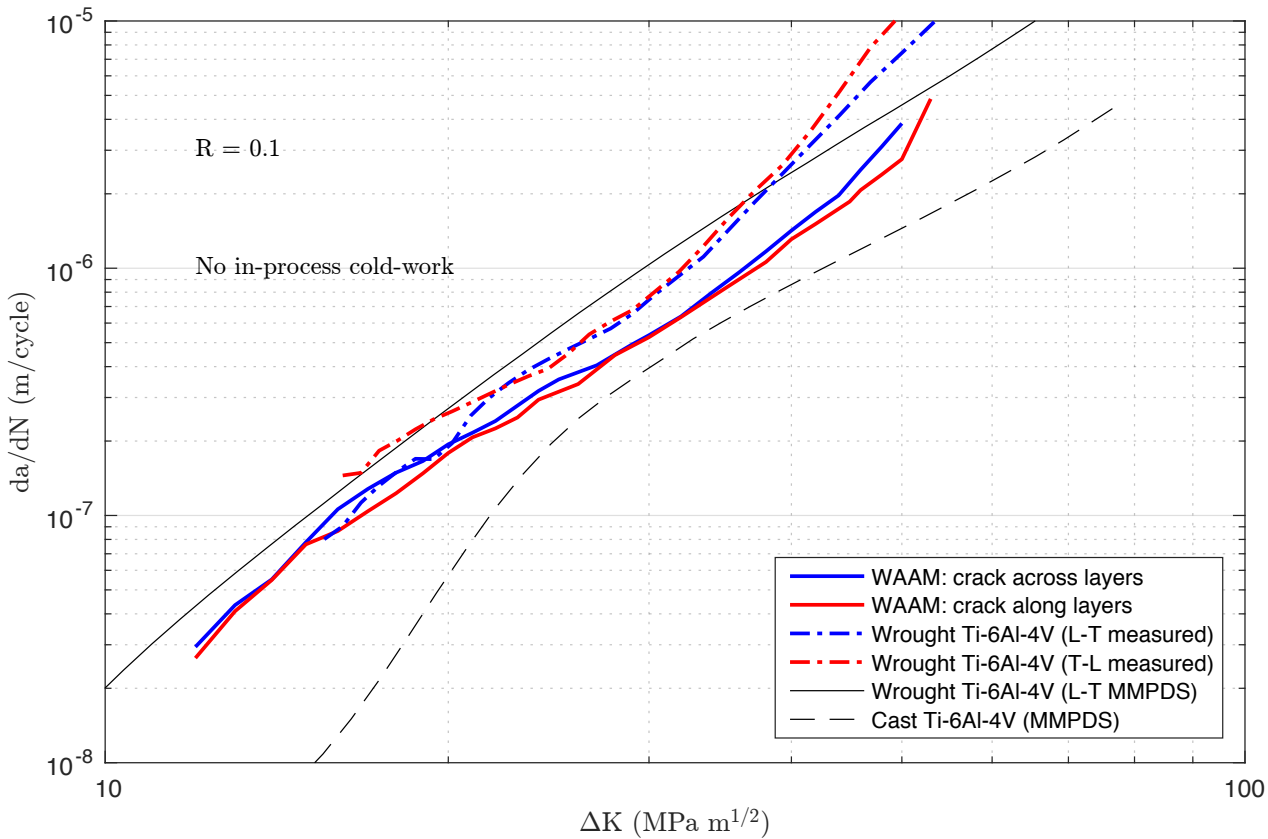
# Ti64 // Fatigue durability



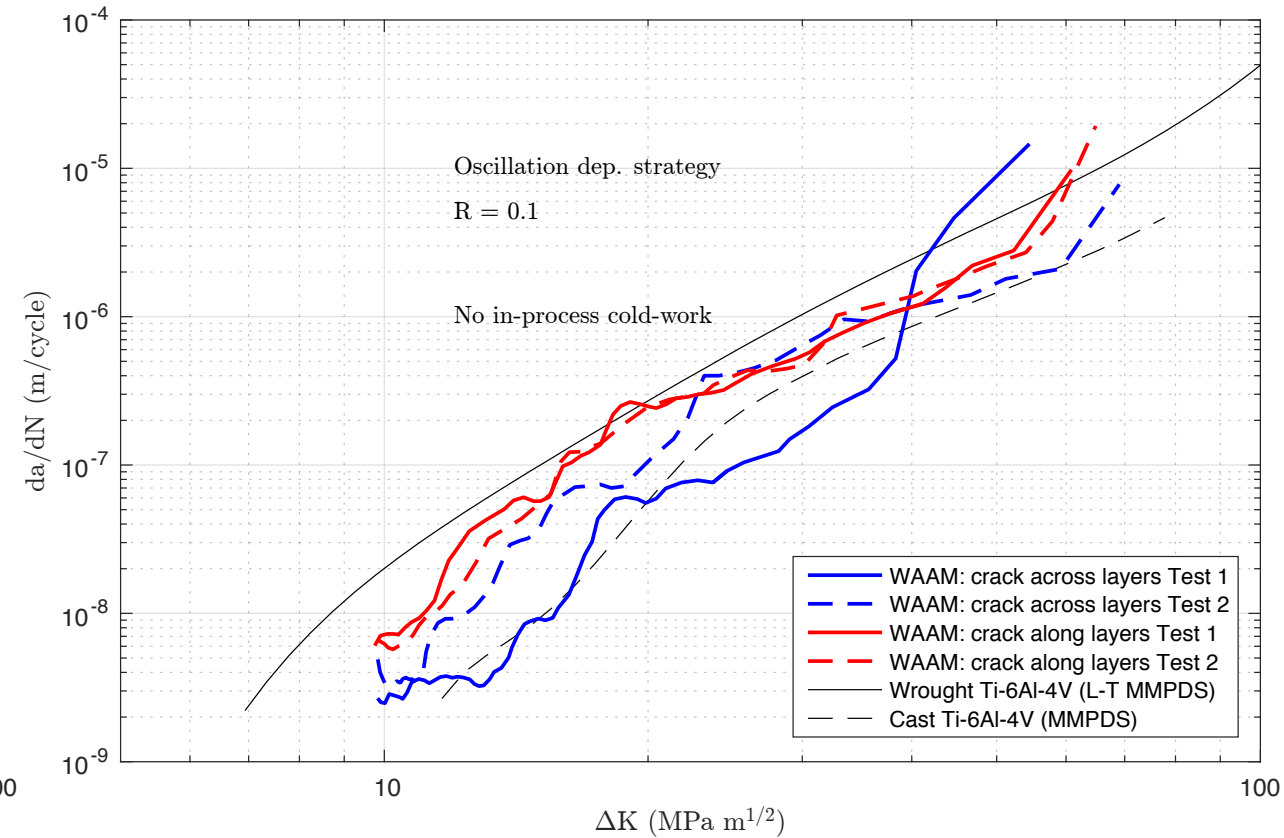
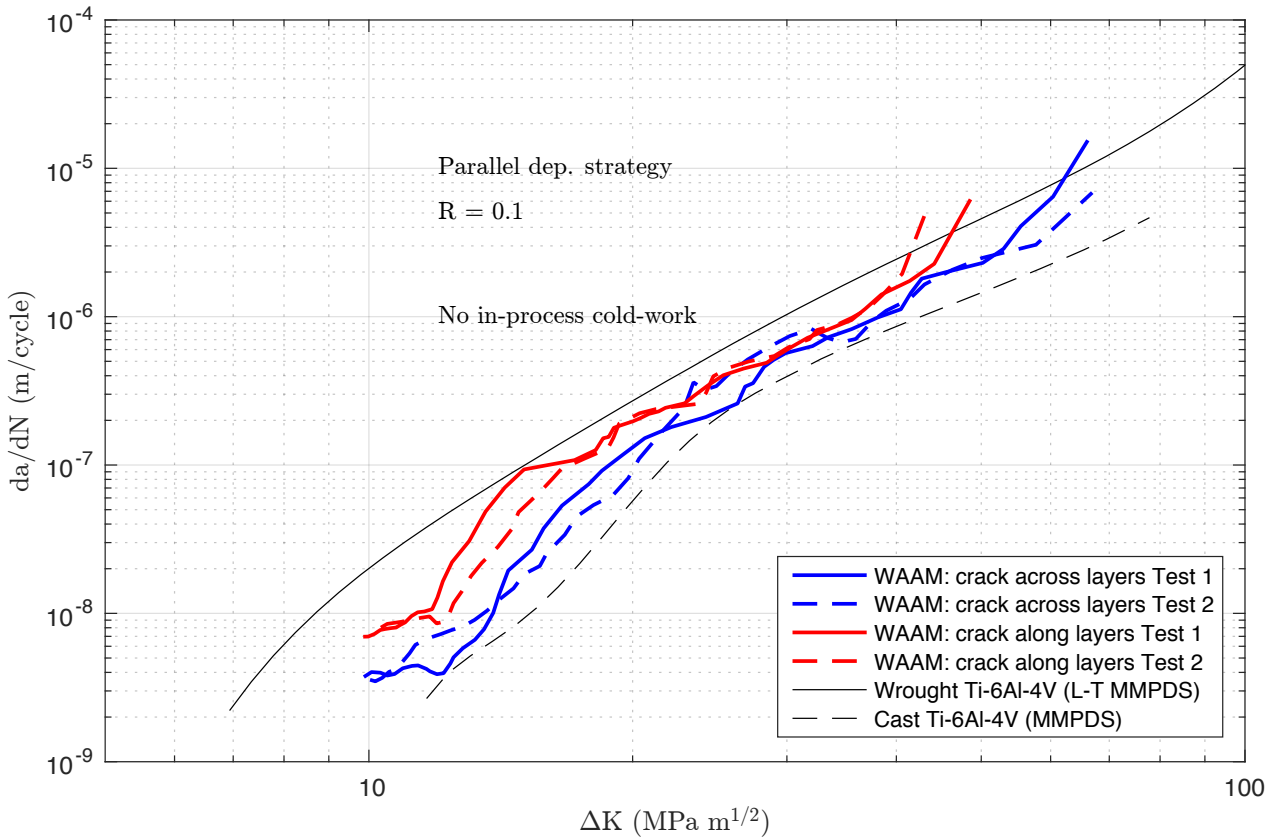
## High cycle fatigue // Oscillation strategy



## Fatigue crack growth rate (single bead, without and with cold-work)



## Fatigue crack growth rate (parallel and oscillated)

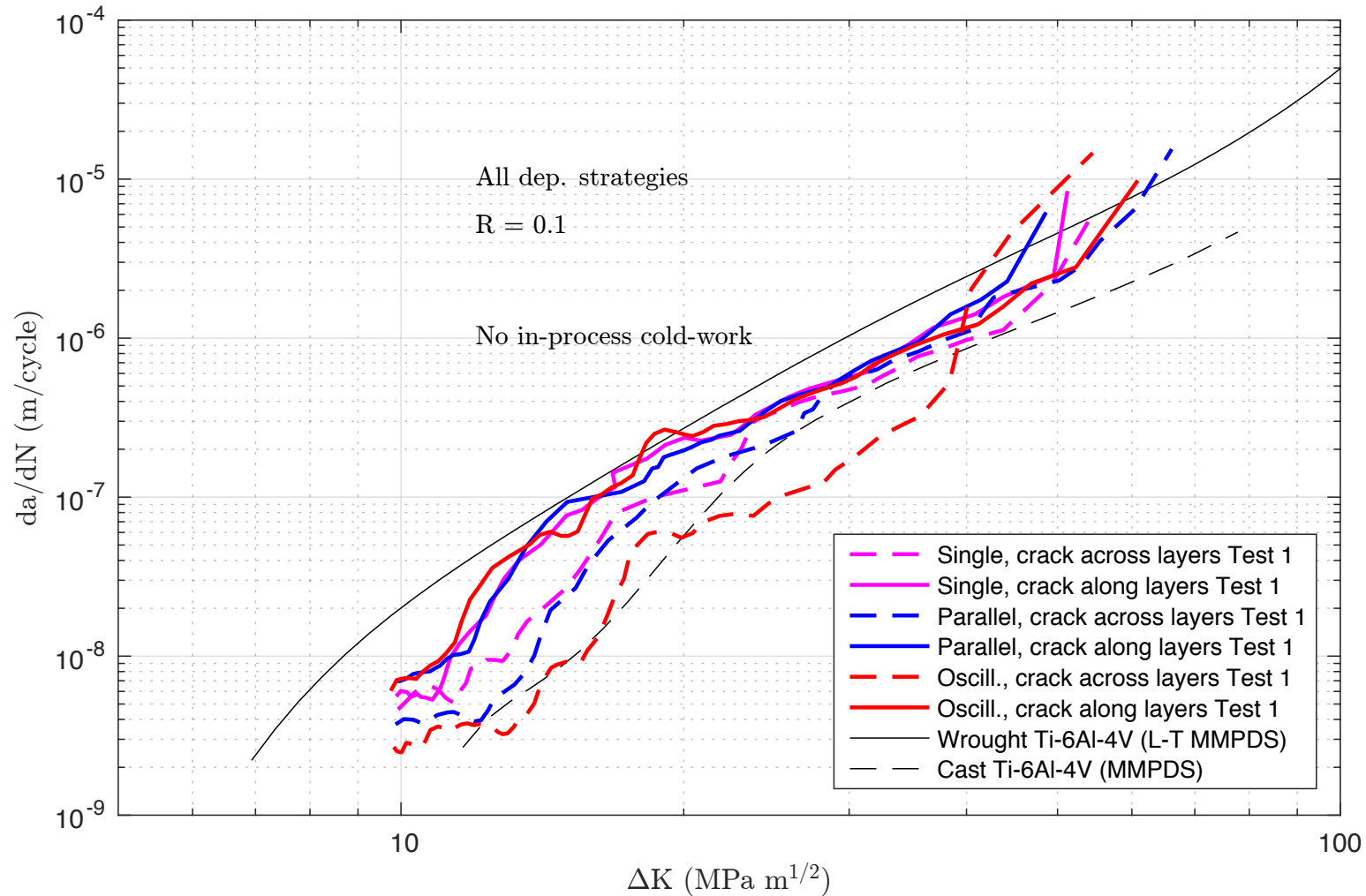




# Ti64 // Damage tolerance



## Recap FCGR

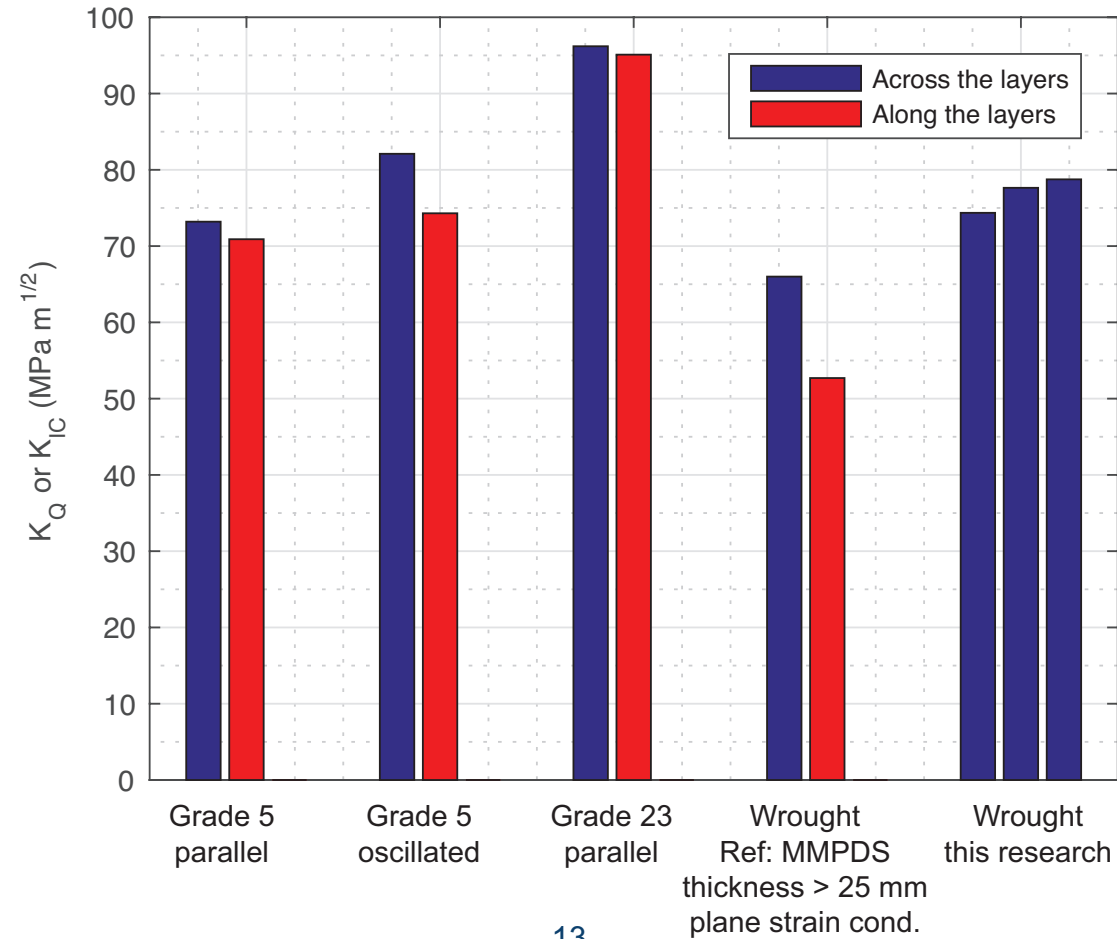




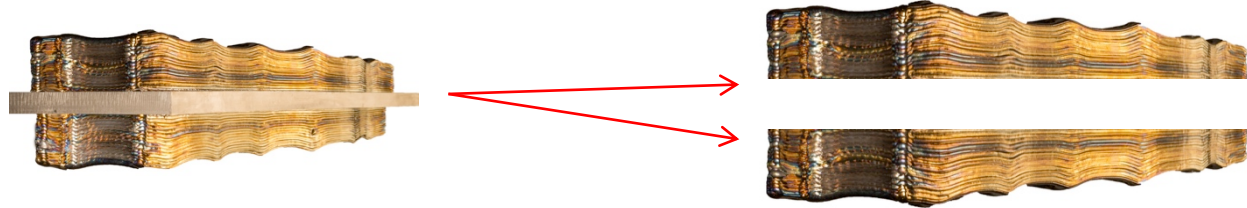
# Ti64 // Damage tolerance



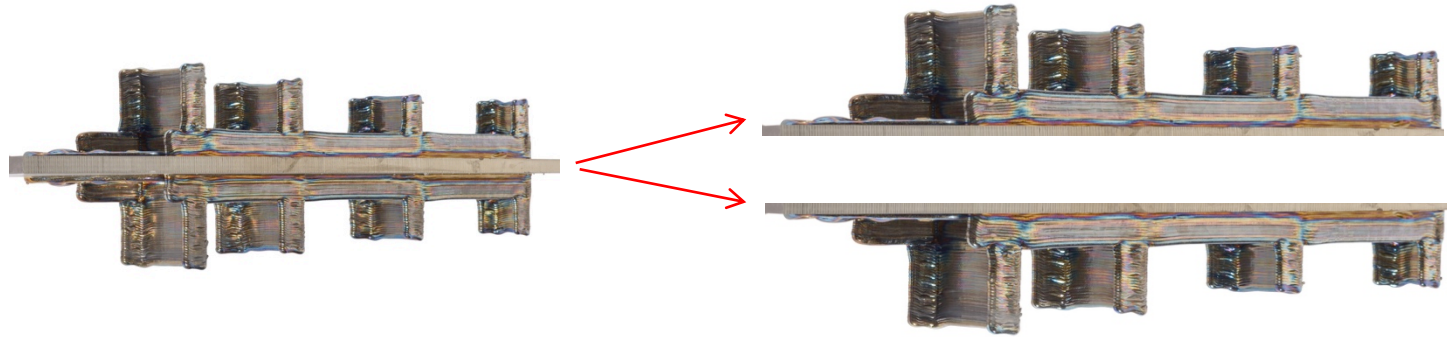
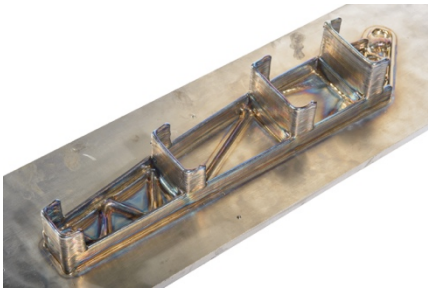
## Fracture toughness



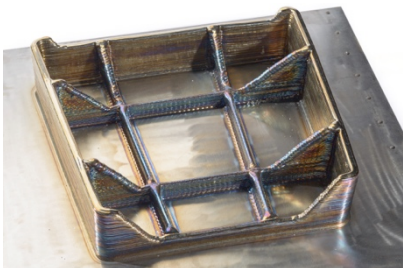
- Case 1: fully sacrificial



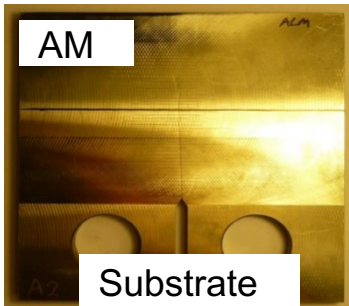
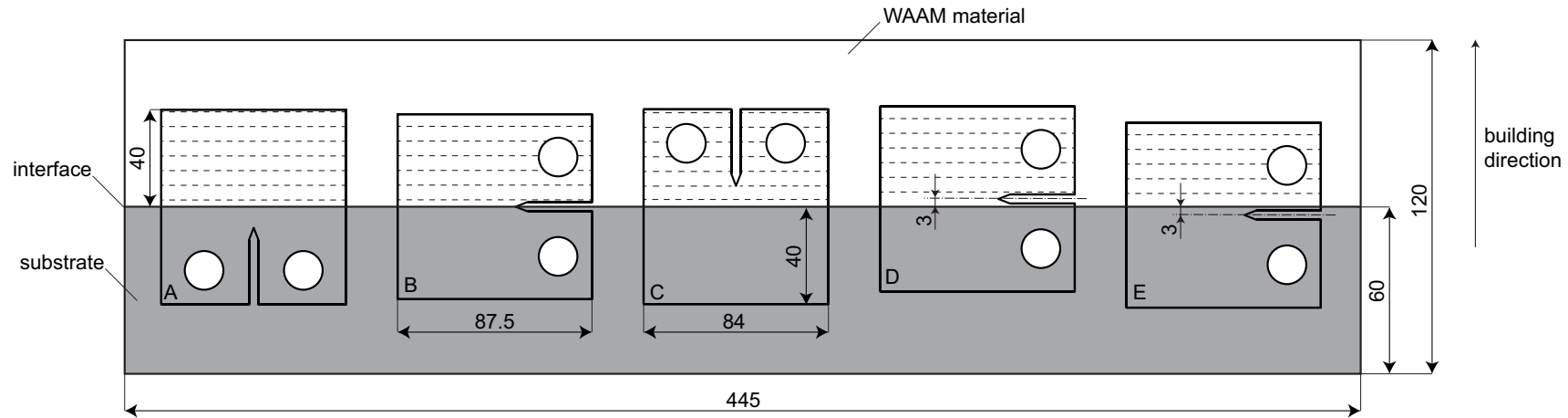
- Case 2: plate at the bottom



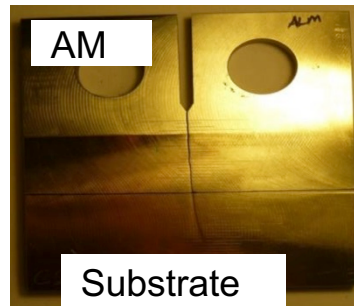
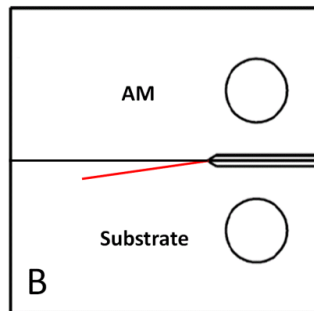
- Case 3: symmetric structure



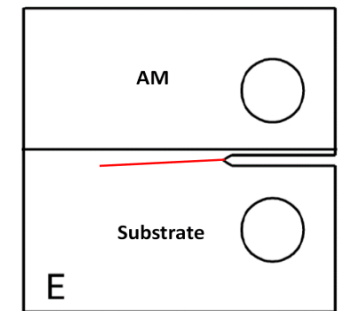
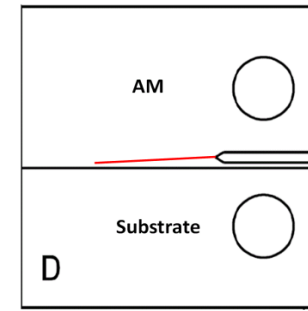
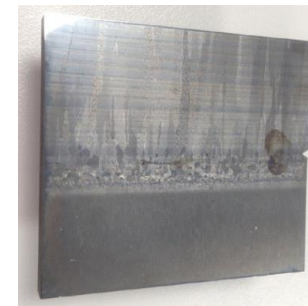
# Ti64 // Crack growth trajectory at the interface



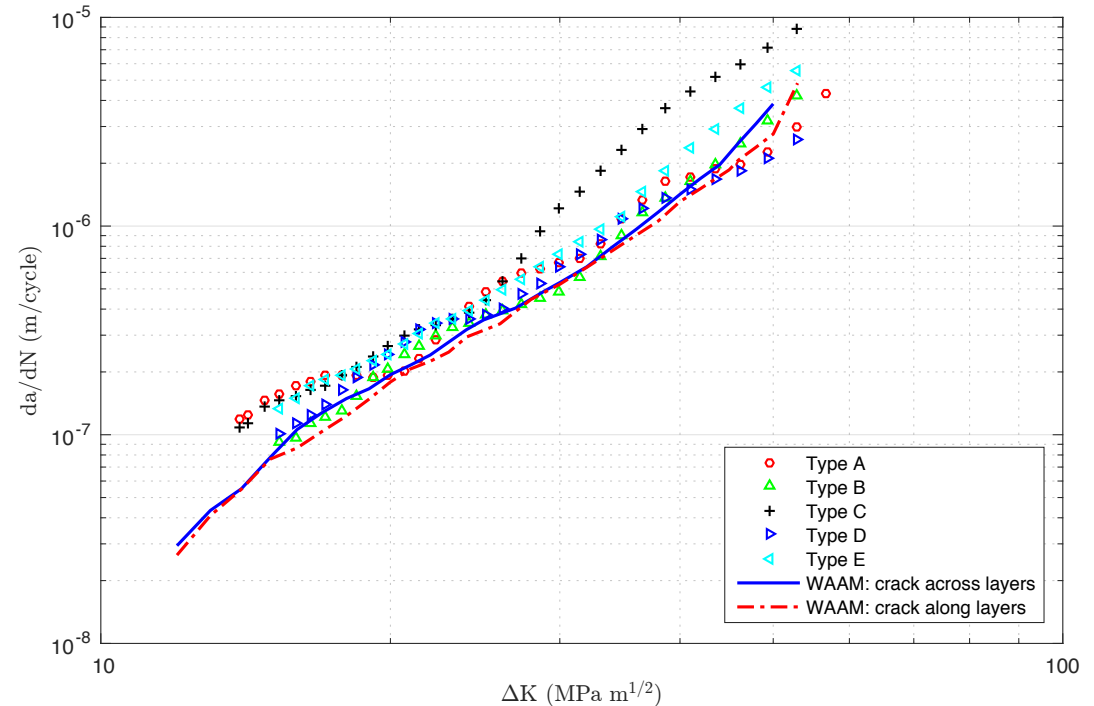
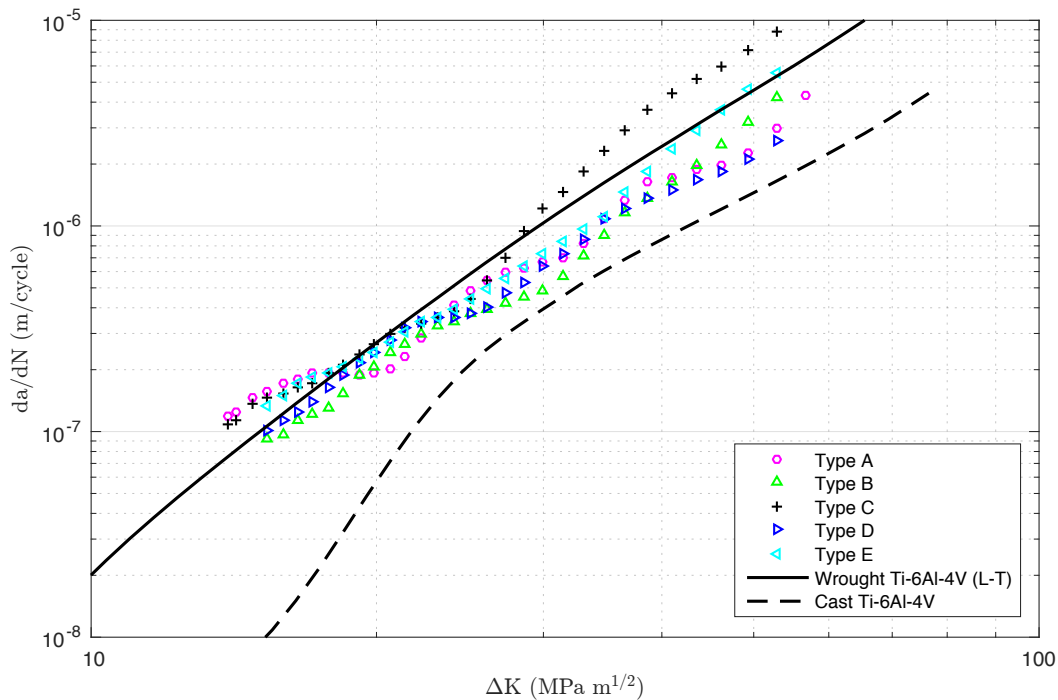
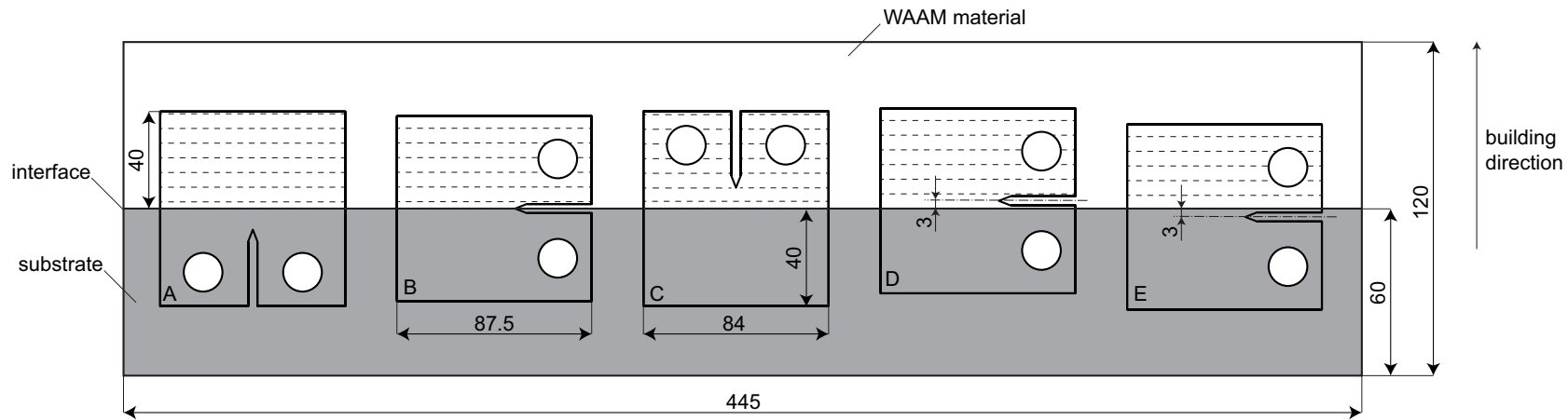
Crack trajectory maintains almost a straight line



Crack trajectory maintains almost a straight line



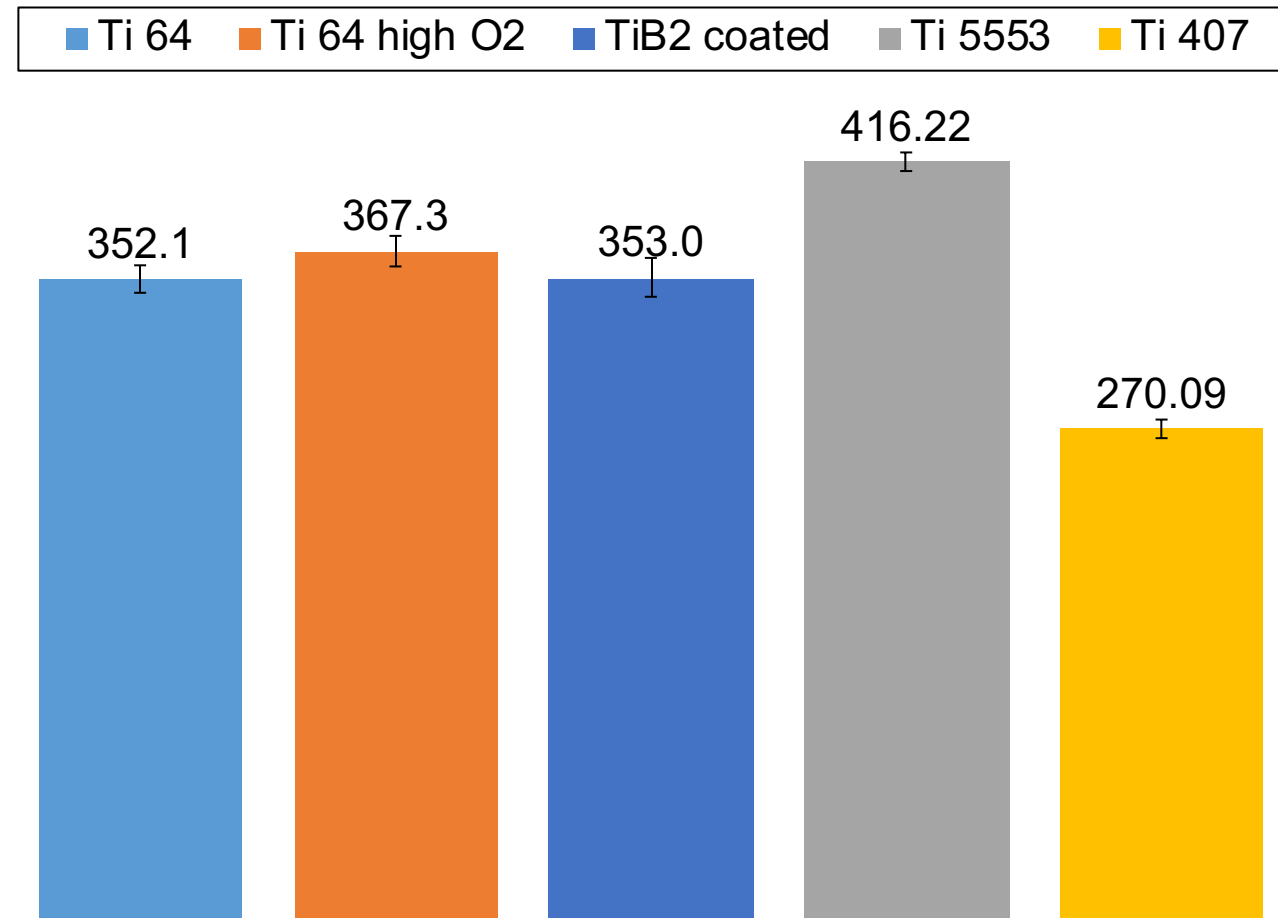
# Ti64 // Crack growth trajectory at the interface



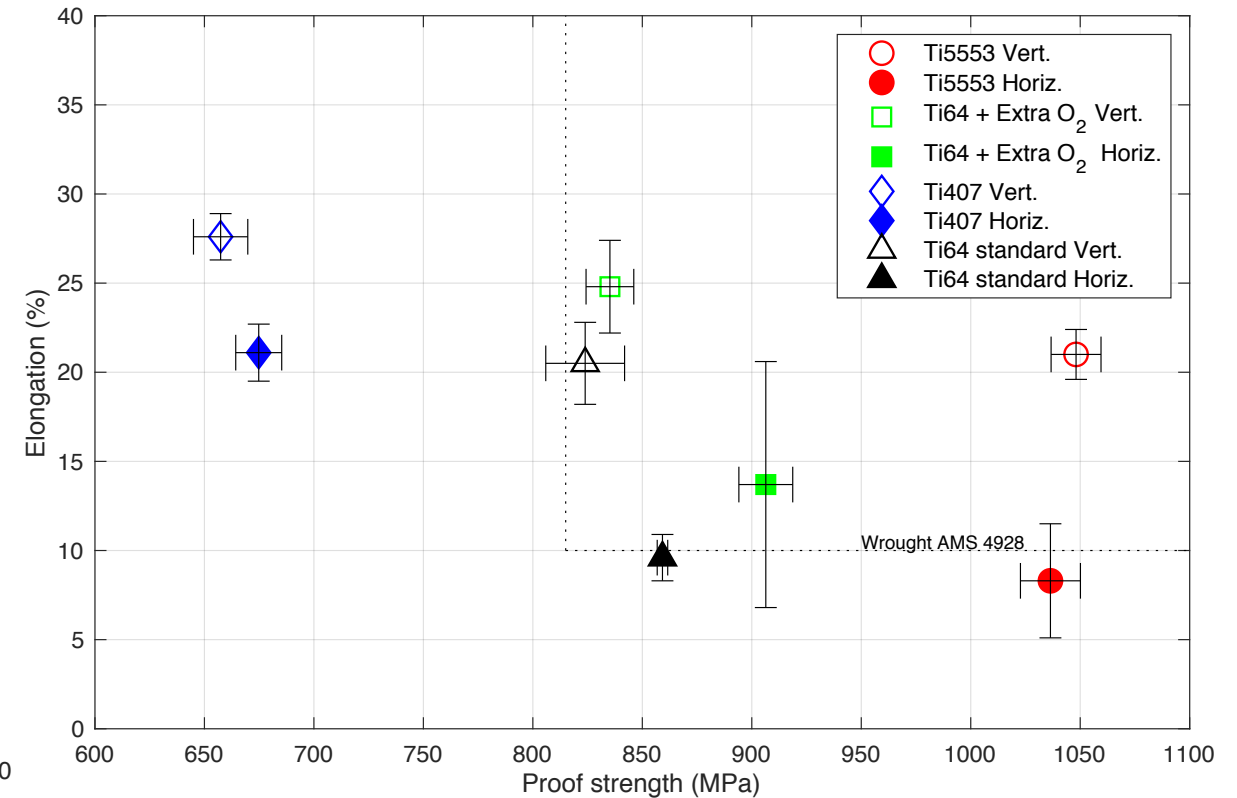
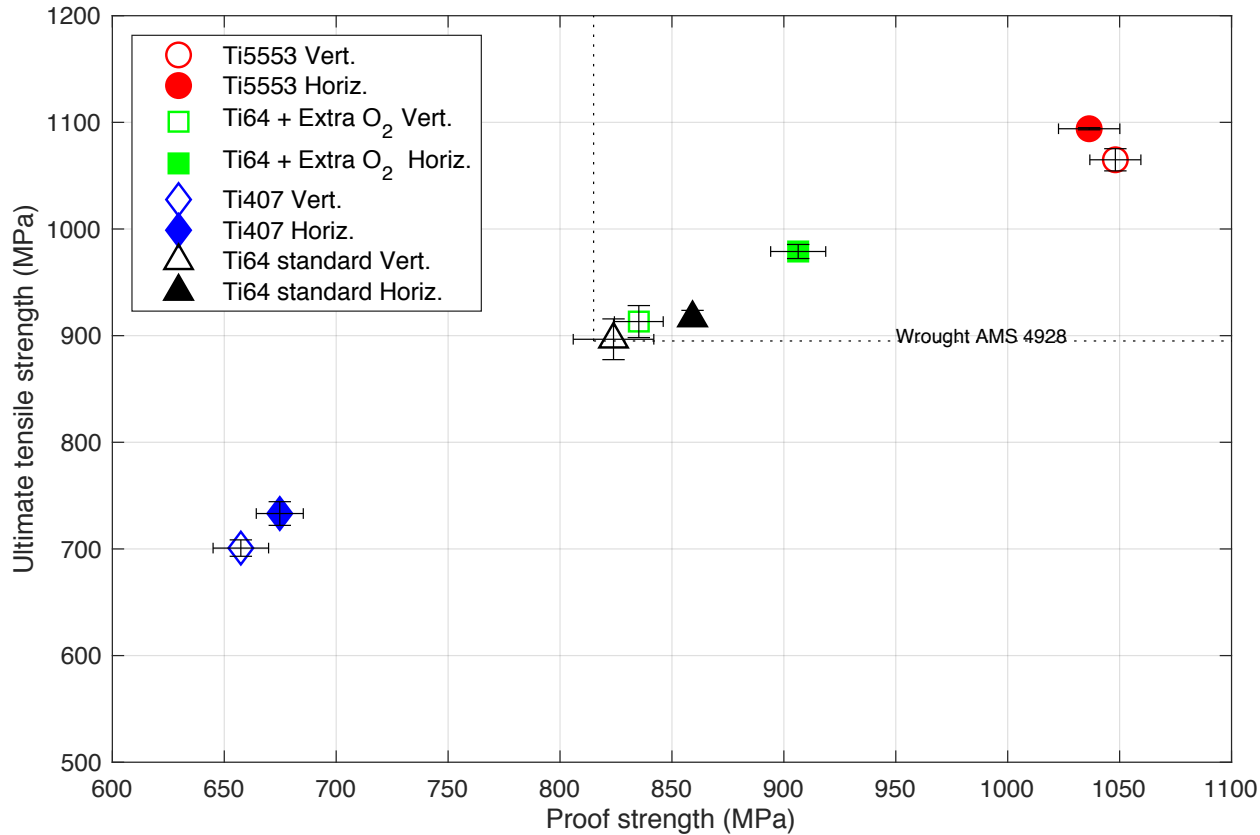


- Ti-5Al-5Mo-5V-3Cr (5553)
  - → UTS up to 1300 MPa
- Ti64 with 2000ppm O<sub>2</sub>
  - → + 500ppm O<sub>2</sub> = + 70 Mpa
- Ti64 coated with TiB<sub>2</sub>
  - → grain refinement
- Timetal 407
  - → medium strength, high ductility
  - → energy absorption = 1.6 x Ti64
  - → machinability = 2 x Ti64

### Vickers Hardness



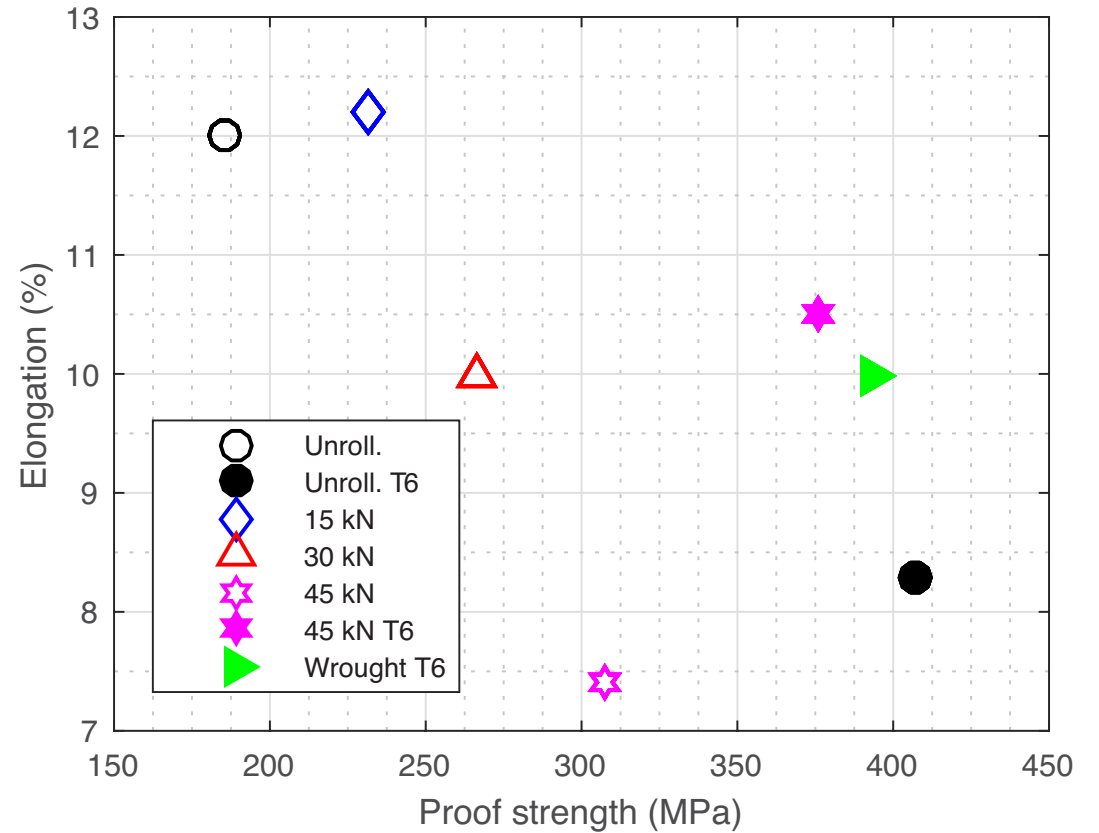
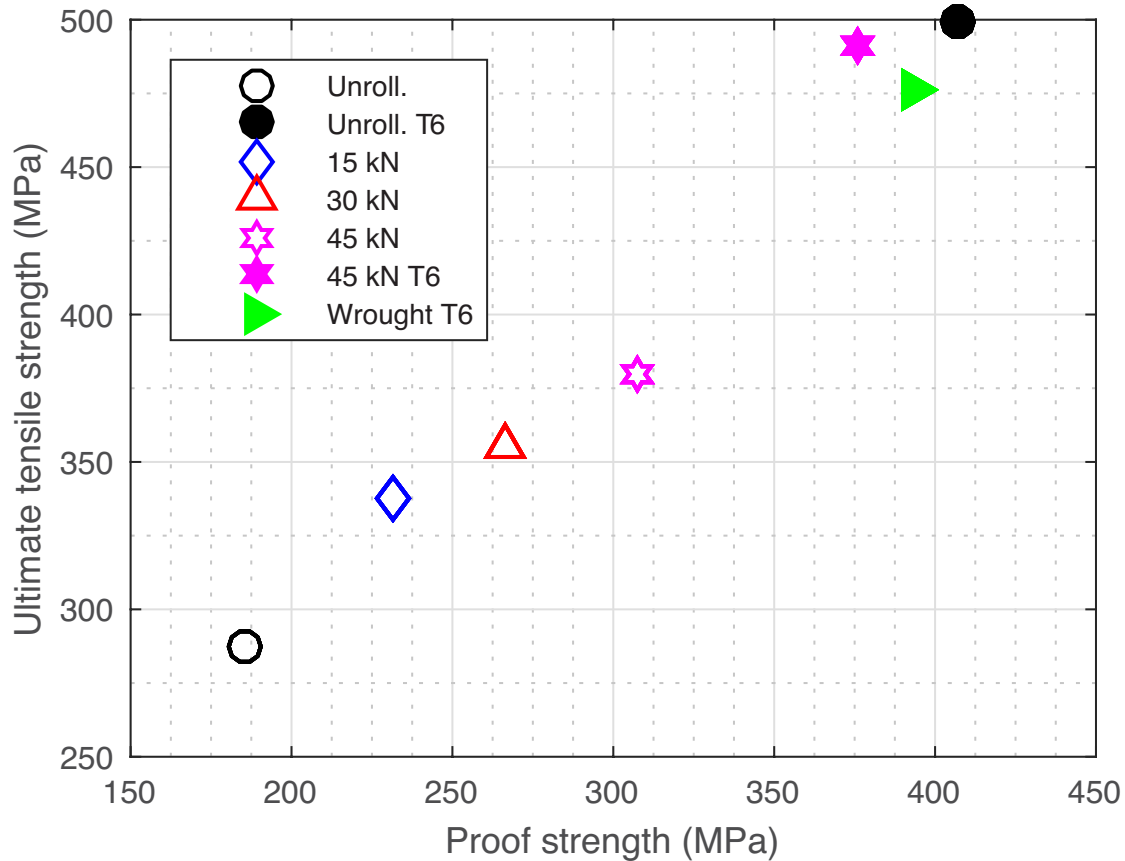
## Directionality



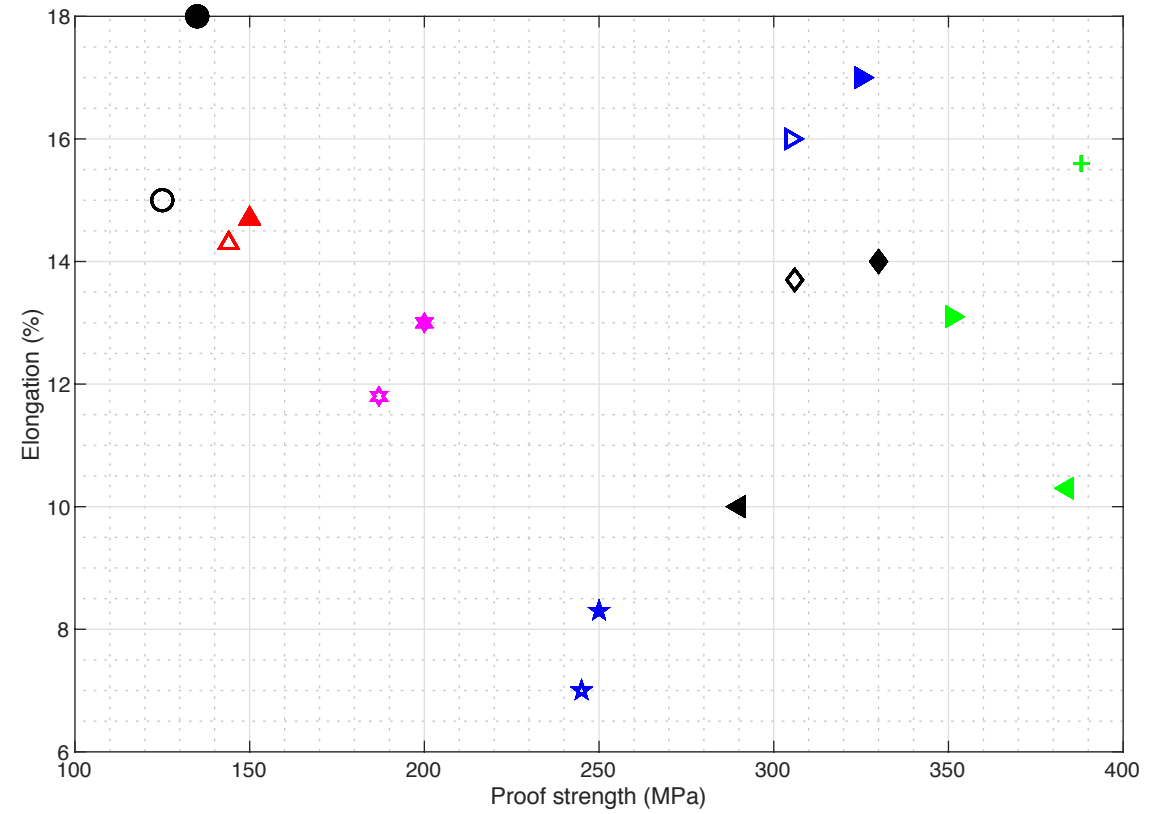
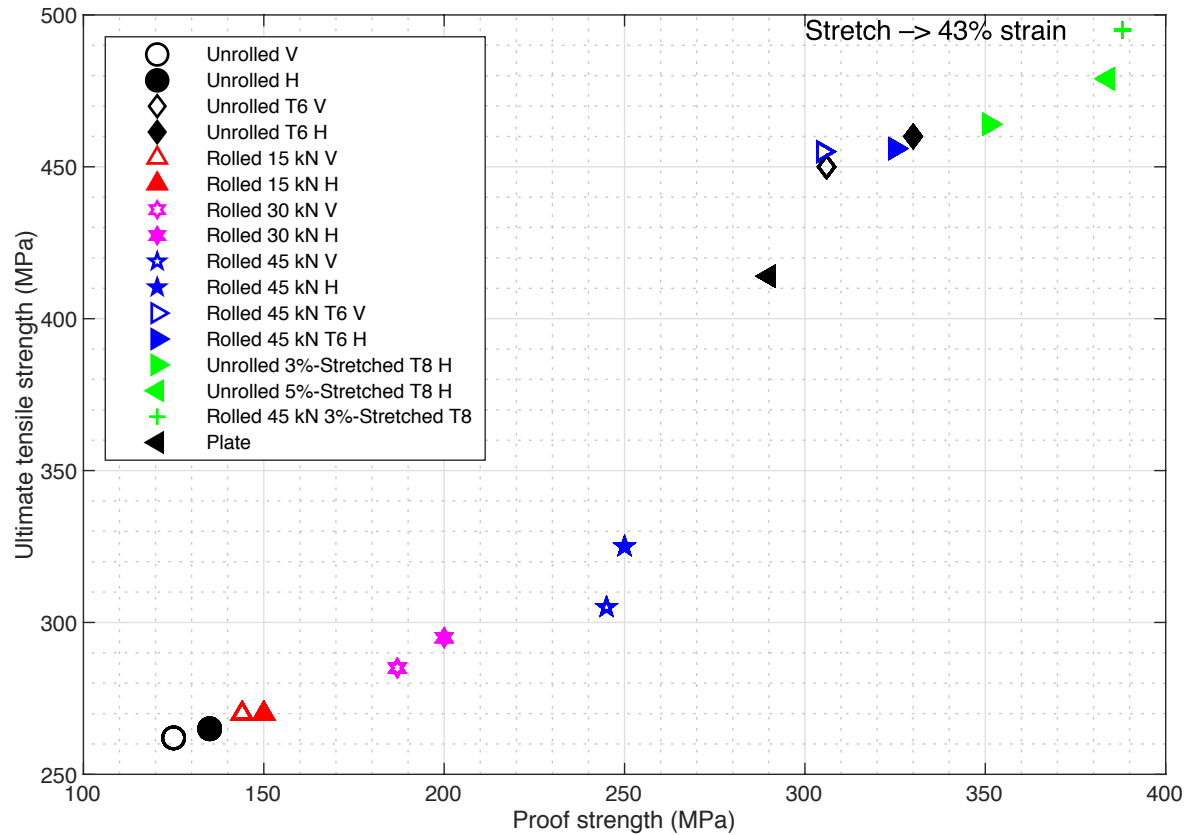


# Aluminium

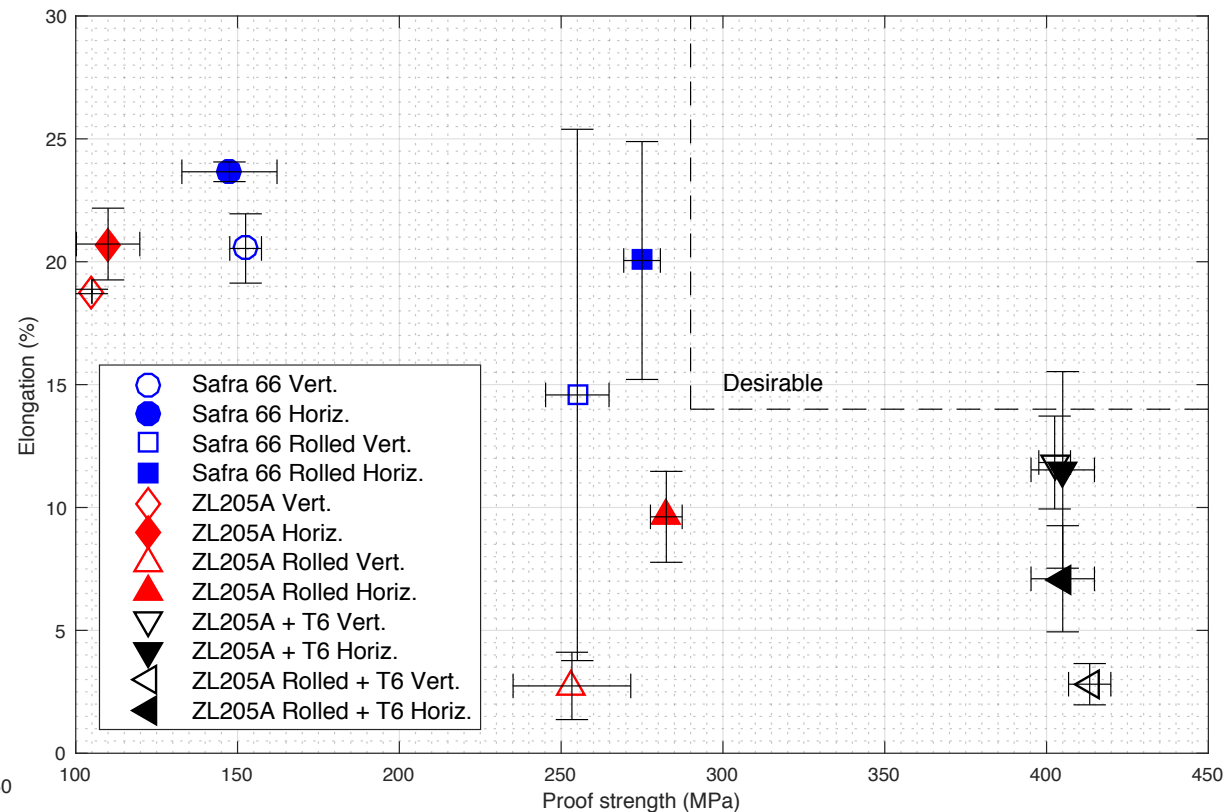
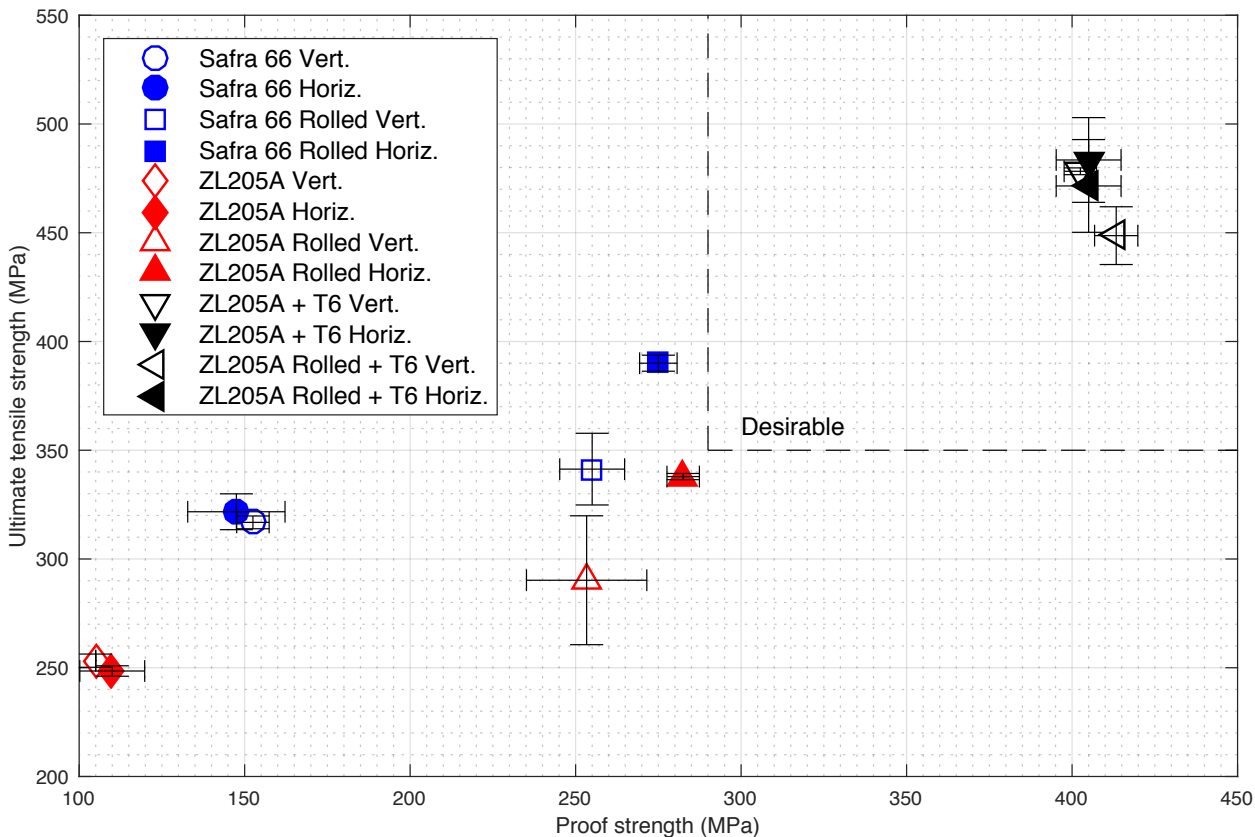
## Single beads – all values measured in the horizontal direction



## Thin walls (CMT, single beads)



## Thin walls (single beads)

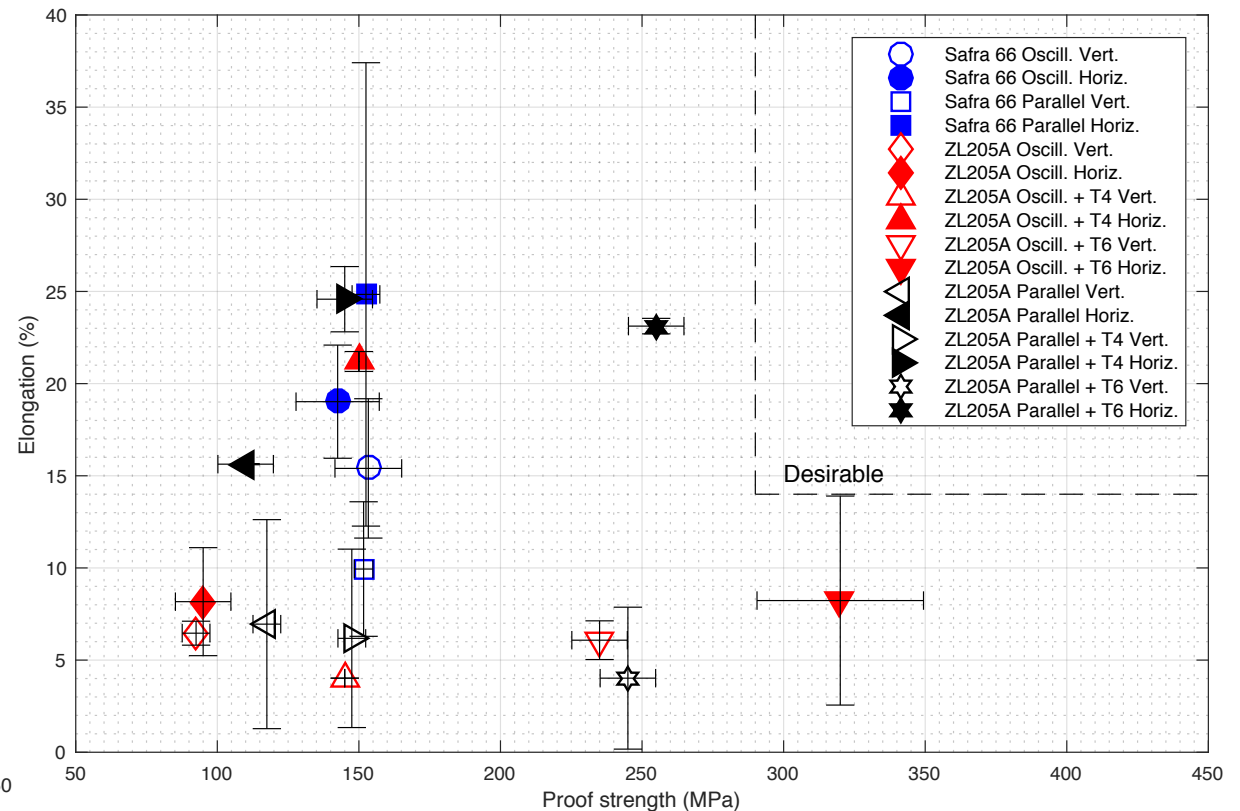
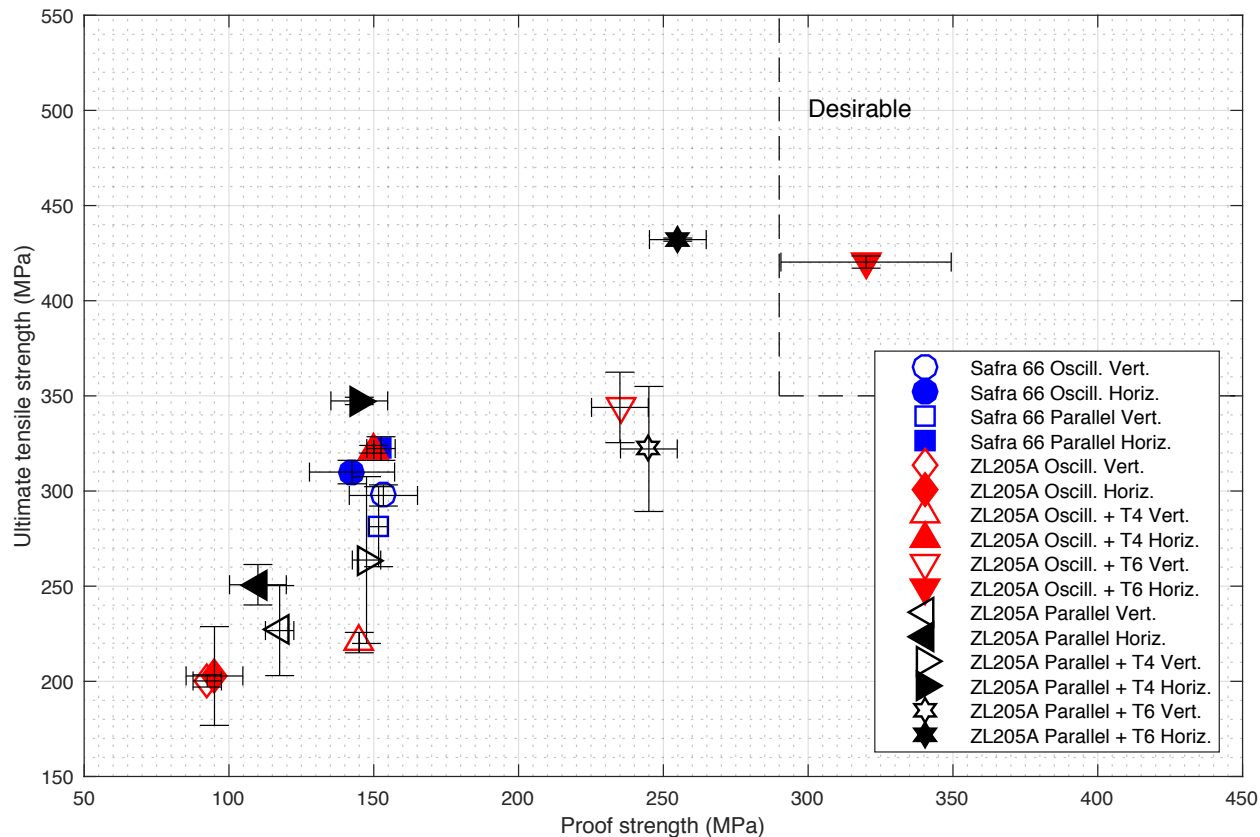




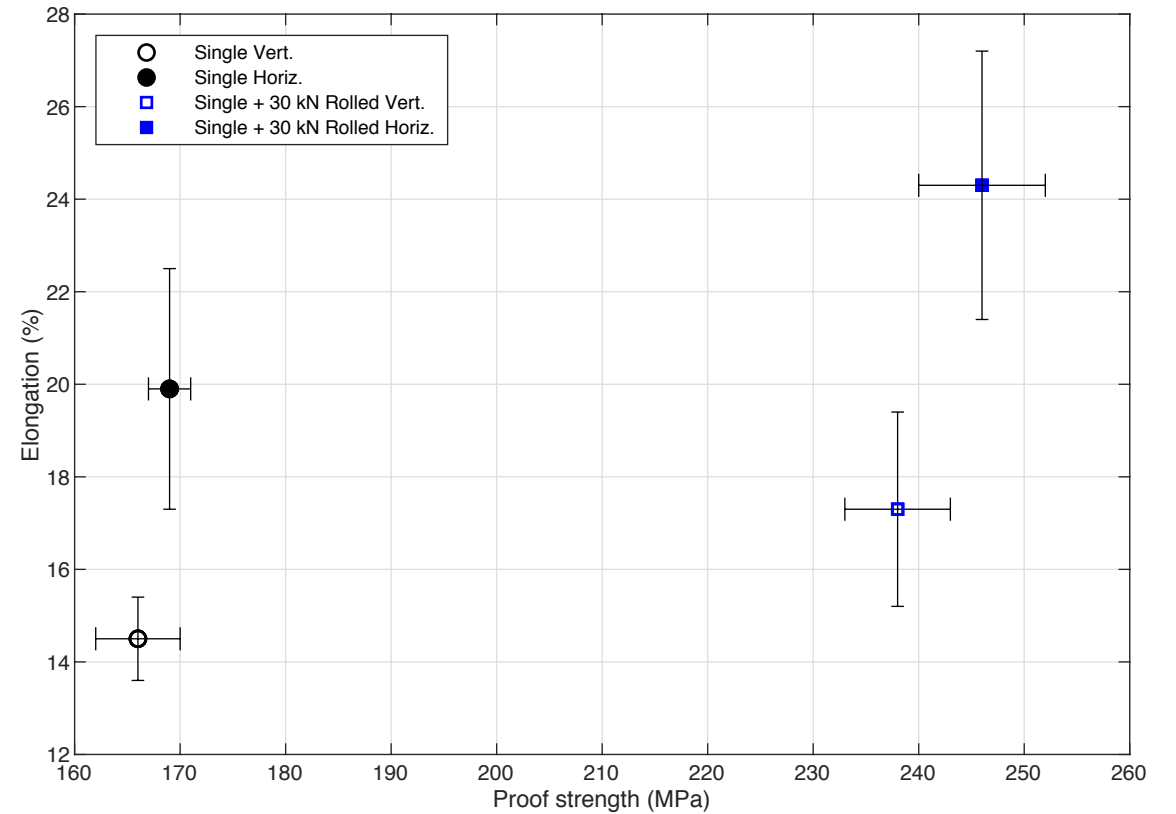
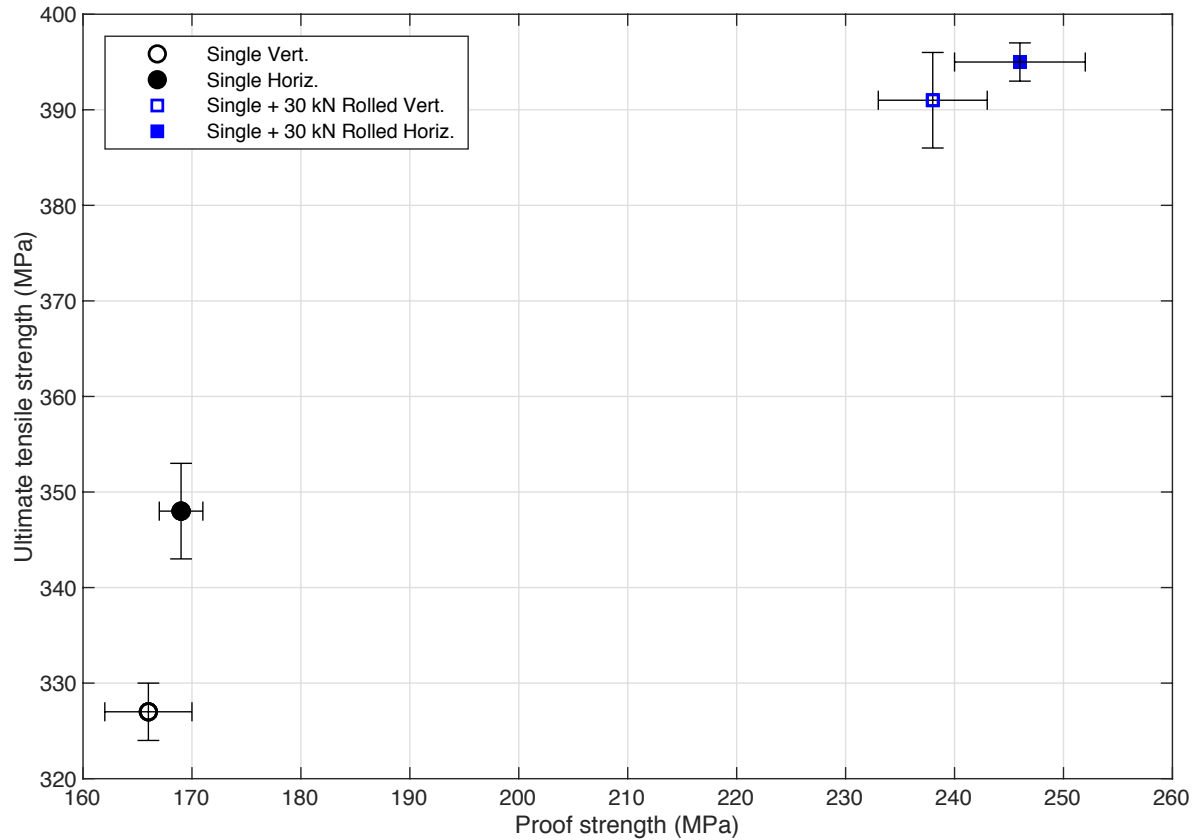
# Aluminium Safra 66 / ZL205A



## Thick walls

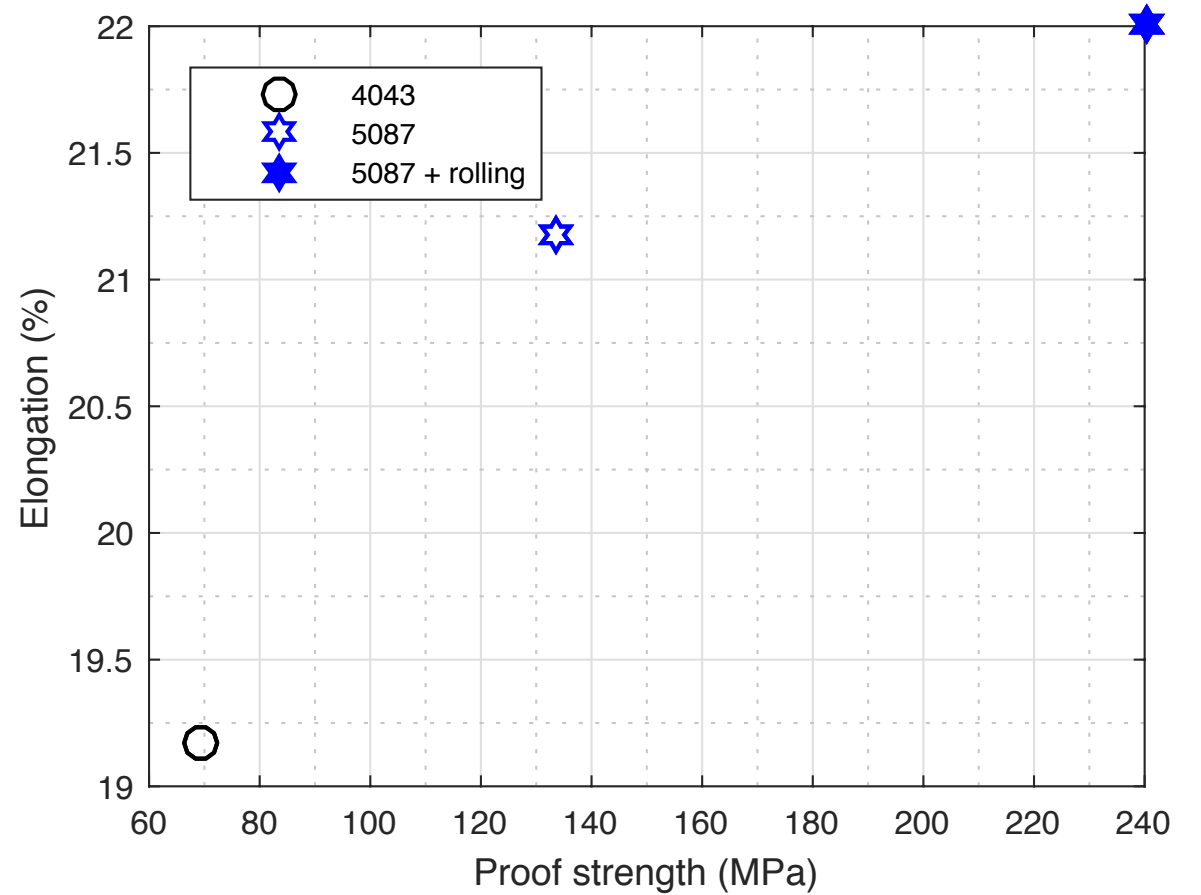
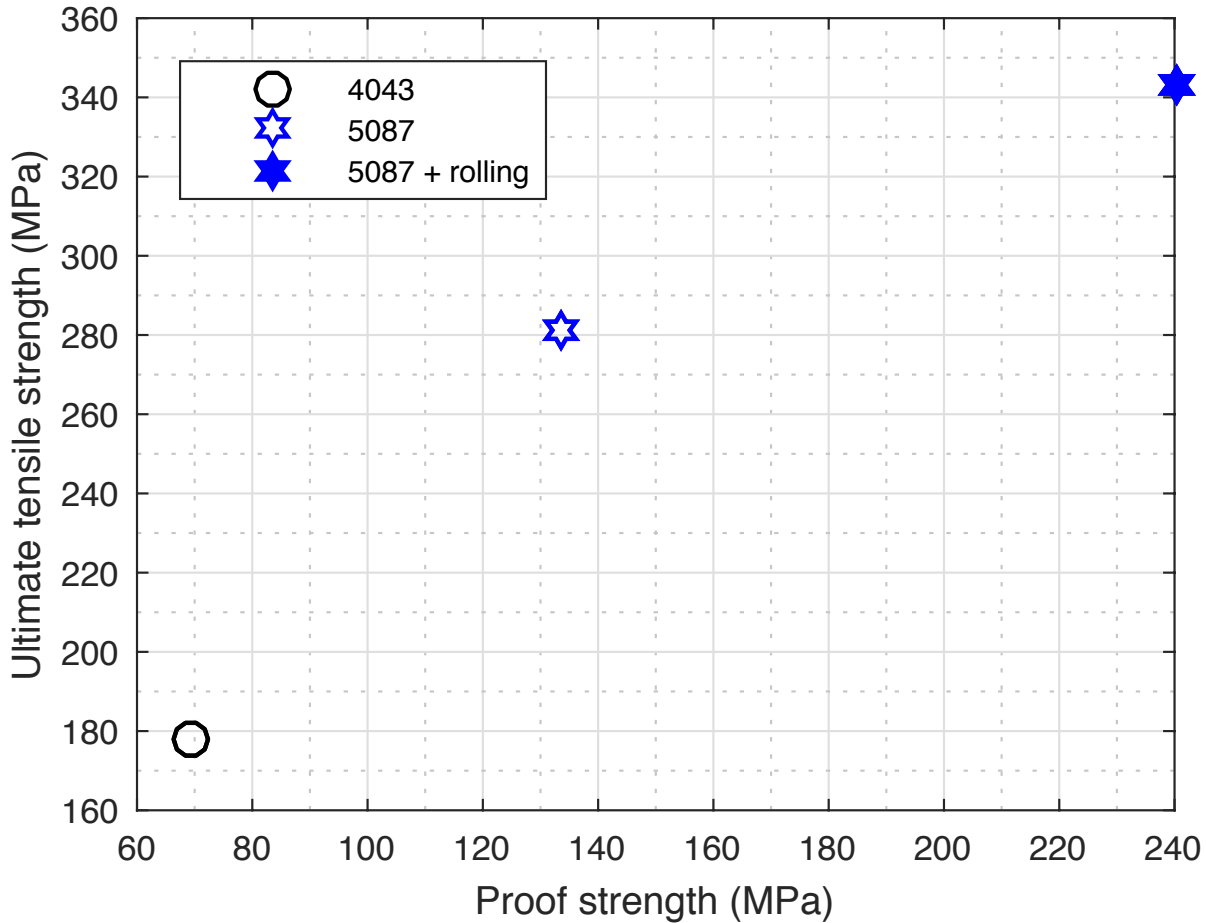


## Thin walls (single beads)





## Average values





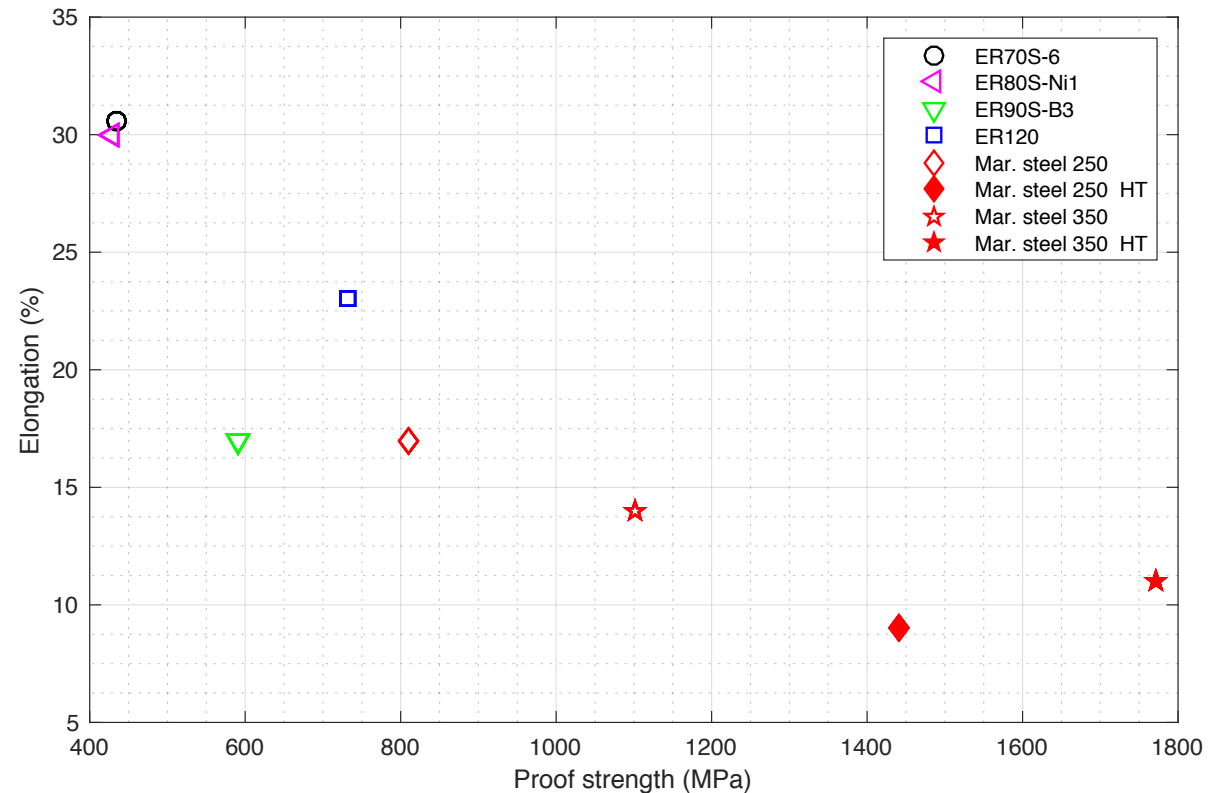
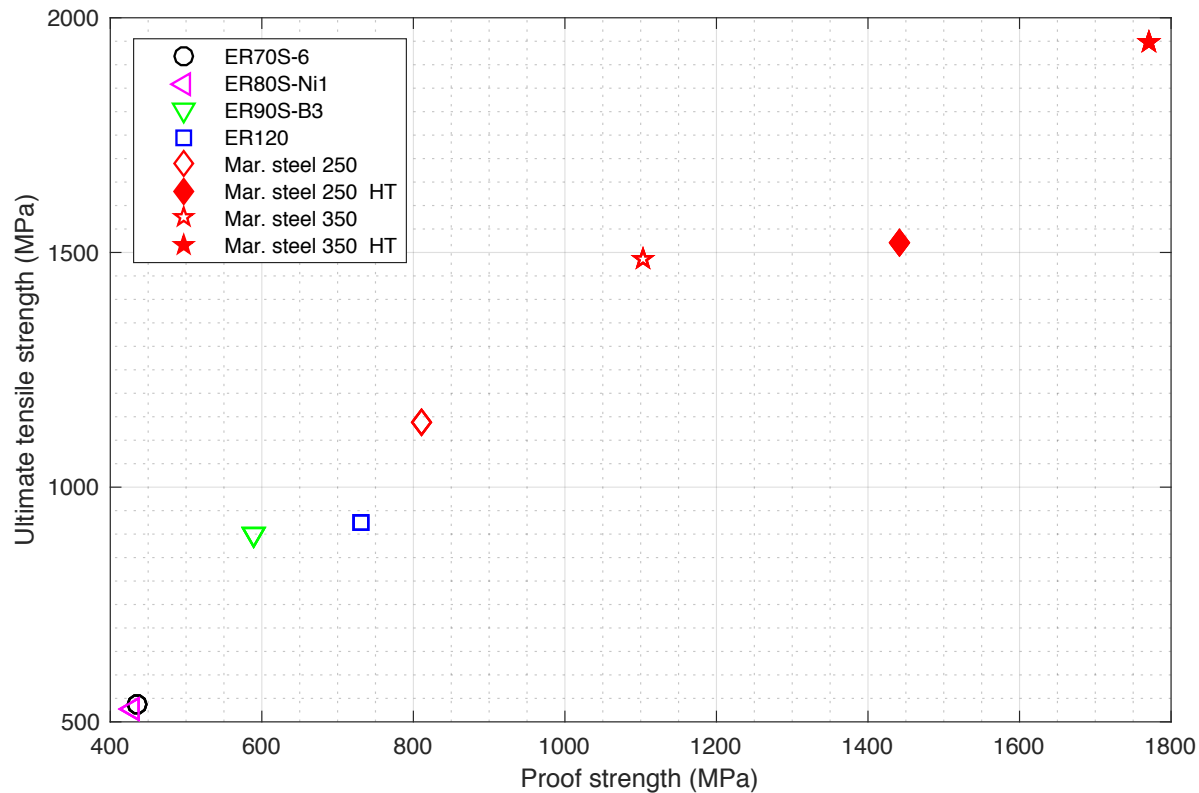
# Steels



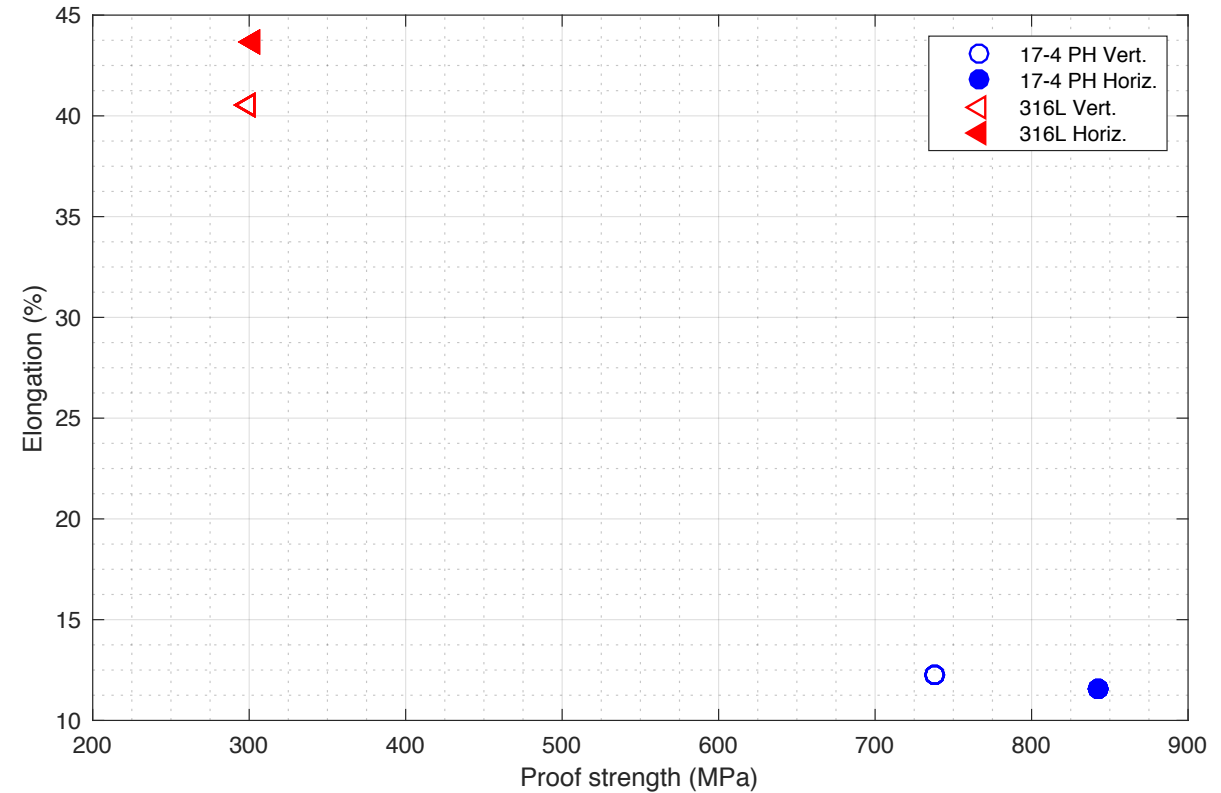
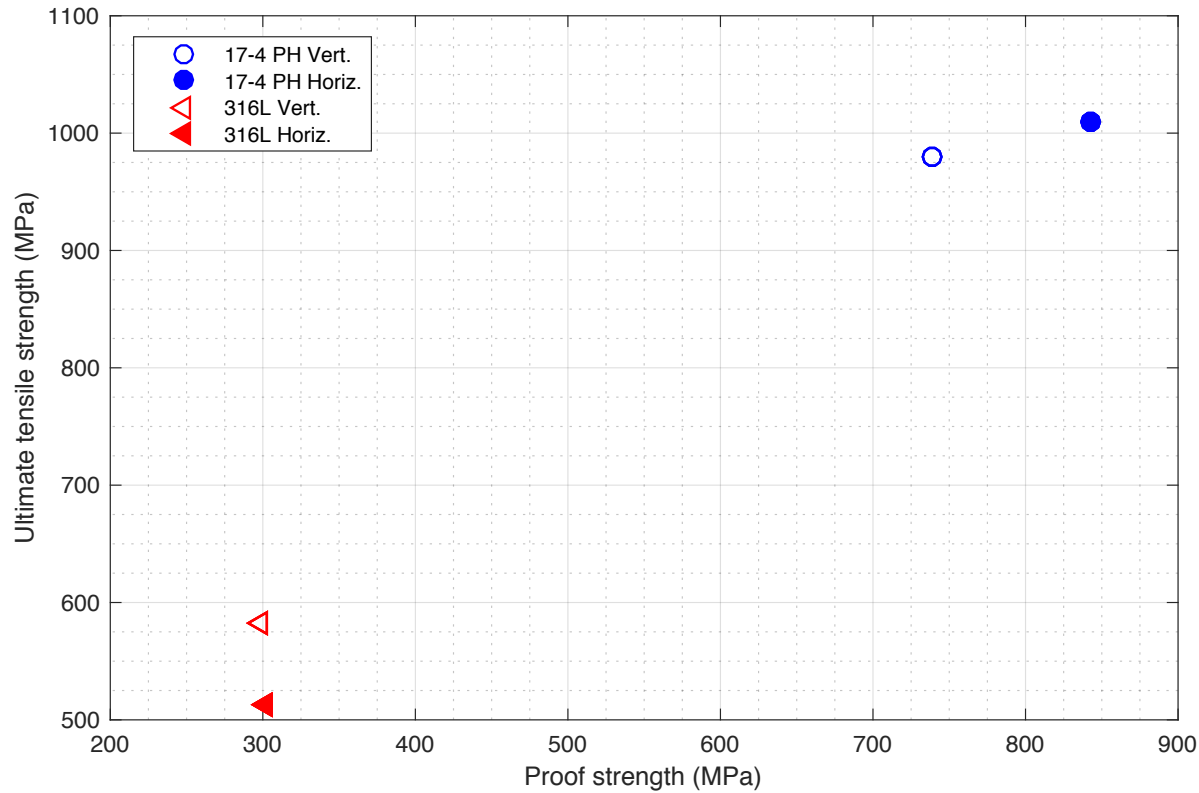
# Steels (work in progress)



## Average values

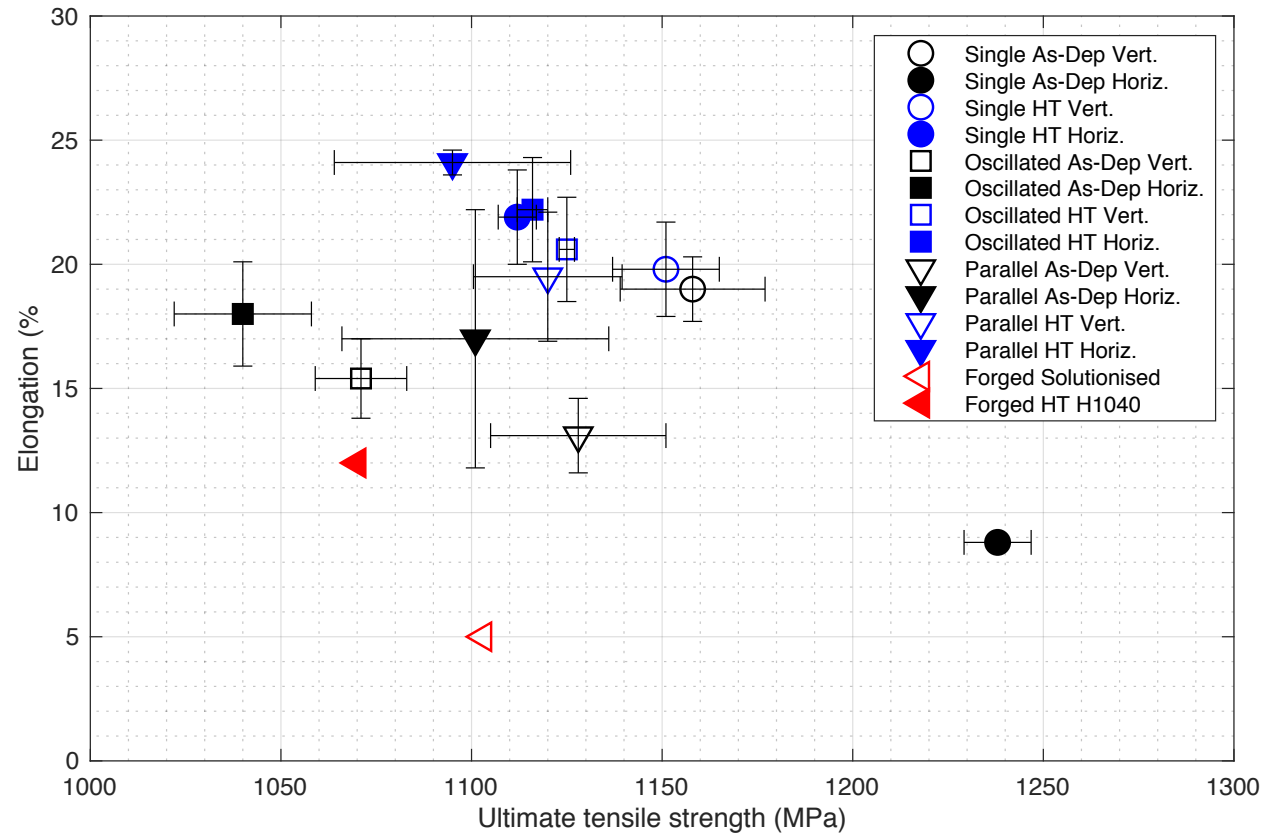


## Directionality



## Plasma

Marker indicates deposition strategy. Colour indicates heat-treatment conditions





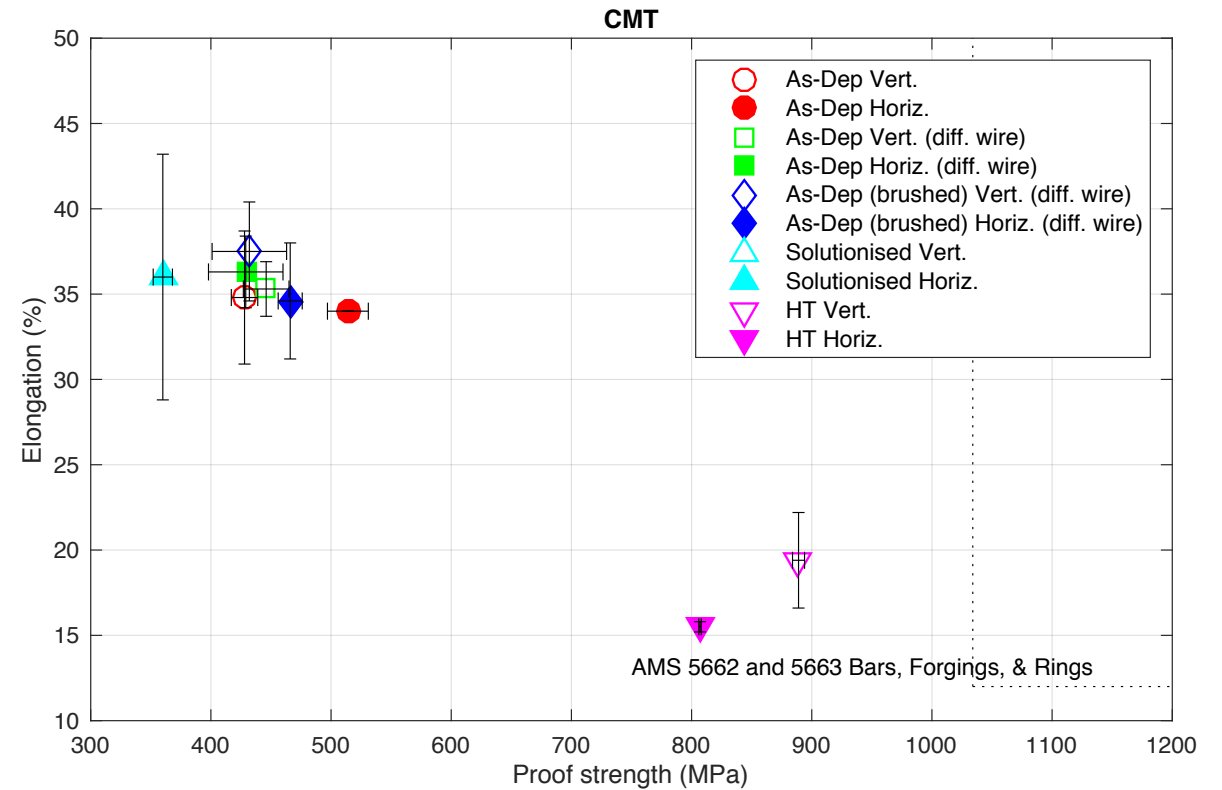
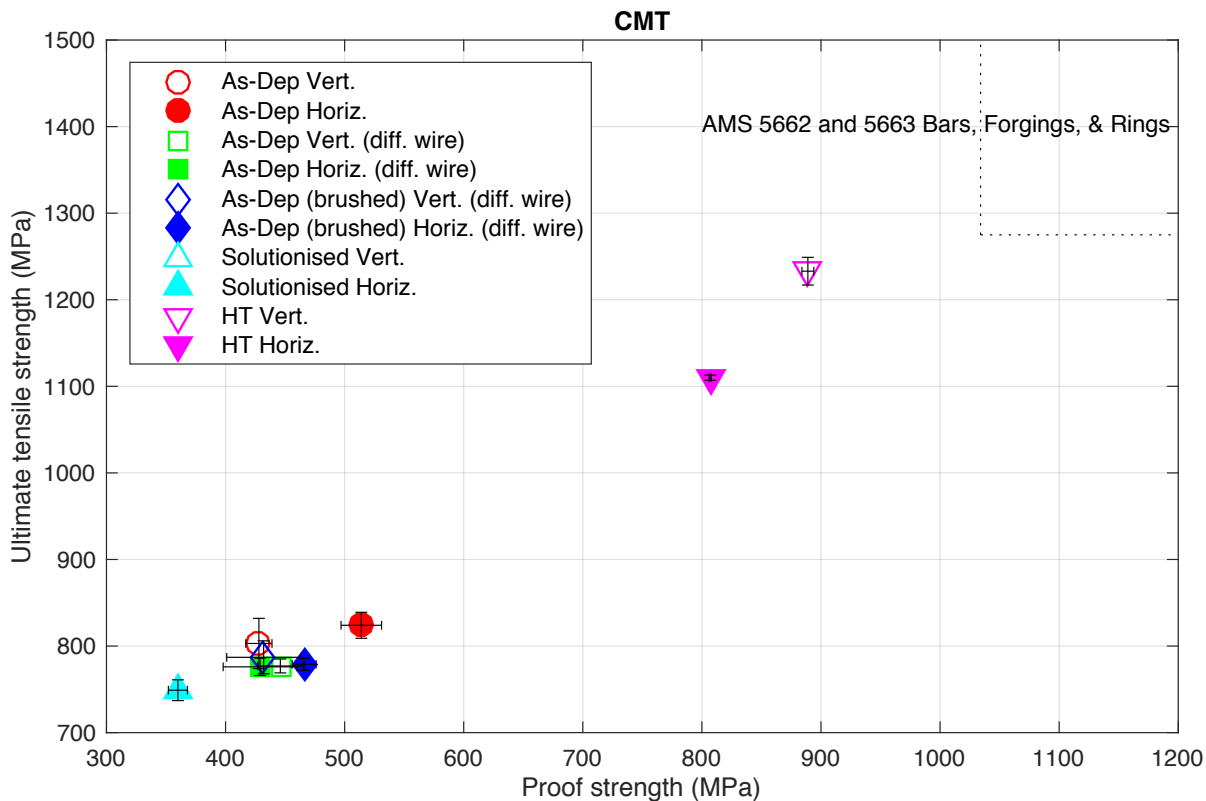
# Inconel



# Inconel® 718



## CMT (brushed = mechanical cleaning of surface prior to successive layer)



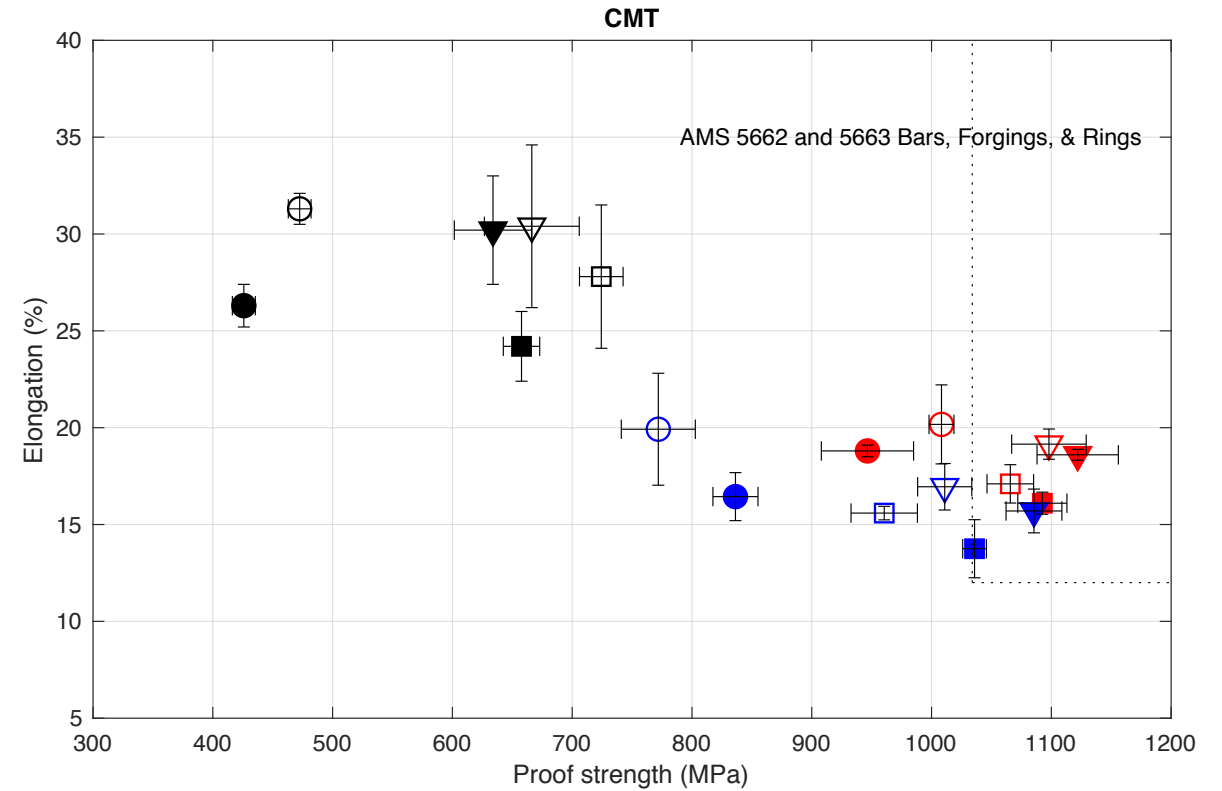
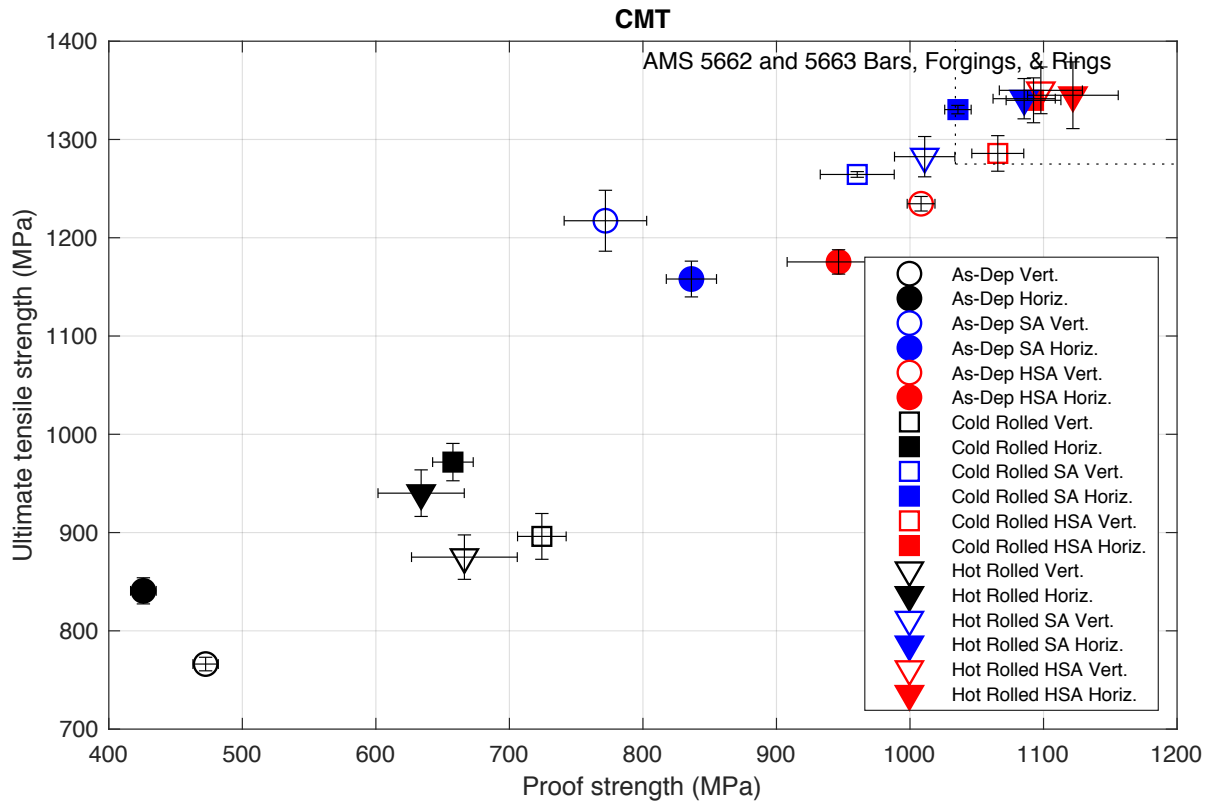


# Inconel® 718



## CMT (including cold in-process rolling and hot in-process rolling – 50 kN)

Marker indicates mechanical-work condition. Colour indicates heat-treatment conditions



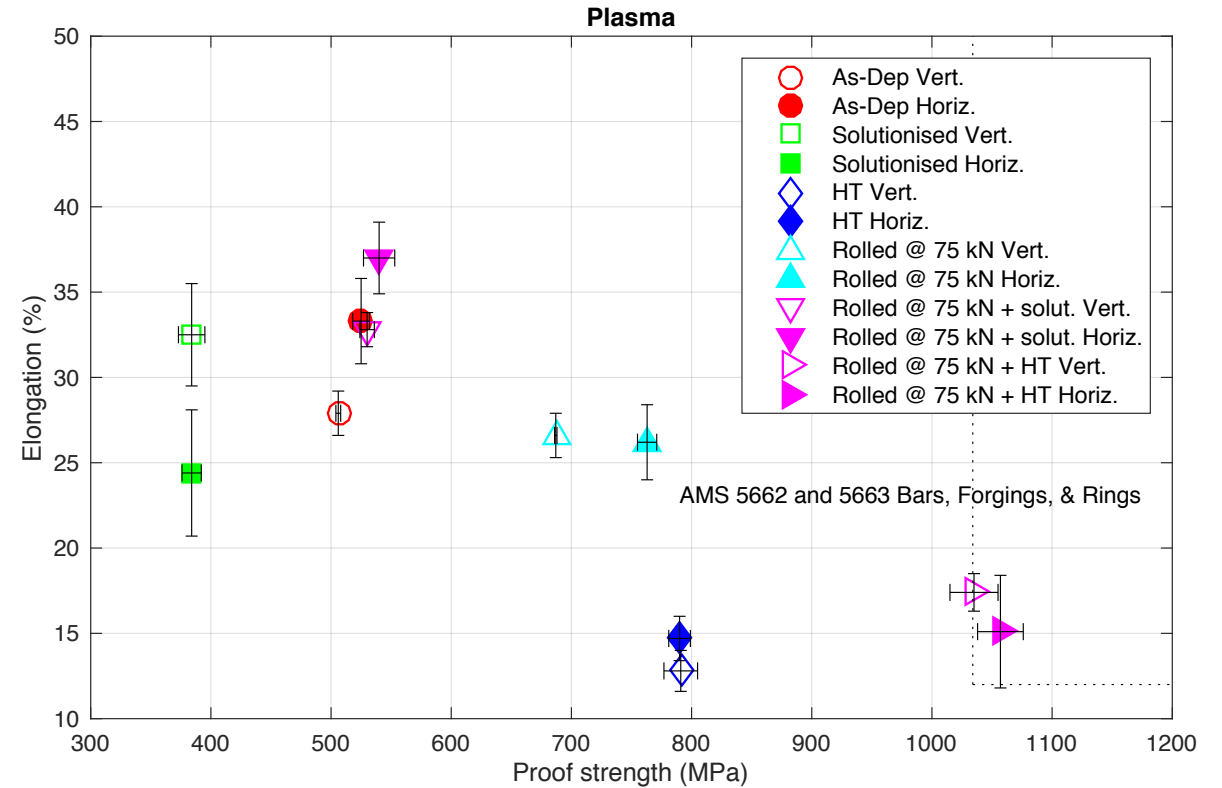
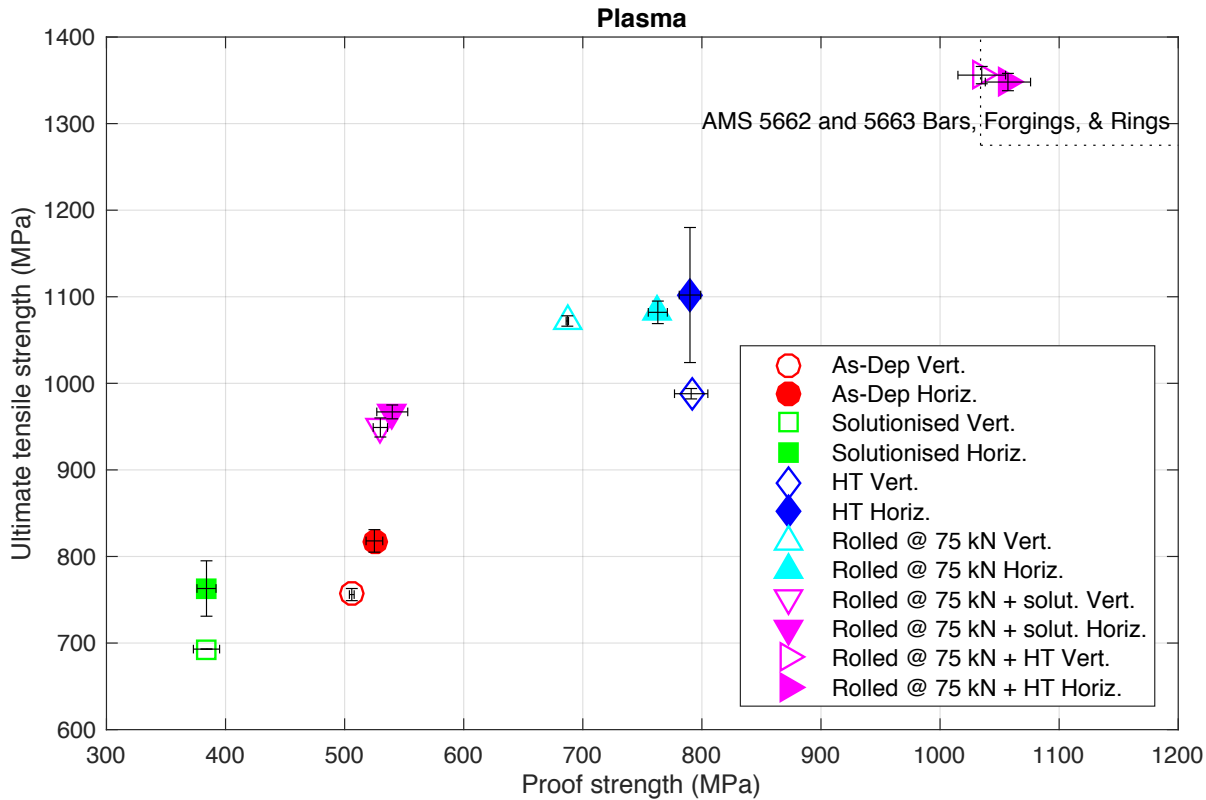




# Inconel® 718



## Plasma (including cold in-process rolling)

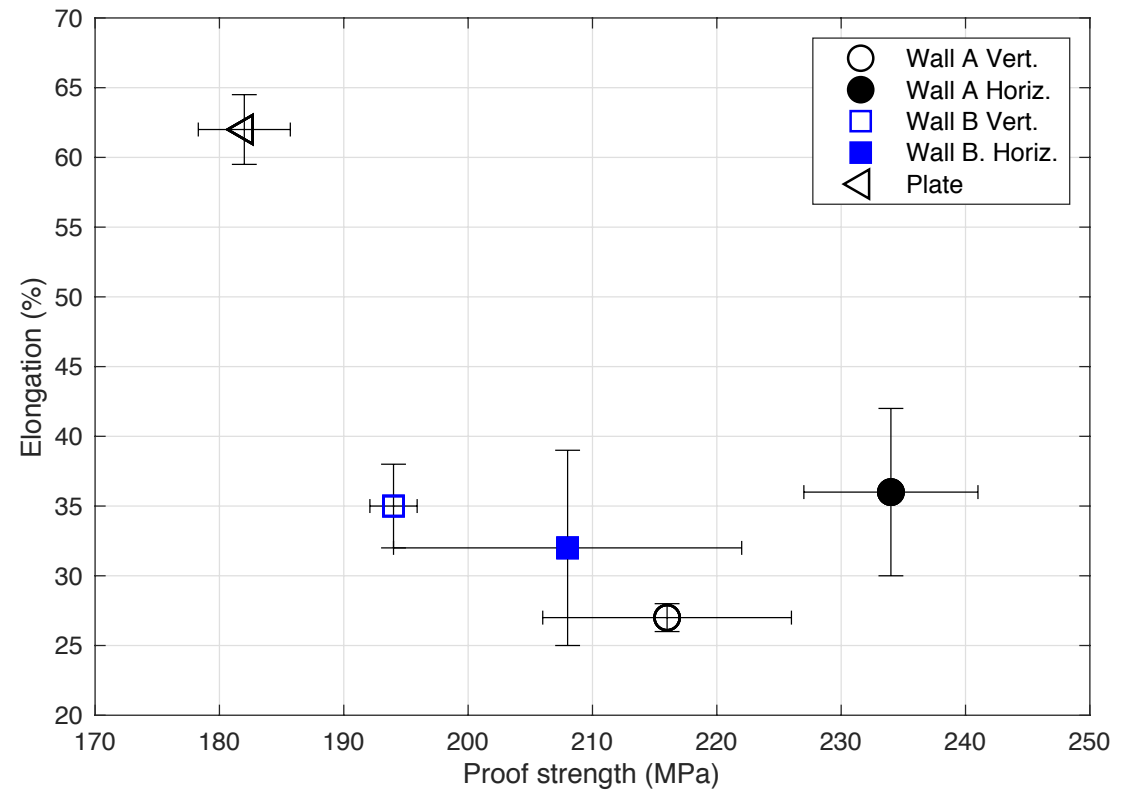
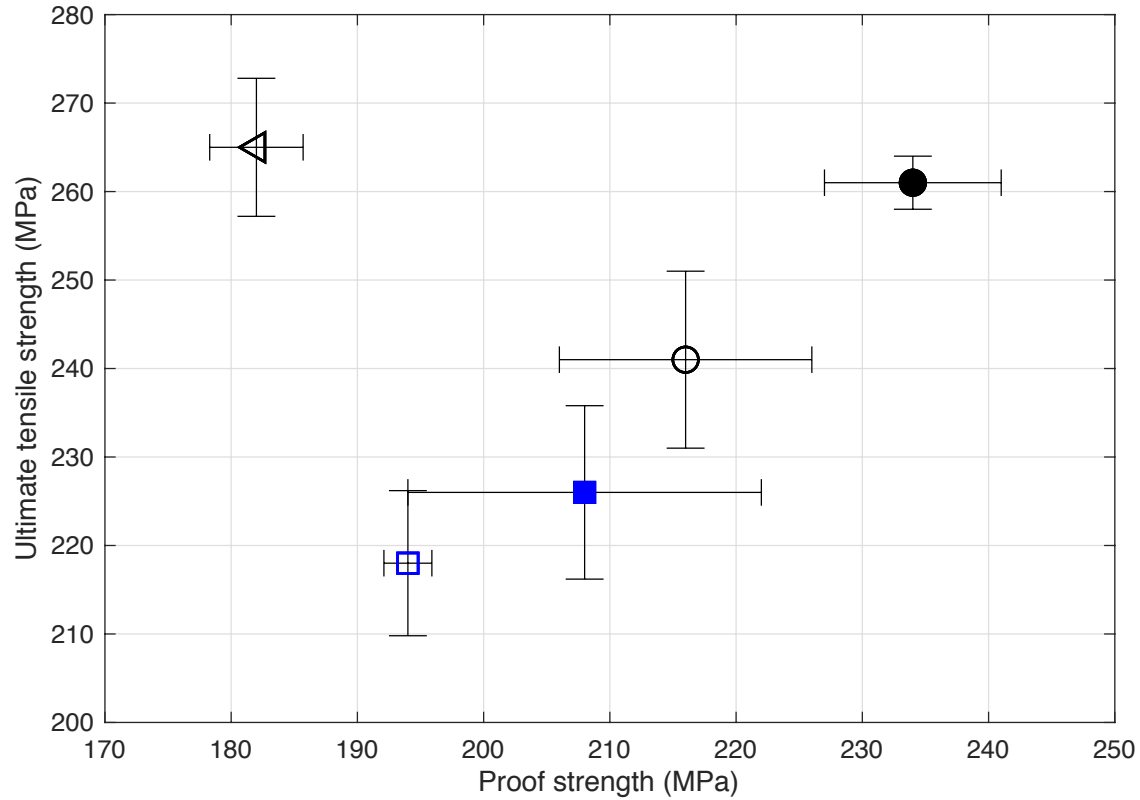




# Tantalum



# Tantalum



	W	Mo	Ta	Ti	V	Cr	Fe	C	N	O	K
<b>Substrate</b>	<0.05	<0.05	99.99	<0.05	<0.05	<0.05	<0.05	33 ppm	<10 ppm	60 ppm	<10 ppm
<b>Wire A</b>	<0.05	<0.05	99.98	<0.05	<0.05	<0.05	<0.05	36 ppm	11 ppm	190 ppm	<10 ppm
<b>Wire B</b>	<0.05	<0.05	99.87	<0.05	<0.05	<0.05	<0.05	20 ppm	<10 ppm	86 ppm	<10 ppm
<b>Wall A</b>	<0.05	<0.05	99.97	<0.05	<0.05	<0.05	<0.05	48 ppm	13 ppm	226 ppm	<10 ppm
<b>Wall B</b>	<0.05	<0.05	99.73	<0.05	<0.05	<0.05	<0.05	29 ppm	<10 ppm	164 ppm	<10 ppm



**WAAM**

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