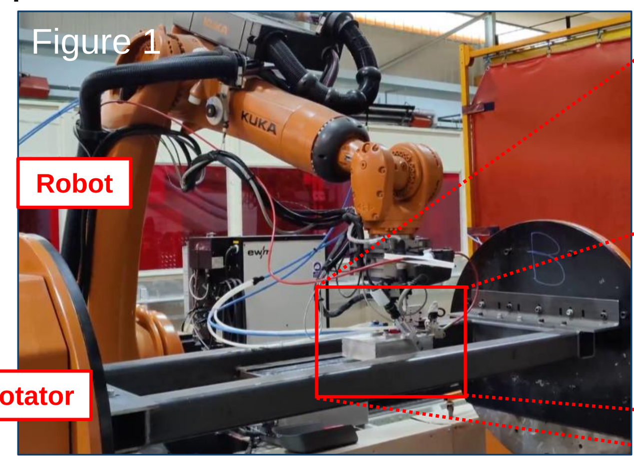
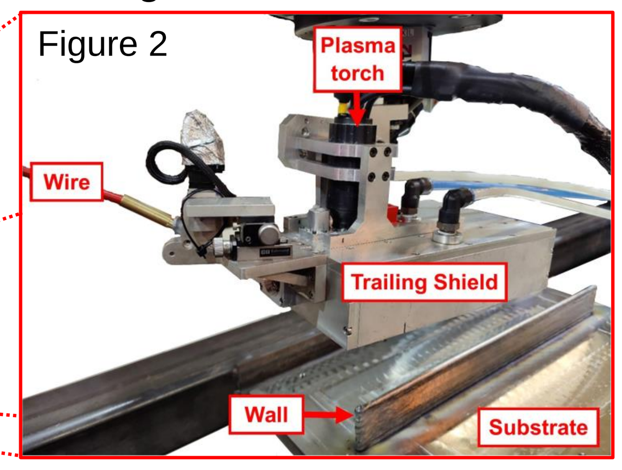
Microstructure and mechanical properties of Inconel 718 & 625 produced through the WAAM process

INTRODUCTION

- Wire + Arc Additive Manufacturing (WAAM) is the combination of an electric arc as a heat source and wire as a feedstock.
- For this project, a plasma arc welding process was combined with Inconel 718 (IN718) and Inconel 625 (IN625) wire and was used to deposit wall structures in a layer-by-layer process.
- The key difference between welded components and the WAAM system is the thermal profile of as-deposited WAAM components.
- Objectives:
    - To investigate room-temperature (RT) mechanical properties of IN718 & IN625 and as-deposited (as-dep) microstructure.
    - To investigate microstructure and mechanical properties of heat-treated IN625 at RT.
    - To analyse performance of as-dep and heat-treated variant compared to maximum achievable from wrought data.

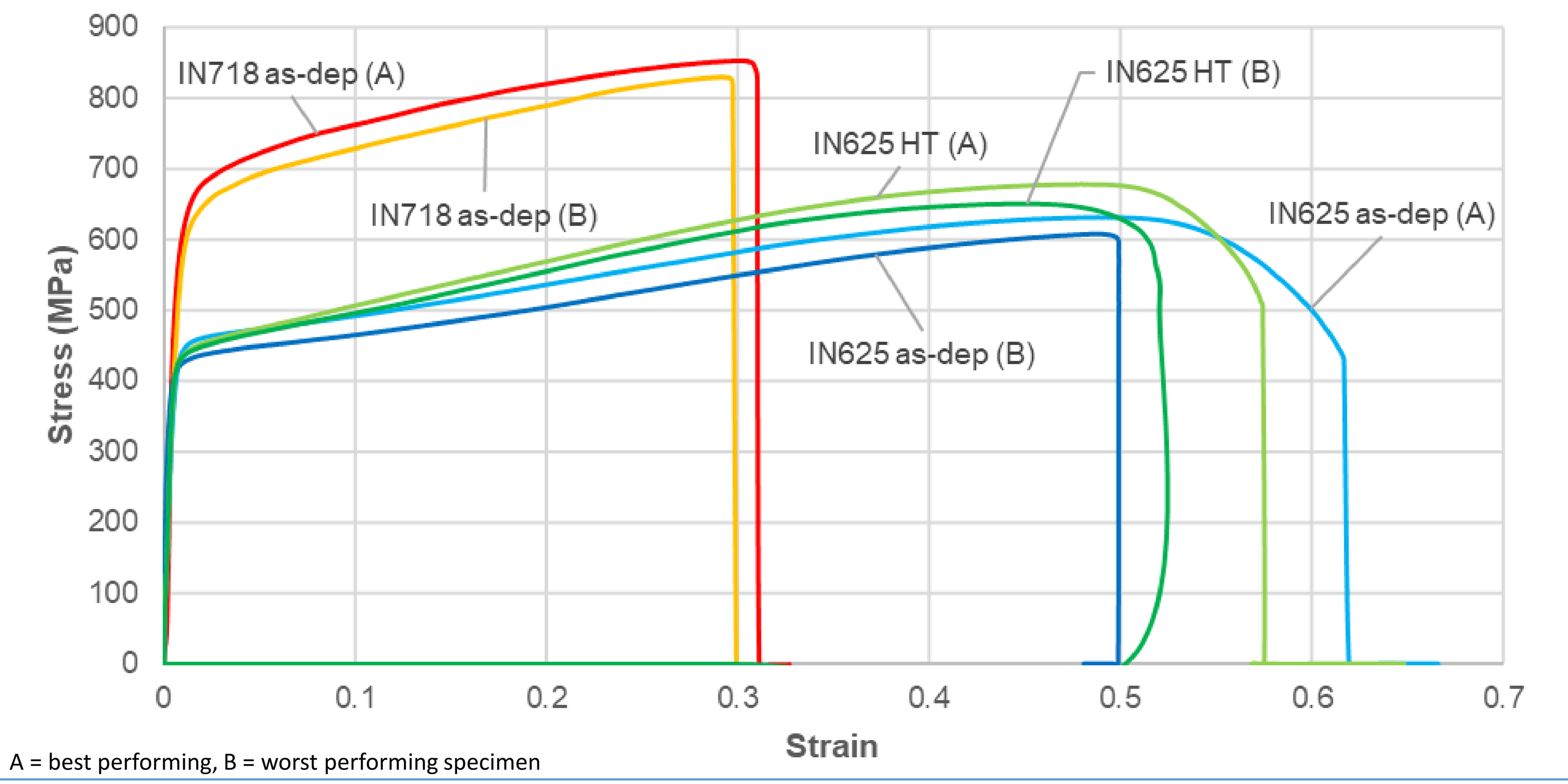




RT TENSILE PERFORMANCE

- Heat treating IN625 increases UTS by 6 %
- As-dep IN625 performs better in relation to wrought UTS than IN718

Alloy	Condition		UTS (MPa)	0.2% YS (MPa)	Elongation (%)
IN718	WAAM	as-dep	841.70	528.84	30.47%
	Wrought [e]		1435	1185	21%
IN625	WAAM	as-dep	622.21	396.67	57.26%
		Heat treated	659.70	328.36	41.88%
	Wrought [e]		965	490	50%



A = best performing, B = worst performing specimen

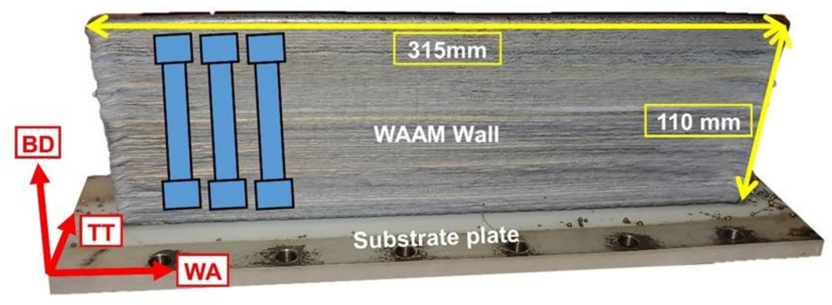
Location of tensile specimens

Axis key:

BD = Build direction

TT = Through thickness

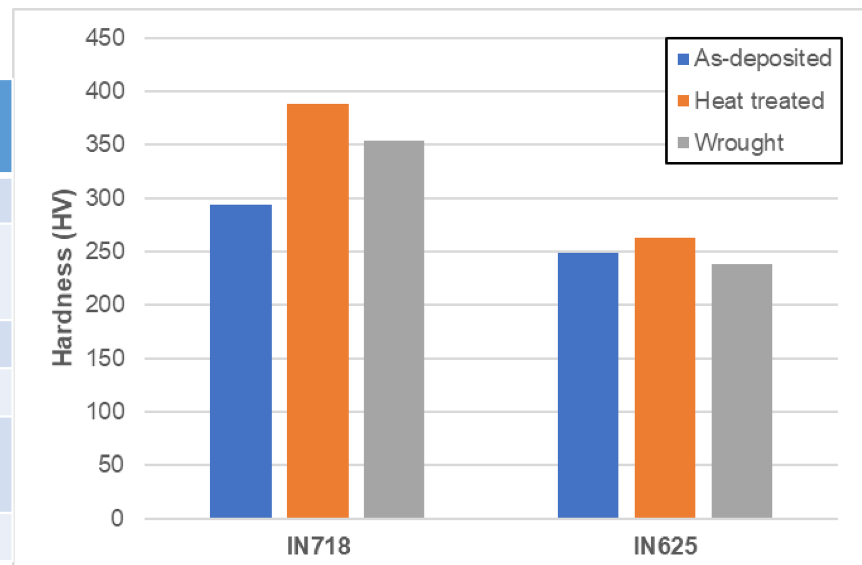
WA = Wall axis



RT HARDNESS

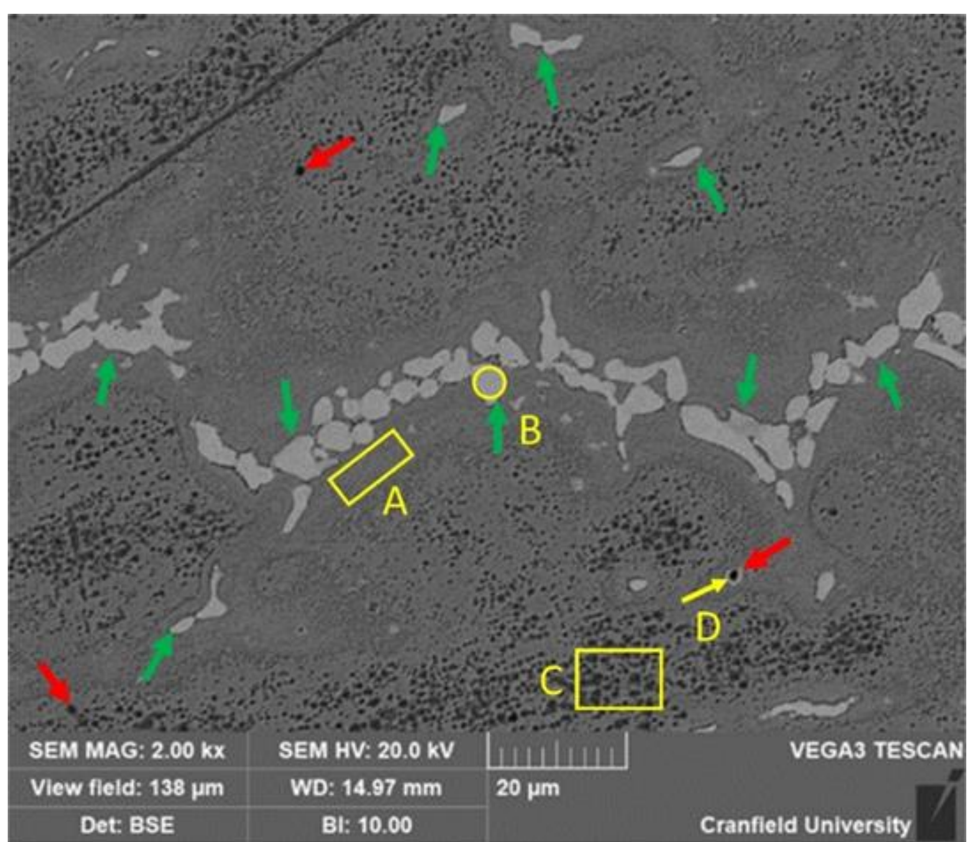
- Compared to as-deposited material:
    - Heat treating IN625 increases hardness by 5.7 %
    - Heat treating IN718 increases hardness by 32 %
- WAAM process partially ages alloys
    - IN718 undergoes a more extensive ageing process

Alloy	Condition		Hardness (HV)
IN718	WAAM	as-dep	293.9
		Heat treated	388 [a]
	Wrought		354 [b]
IN625	WAAM	as-dep	248.5 [c]
		Heat treated	262.8 [c]
	Wrought		238 [d]

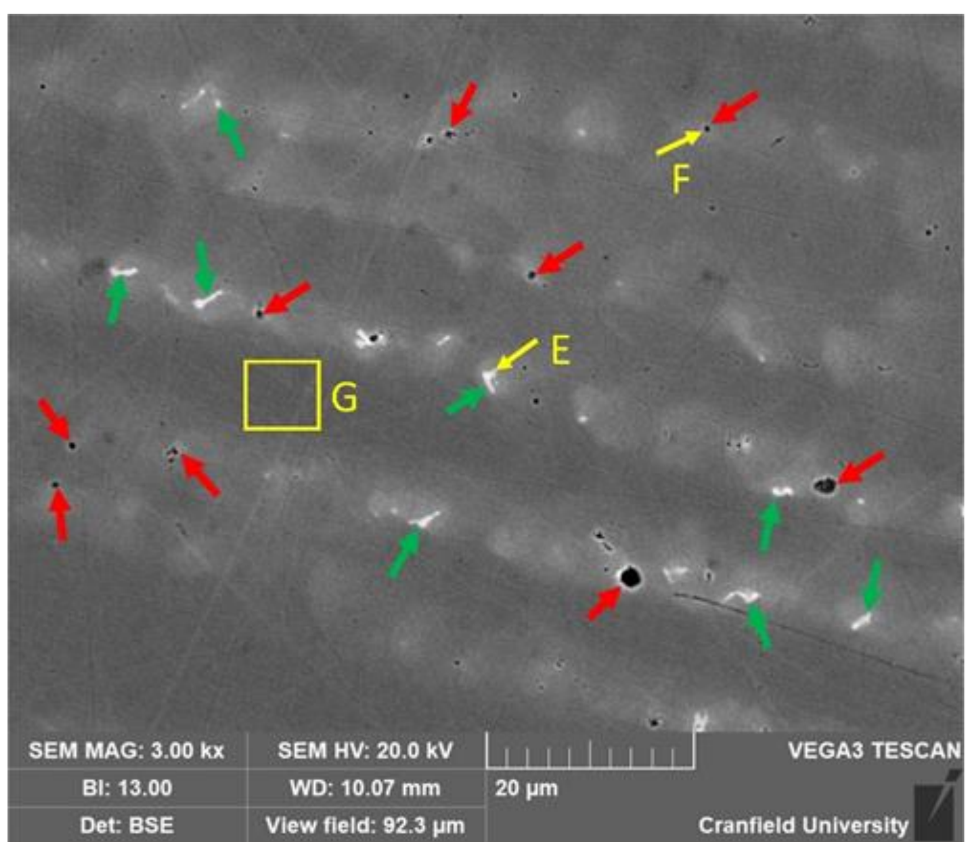


MICROSTRUCTURE

- Complex intermetallic phase – segregated **Ni_2Nb/Cr_2Mo**
- Ti rich carbides – **TiC**
- Sites where composition was analysed



IN718 – (TT & WA cross-section) as-deposited sample showing grain boundary and segregated zones.



IN625 - (TT & WA cross-section) post-deposition heat-treated sample showing segregated zones.

EDS Composition – compared to wire composition

green = more, red = less, purple = anomaly

Spectrum Label	% At.						
	IN718				IN625		
	A	B	C	D	E	F	G
C	12.04	0	10.02	0	18.35	12.82	9.73
F	6.95						
Al	1.11	0	1.25	15.20	0.22	0.31	0.38
Si					0.73	0.18	0.12
Ti	1.50	1.95	0.63	51.85	0.25	1.52	0.17
Cr	16.64	17.67	19.97	0	17.24	20.32	23.64
Fe	13.77	12.96	18.30	0		0.17	0.21
Ni	42.51	46.26	46.92	0	35.18	50.61	60.36
Nb	3.91	21.15	1.39	32.95	16.46	7.81	1.00
Mo	1.58	0	1.53	0	11.58	6.25	4.39

CONCLUSIONS

- Nb & Mo segregate and contribute to formation of Laves phases, specifically A_2B type, indicated in both alloys with precipitation seen at the grain boundaries and inter-dendritic regions.
- WAAM build alloys in as-deposited condition achieved on average 62 % of their max. stated values from wrought data.
- WAAM partially ages IN625 and heat-treating increases UTS performance by ~6 %.

Mr William Sean James, Dr Supriyo Ganguly, Dr Goncalo Pardal

Welding Engineering & Laser Processing Centre
Cranfield University

w.james@cranfield.ac.uk

www.cranfield.ac.uk

References: **[a]** Xu, X., Ganguly, S., Ding, J., Seow, C. E. and Williams, S. (2018) 'Enhancing mechanical properties of wire + arc additively manufactured INCONEL 718 superalloy through in-process thermomechanical processing', Materials and Design. Elsevier Ltd, 160, pp. 1042–1051. **[b]** Special Metals (2007) INCONEL® alloy 718. Available at: https://www.specialmetals.com/assets/smc/documents/inconel_alloy_718.pdf (Accessed: 8 May 2020). **[c]** Kasravi, N., Hidayat, R., Tuncer, C., Themistokleous, M. and Sambo, A. M. (2021) ADDITIVE MANUFACTURE OF ALLOYS FOR HIGH TEMPERATURE APPLICATION. Cranfield University. **[d]** Special Metals (2013) INCONEL® alloy 625. Available at: https://www.specialmetals.com/assets/smc/documents/alloys/inconel/inconel-alloy-625.pdf (Accessed: 4 June 2020). **[e]** Donachie, M. J. (2002) 'Superalloys: A Technical Guide, 2nd Edition', America. doi: 10.1361.