Challenges in Wire-arc Additive Manufacturing (WAAM) of Fe-Co-V Alloy using Metal Powder-Cored Wire



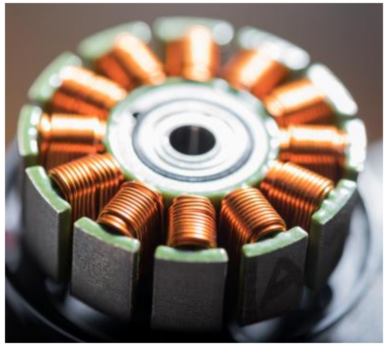
Soumyajit Koley[1,2], Kuladeep Rajamudili[2] Supriyo Ganguly[2]

[1]*Research & Development, **Tata Steel**, India*

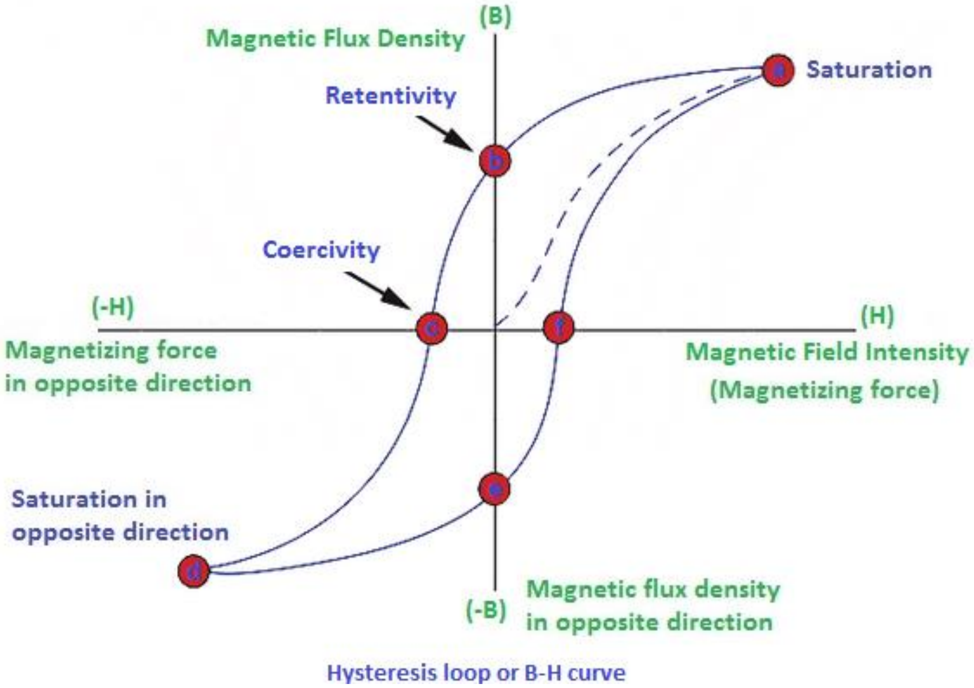
[2]*Welding & Additive Manufacturing Centre, **Cranfield University**, United Kingdom*

Cranfield University TATA STEEL #WeAlsoMakeTomorrow Welding Alloys BROCKHAUS MEASUREMENTS

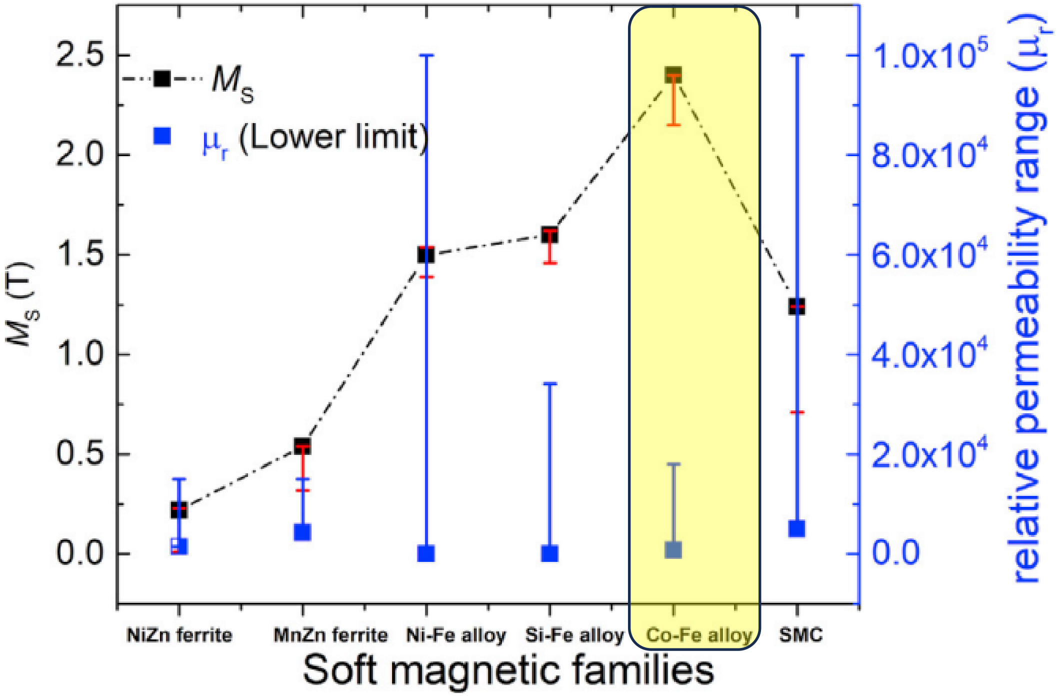
Introduction



Soft-magnetic material - Materials which can be easily magnetized or demagnetized by application of electro-magnetic field



Coercivity < 1000 A/m



Lamichhane et al. / Materials Today Physics 15 (2020) 100255

Background

- The global soft magnetic materials market was valued at **US$47.3 billion in 2018** - projected to reach $87.2 billion by 2026 (CAGR of 8.8%)

- Fe-Co-V alloy is produced commerciall... melting-casting route by few se... such as Carpenter Technology ... etc. However, long and ... production treatment is ...

- Addi... ...ing represents unique set of advan... ...ch as shorter lead time, small order quantity etc.

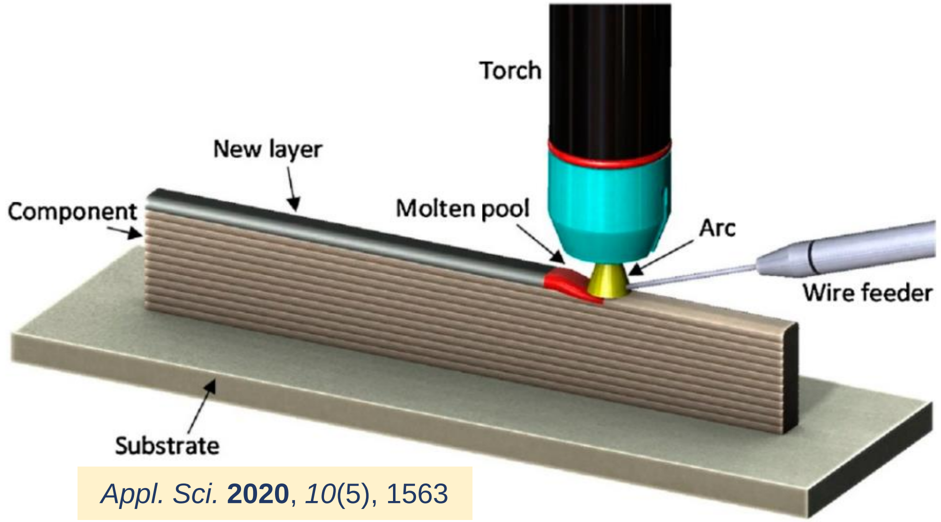
- A few works on LPBF of Fe-Co-V alloy has been done

Possibly this is the 1st approach to produce Fe-Co-V alloy using WAAM

3D printed (LPBF) ***Hall Thruster*** for spacecraft propulsion

Adv. Eng. Mater. 2022, 24, 2100931

Wire-Arc Additive Manufacturing (WAAM)



Appl. Sci. **2020**, *10*(5), 1563

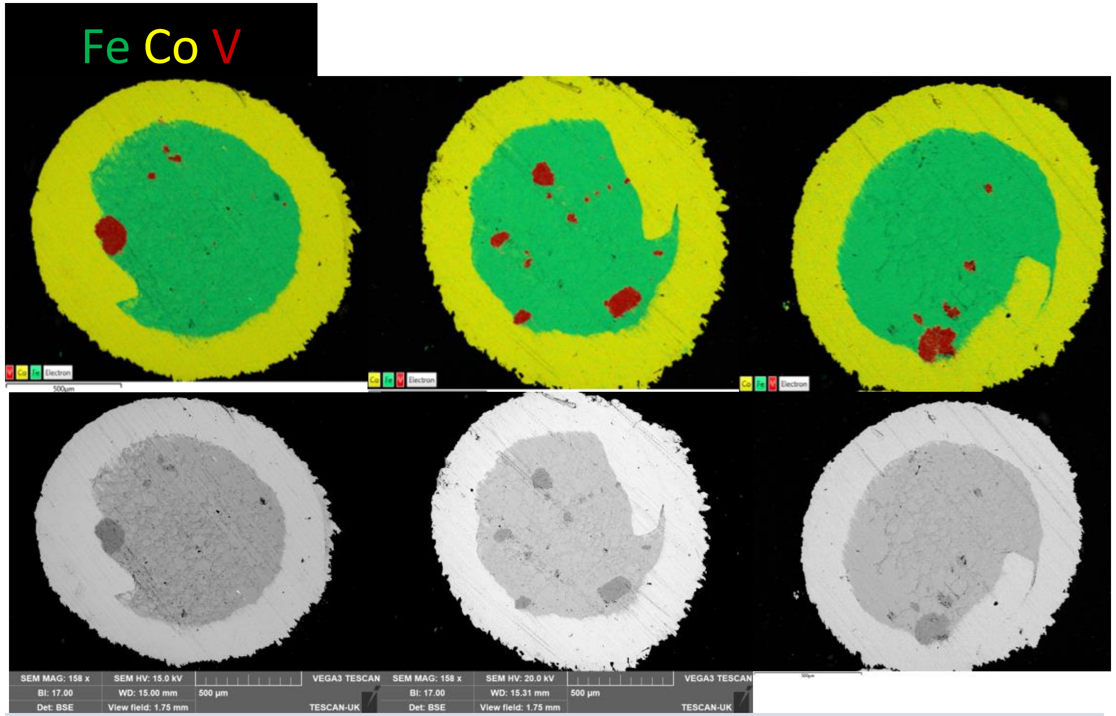
Plasma welding torch with spool wire feeder used

W electrode diameter	:	4 mm
Welding current	:	180 A
Torch Speed	:	2 – 3.75 mm/s
Wire feed rate	:	2 m/min
Wire entry angle	:	30°
Standoff distance	:	8 mm
Torch shielding gas flow	:	18 lpm (Ar)
Plasma gas flow	:	0.8 lpm (Ar)
Pilot arc current	:	18 A

Fe-49Co-2V deposition in Ar atmosphere

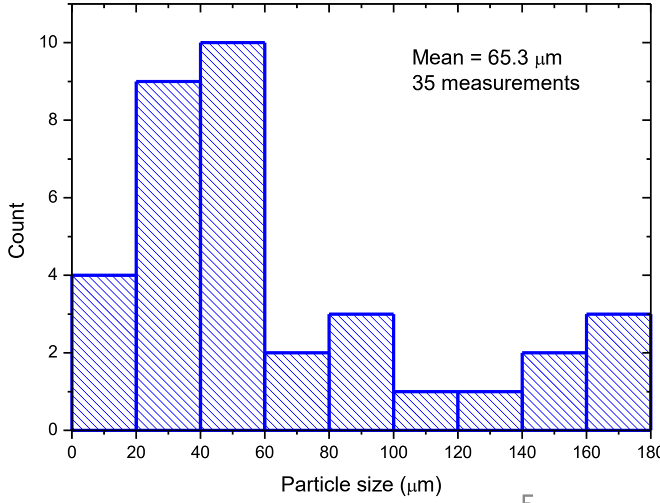
Wire Feedstock

- High hardness and poor ductility of the alloy restrict conventional solid wire-drawing process.
- Metal cored wire used in the study –1.2 mm (dia)
- Co sheath used to cover Fe and V powders
- Wire produced through commercial manufacturing process

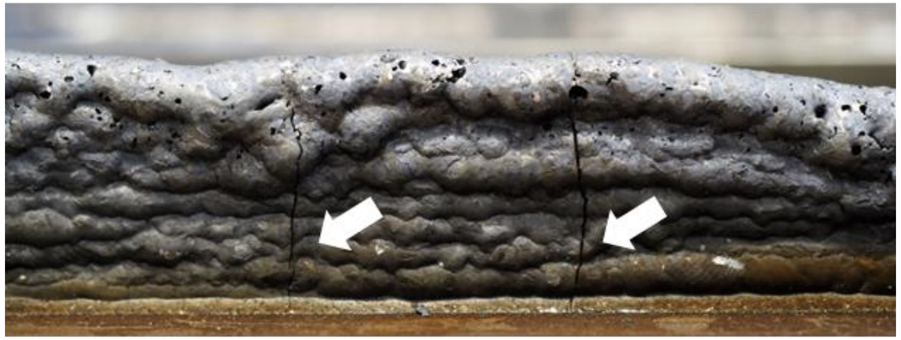


Distribution of alloy elements in the wire

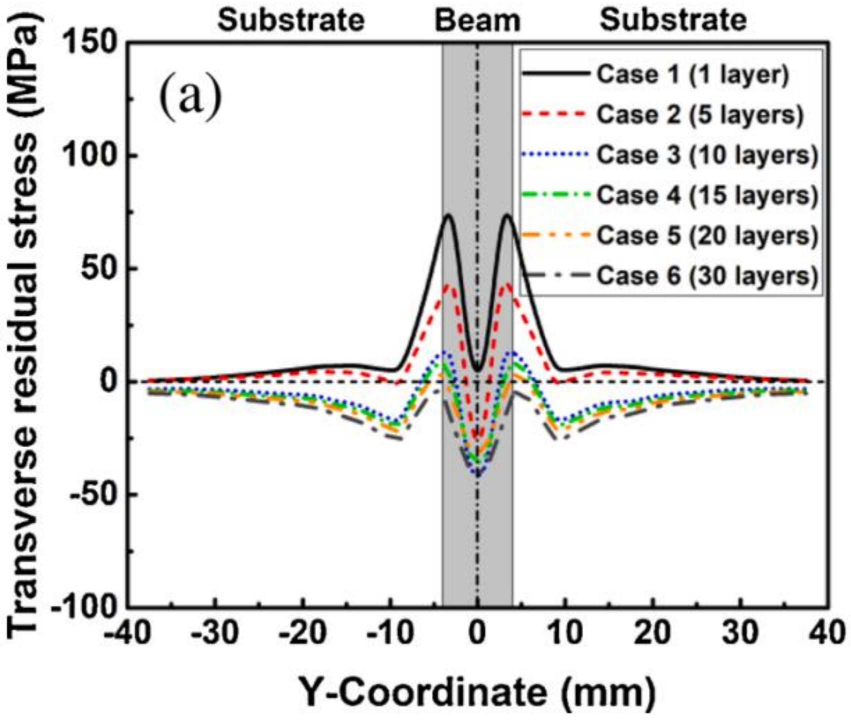
Element	Density (gm/cc)	Area fraction (%)	Melting Point (C)
Co	8.75	37	1495
Fe	7.85	62	1538
V	5.49	0.4	1910

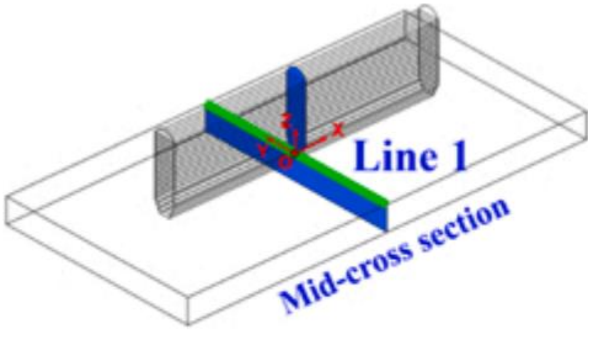


Challenge 1 – Substrate Orientation



Occurrence of vertical cracks at multiple locations

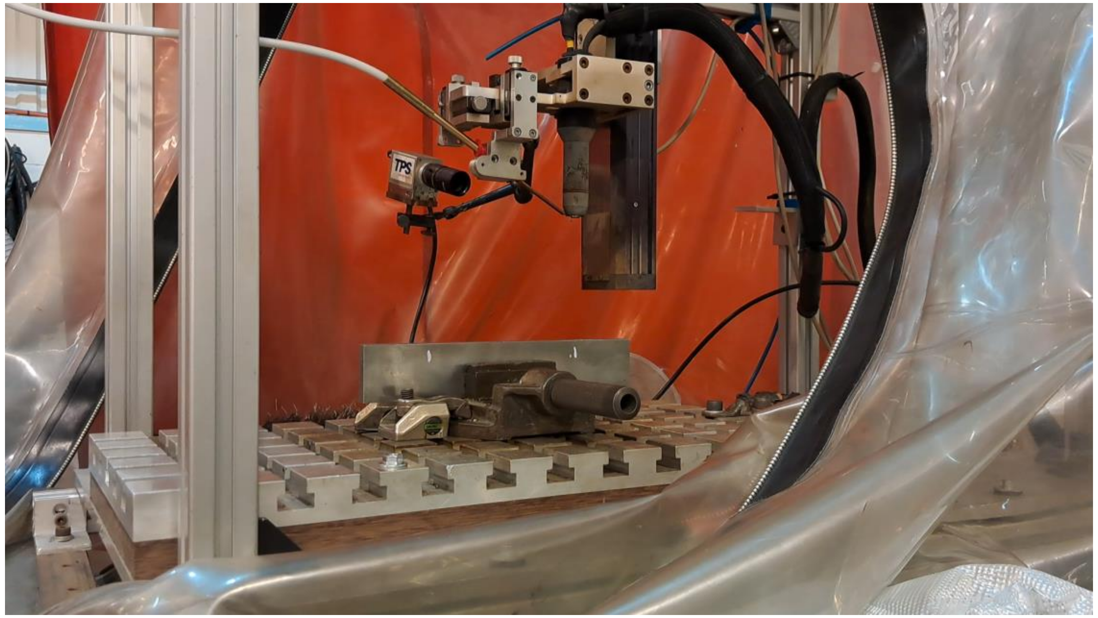


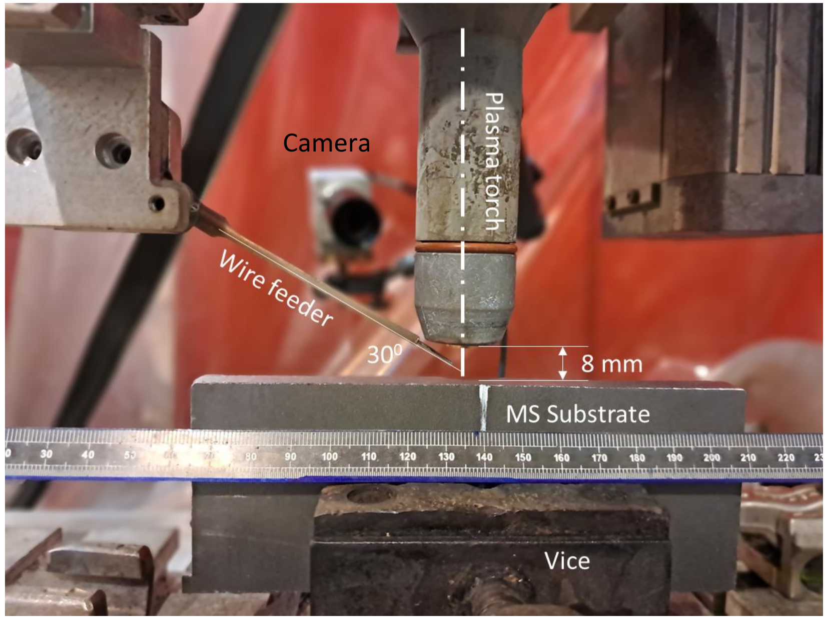


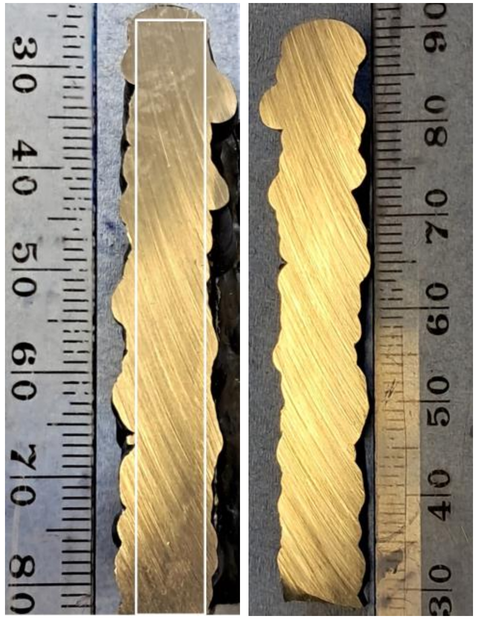
J. Manuf. Proc. 65 (2021) 97-111

- *Residual stress from the deposition process coupled with brittle nature of the alloy leads to cracking.*
- *Shape of the substrate plays an important role.*

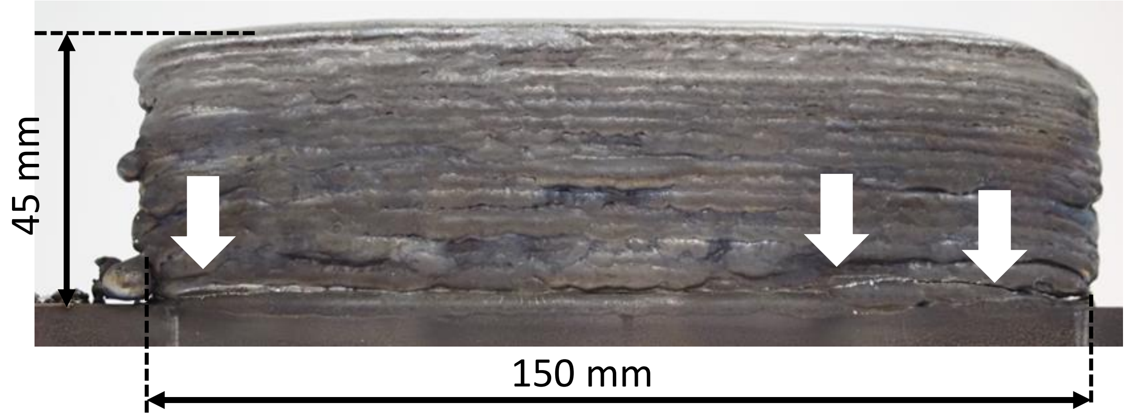
Deposition on the Substrate’s Edge





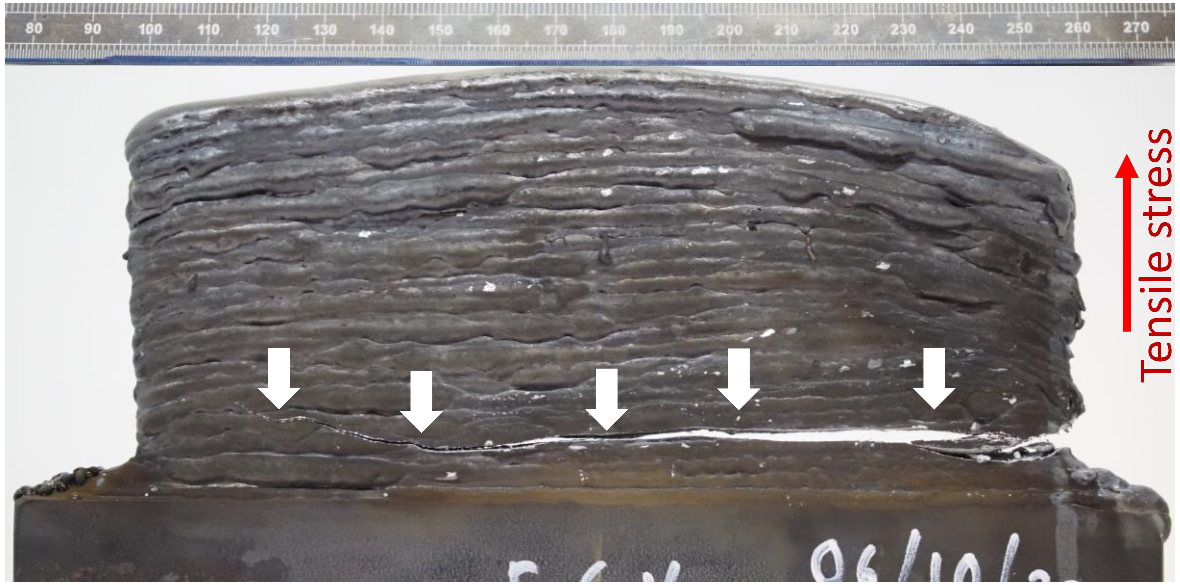


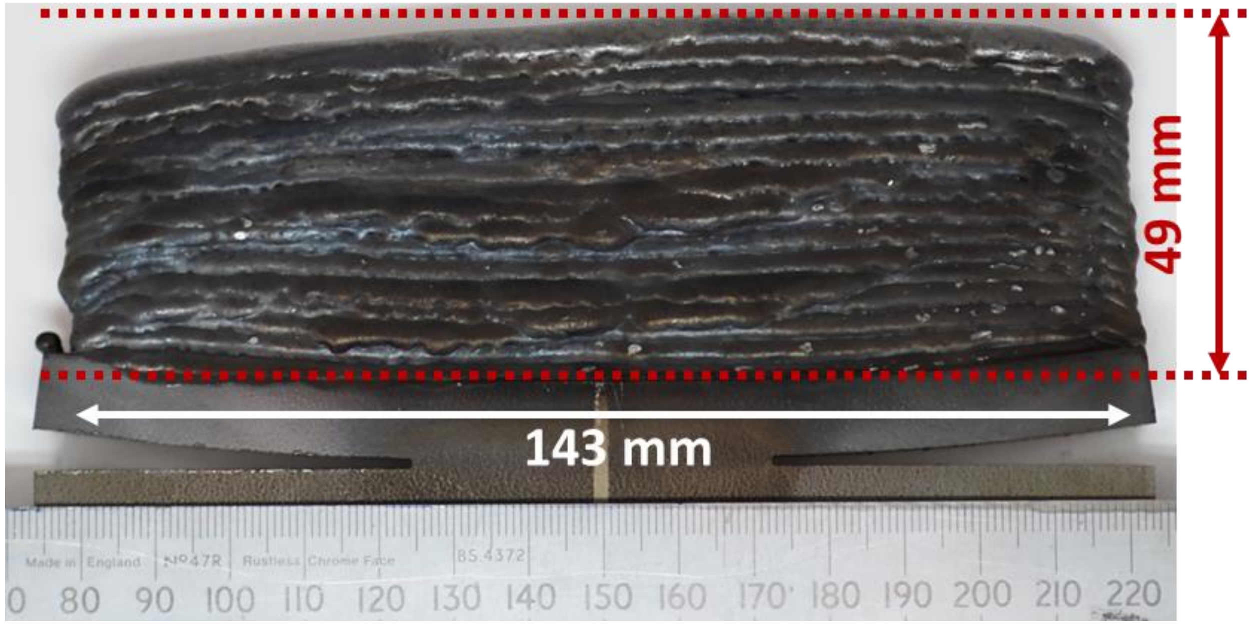
6.75 mm 6.25 mm

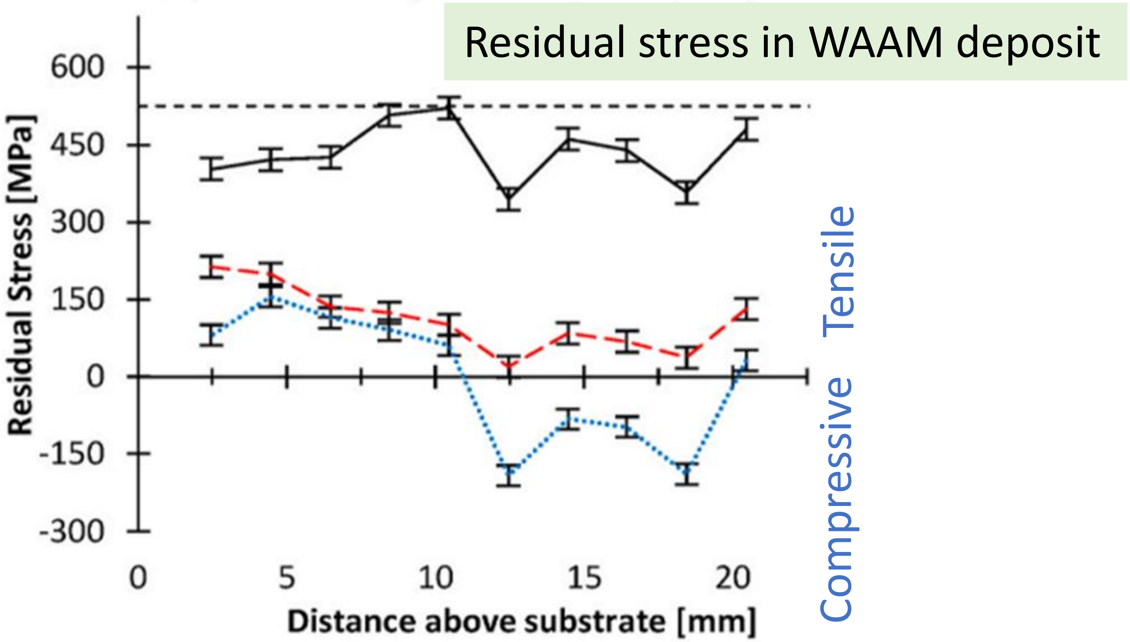


- *Complete elimination of vertical cracks*
- *Edges at the bottom shows minor horizontal crack – wall can be used for further characterization*

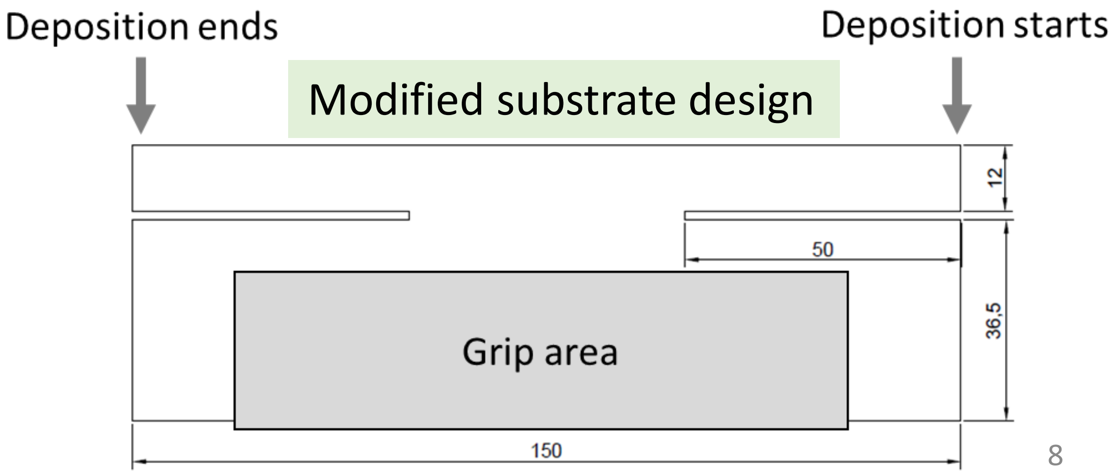
Challenge 2 – Cold Cracking of Deposit





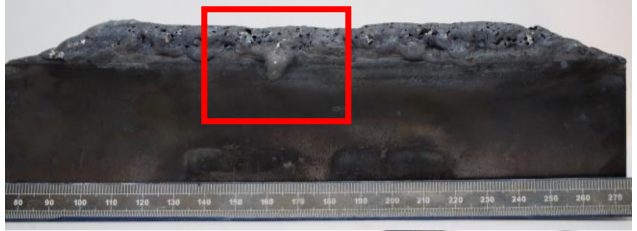


Materials Science & Engineering A 801 (2021) 140368

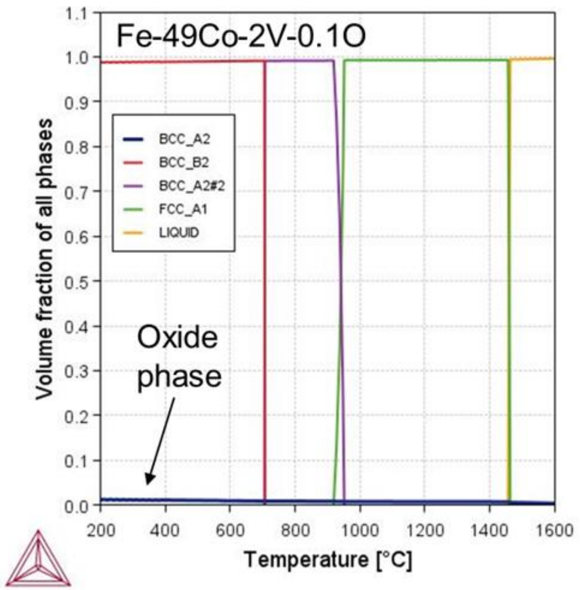


Challenge 3 –Deposition Atmosphere

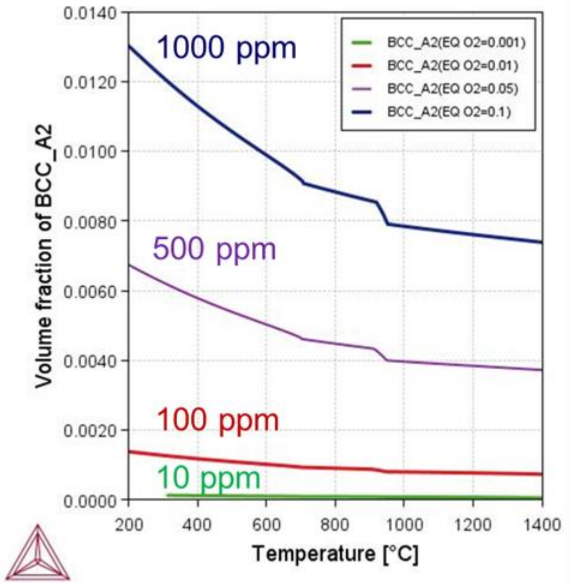
Deposition carried out in open atmosphere using torch shielding



Thermodynamic Simulation of Oxidation - ThermoCalc



Evolution of equilibrium phases while cooling

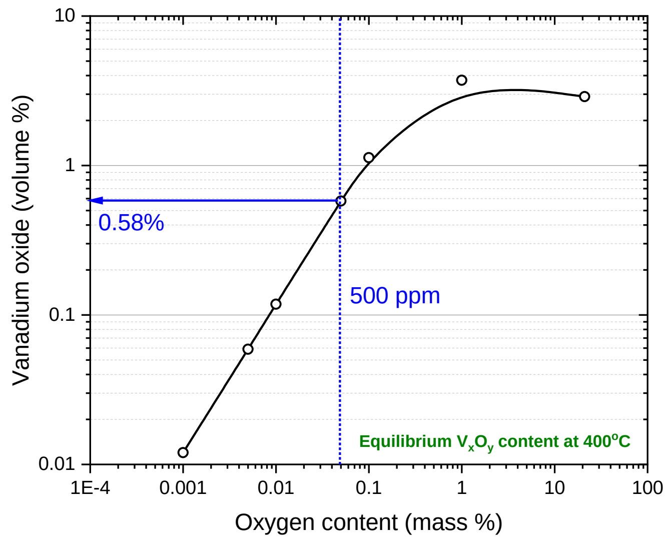


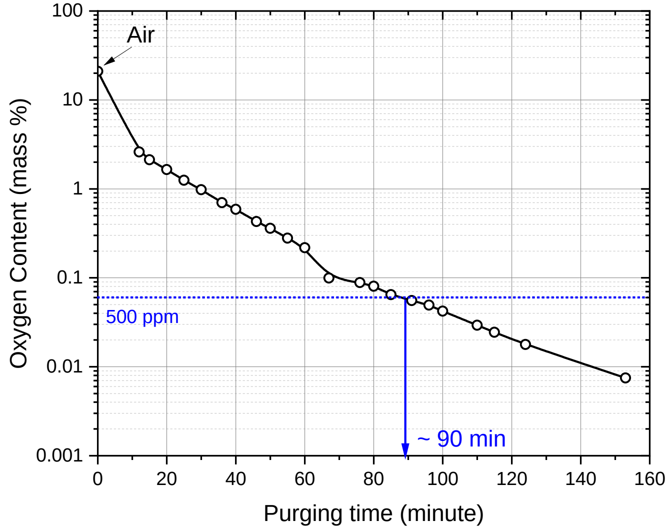
Volume fraction of V_xO_y phases for different atmospheric conditions and T

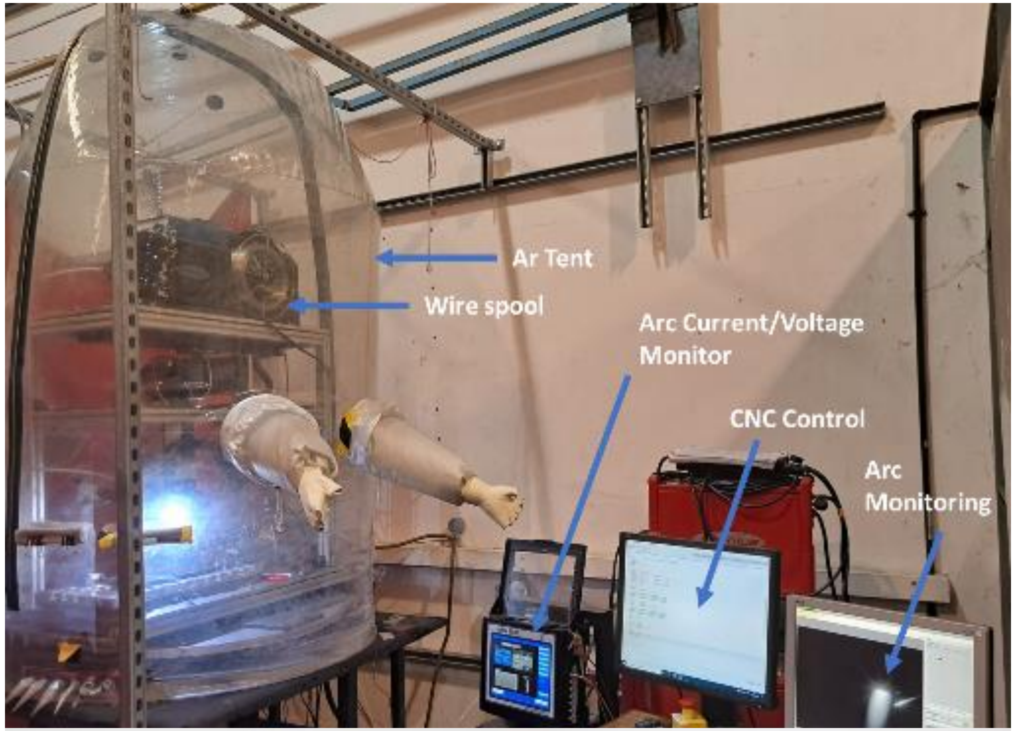
	BCC_A2	BCC_B2
Fe	3.82E-07	0.493
Co	1.01E-12	0.494
V	0.876	0.013
O	0.124	8.38E-13

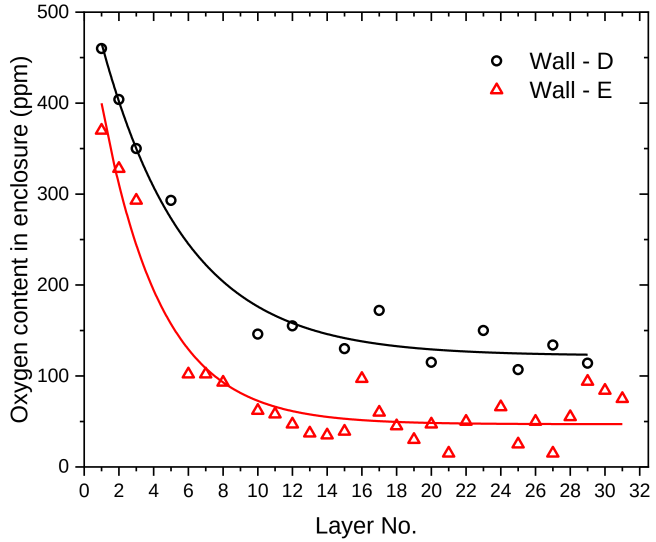
- *Partitioning of constituent elements between major phases*
- *V is getting depleted from B2 phase*

Deposition in Globally Shielded Atmosphere





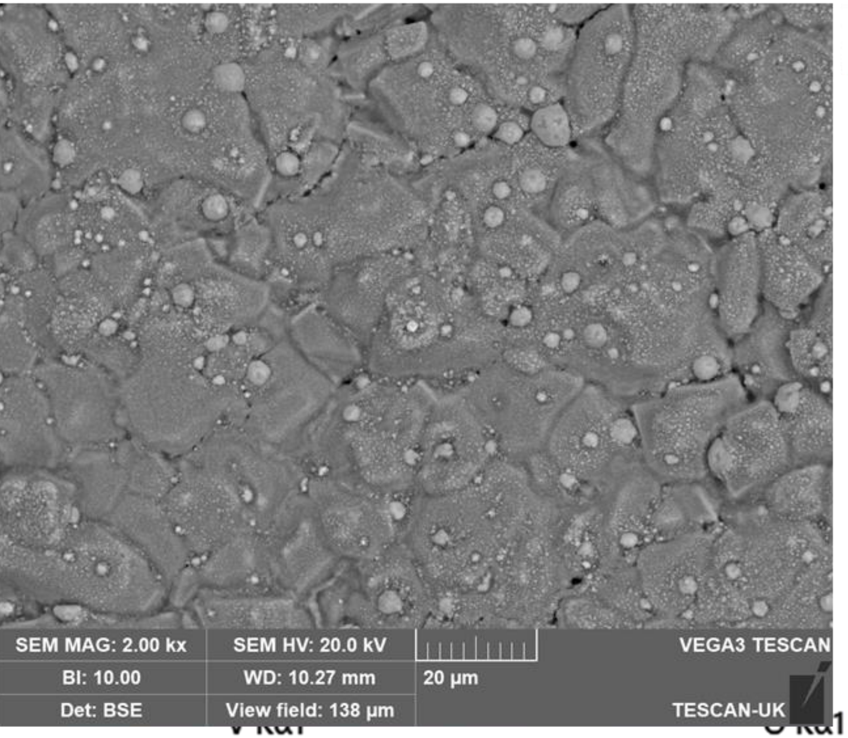


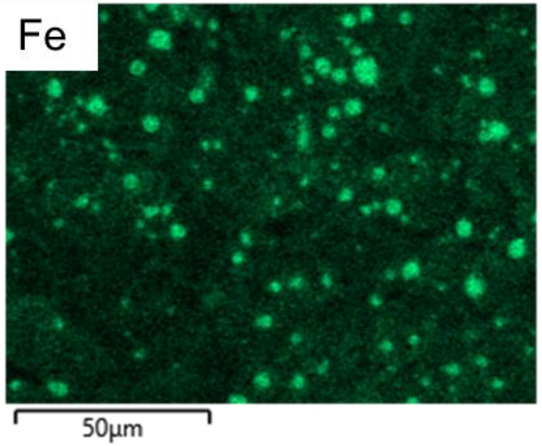


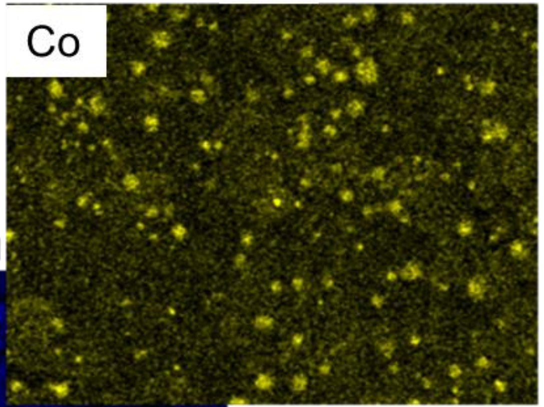
Even after such precaution the wall surface is dull grey/black – indicating presence of oxide(s)

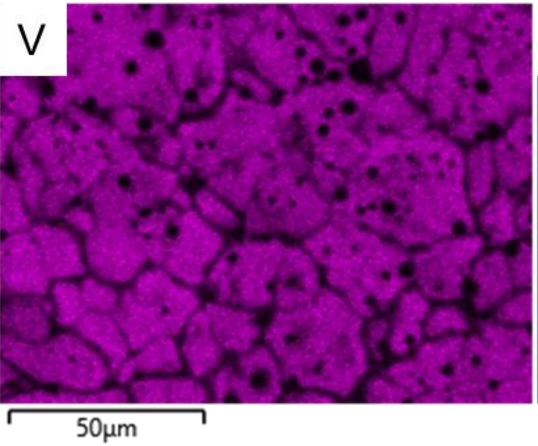
Theoretical calculations indicate an oxygen upper limit of 500 ppm in the enclosure for 0.6 vol% oxidation

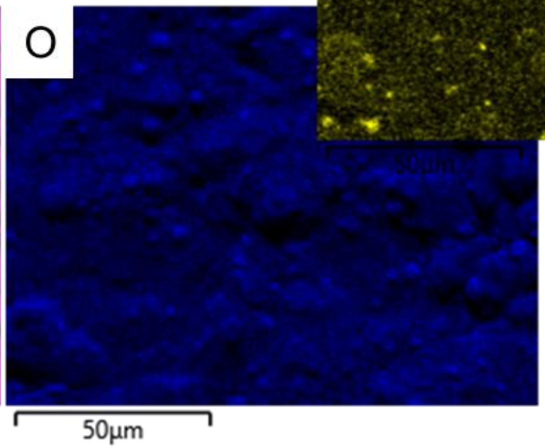
Surface Oxide Characterization

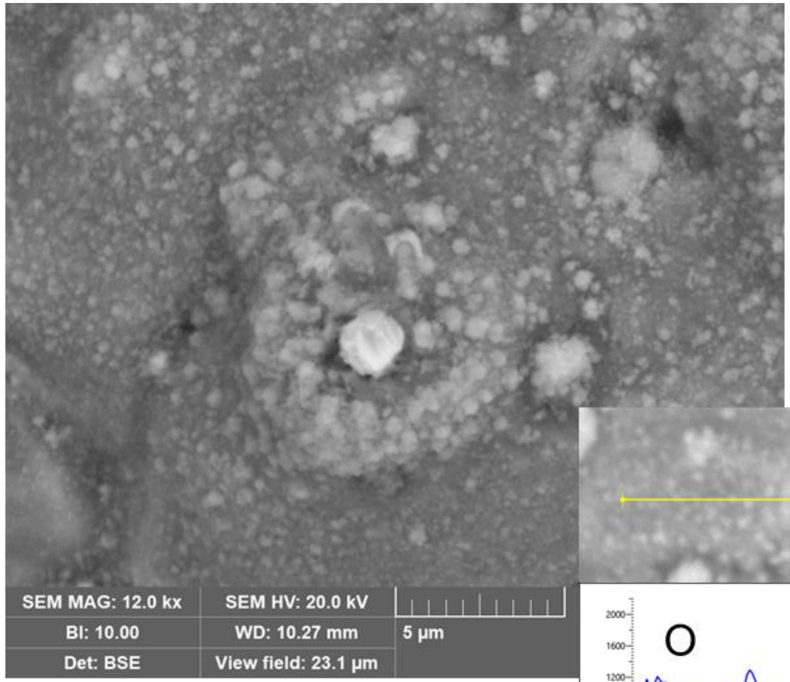


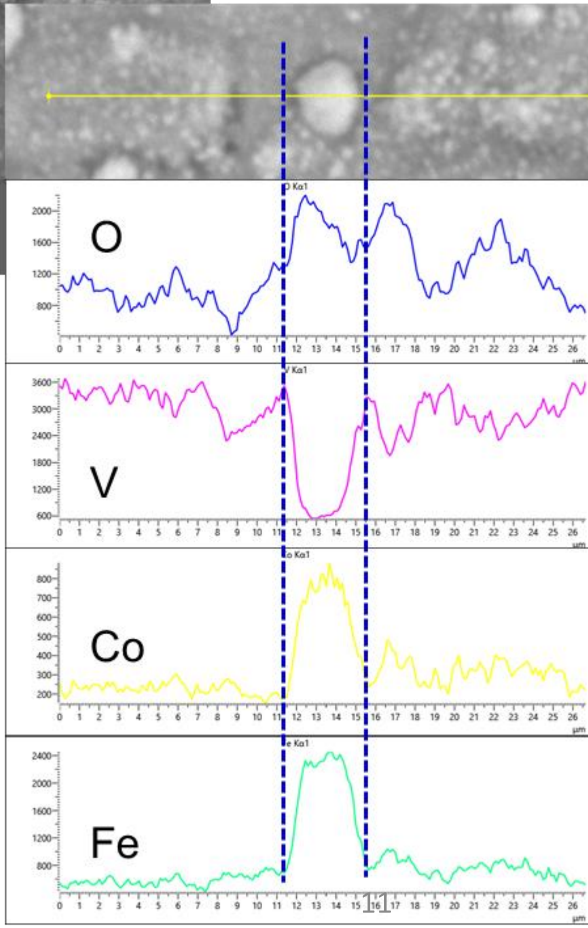






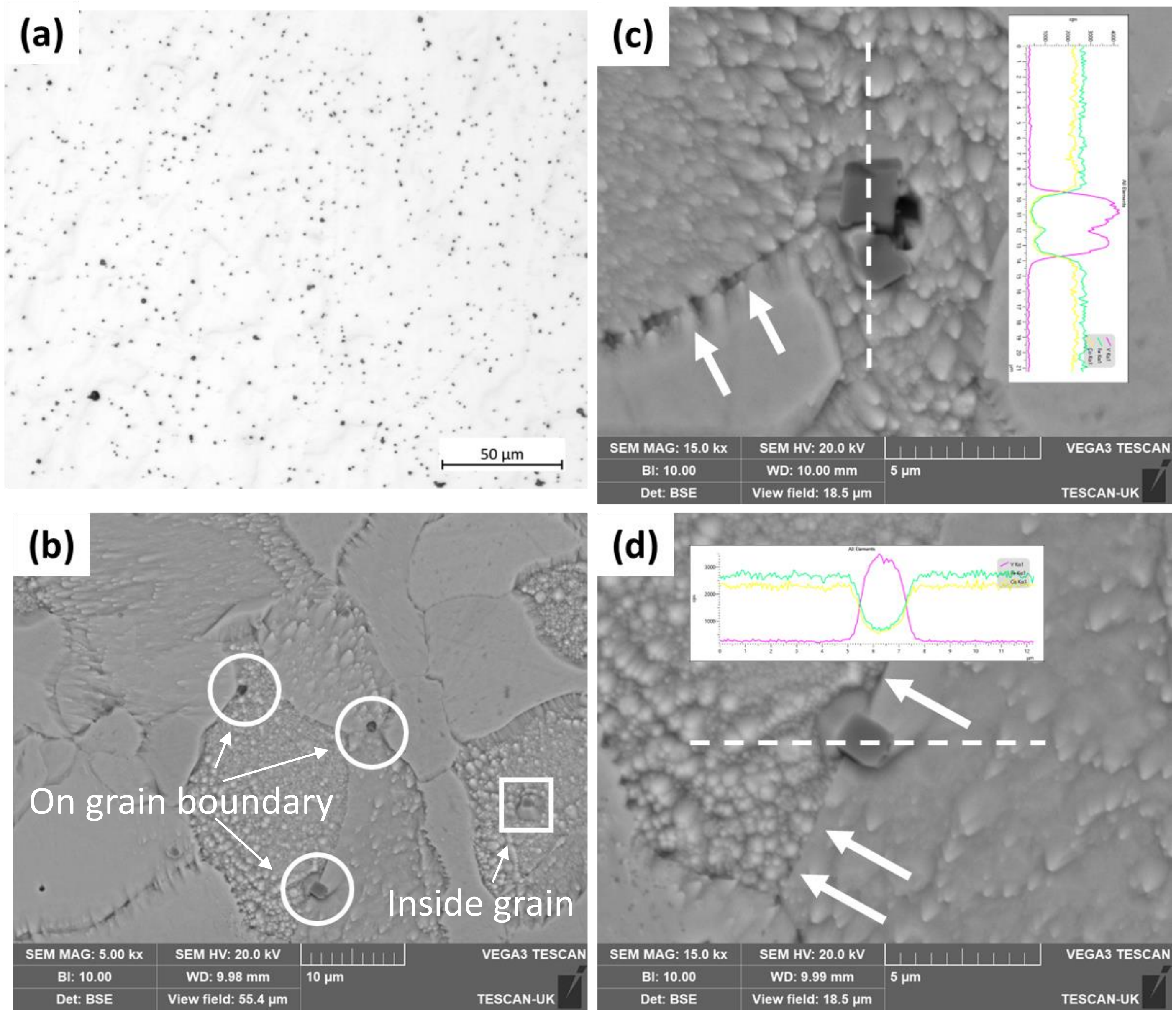




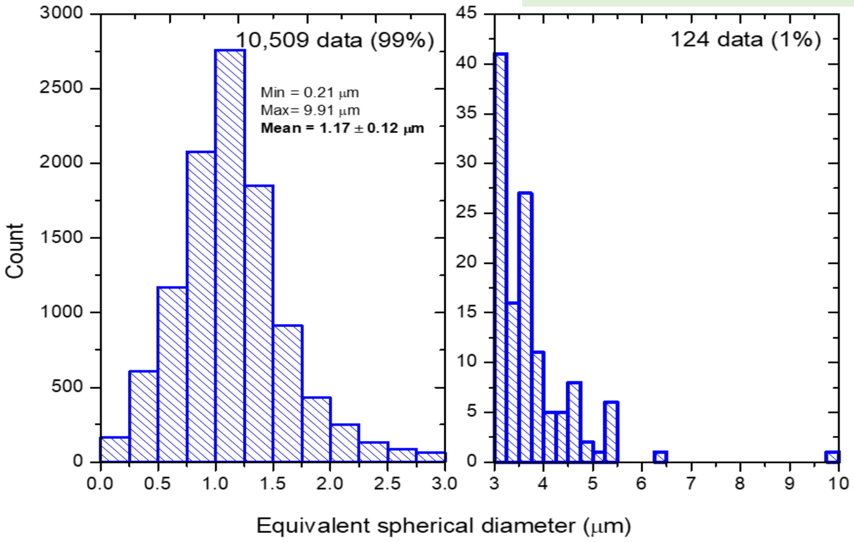


- *Surface is mostly covered with V-oxide*
- *Small globules (5 µm) of Fe-Co-O is also found*
- *However, the oxide layer was **thin enough** and did not deteriorate the tensile or functional properties.*

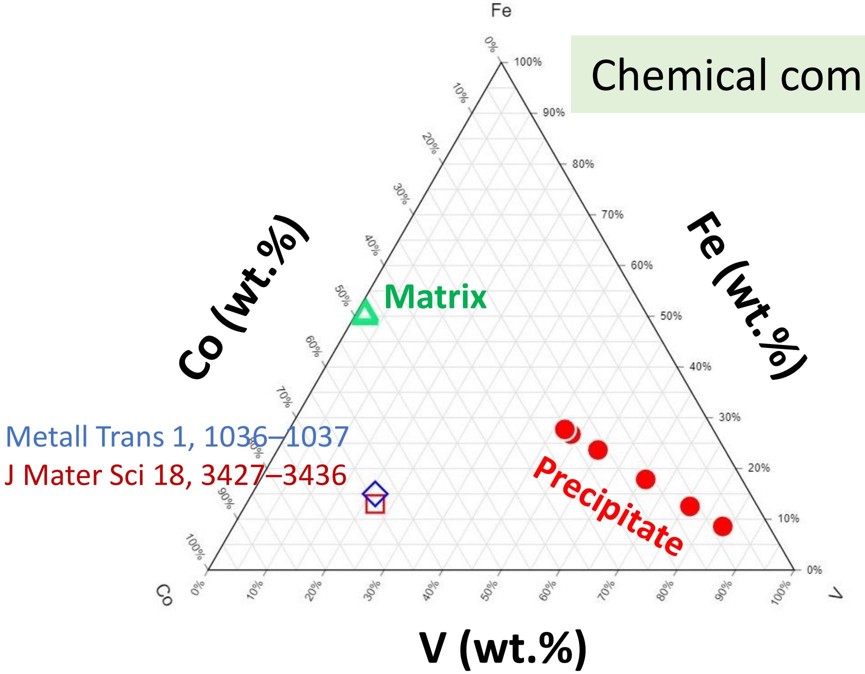
Challenge 4 – Detrimental Secondary Phase



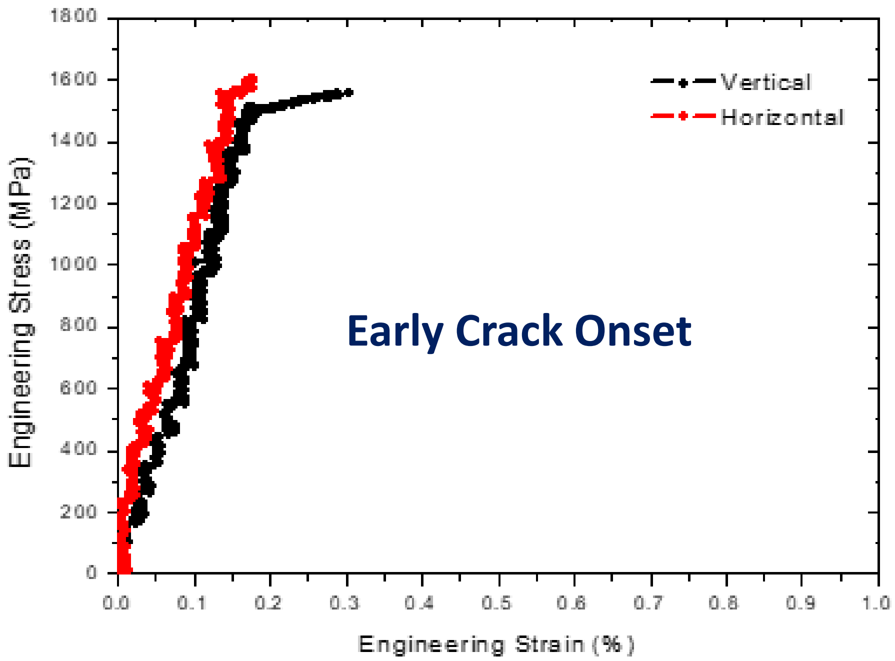
Average size = 1.17 µm

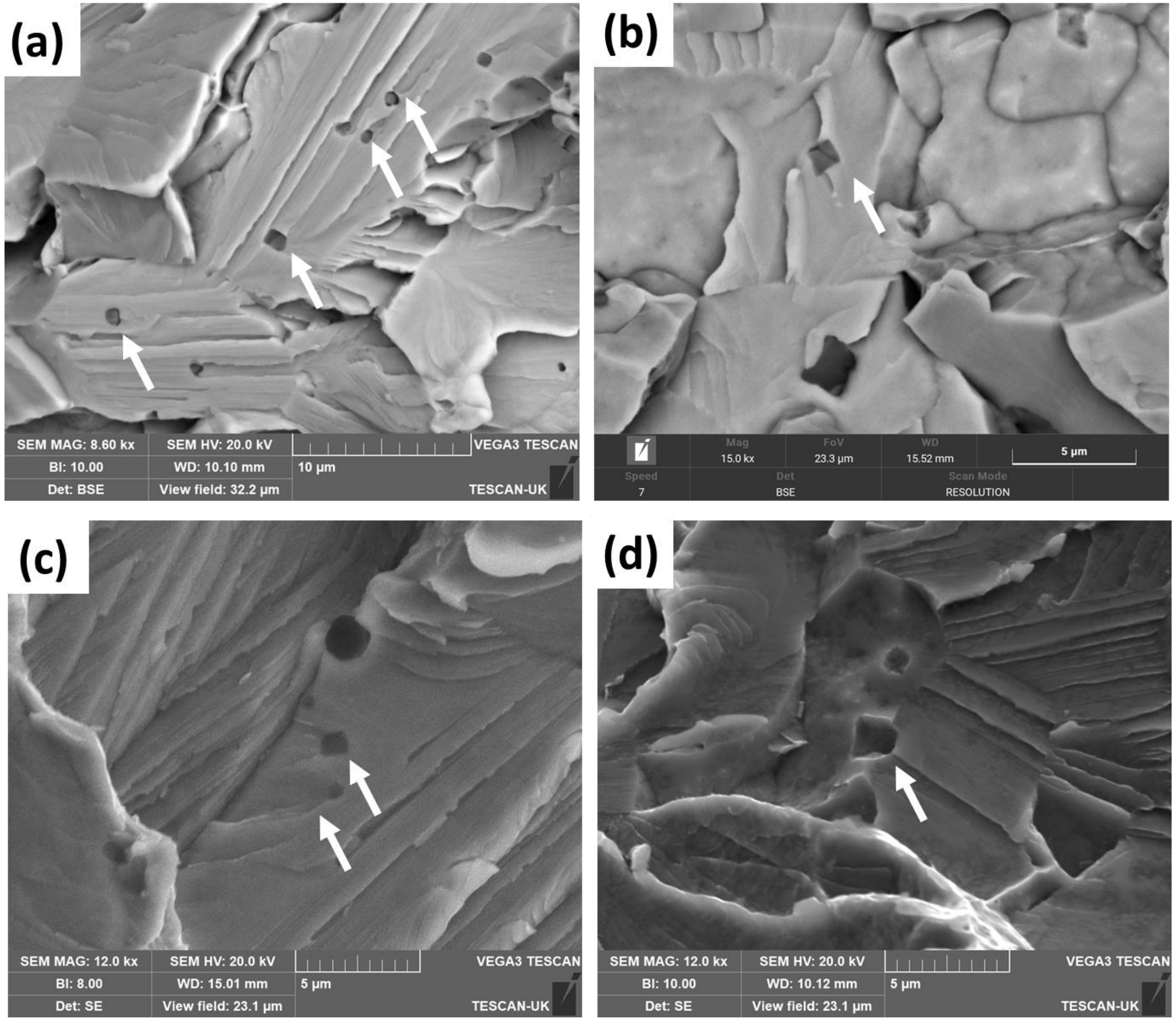


Chemical composition



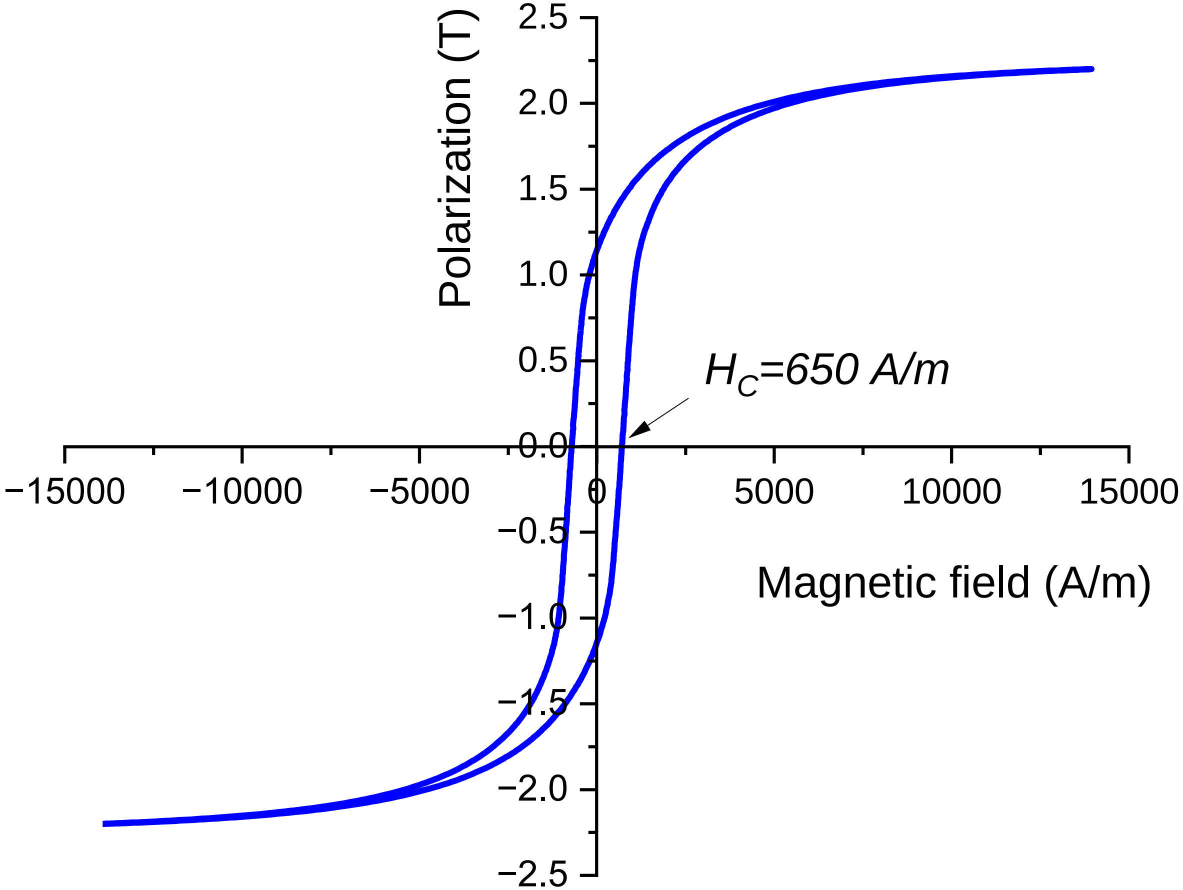
Restricted Ductility

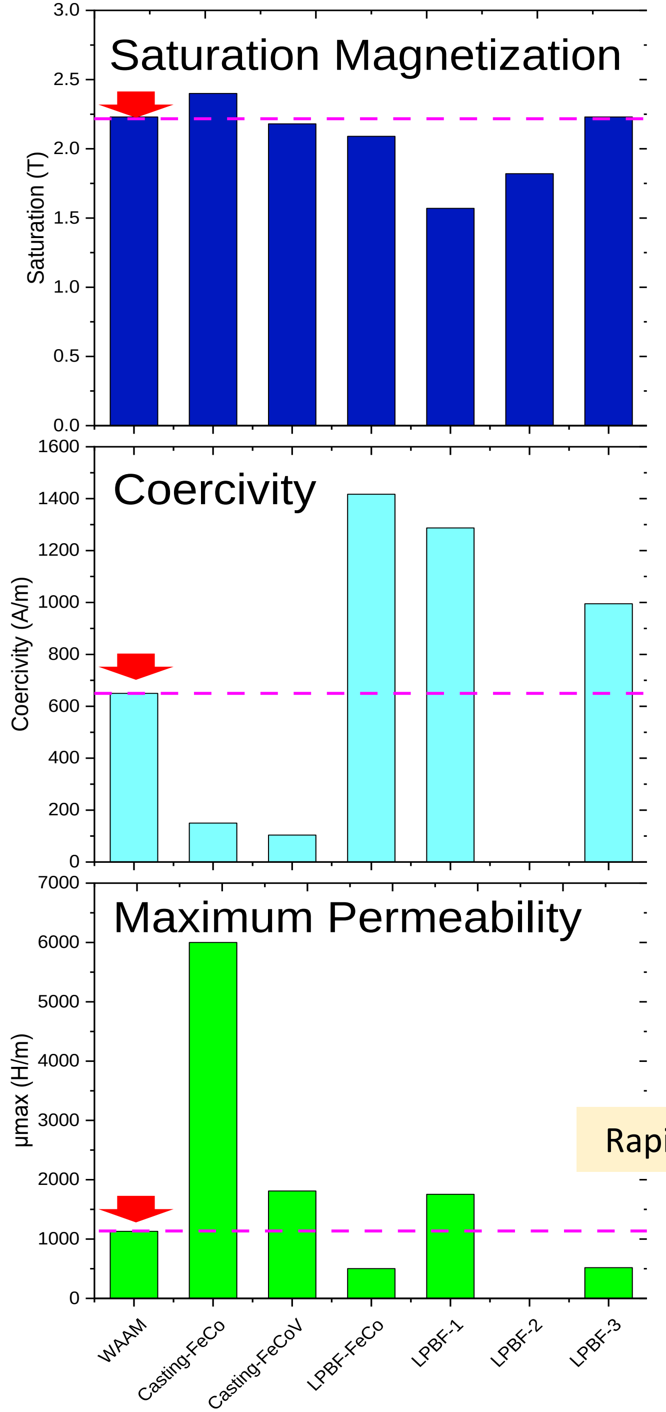




- *Lack of cross-slip in Fe-Co-V system restricts its ductility*
- *Sharp edges/corners acts as stress raisers and onset early crack initiation*

Soft-Magnetic Properties





- ❑ 95% of maximum possible saturation magnetization achieved
- ❑ Coercivity and permeability is inferior to conventionally prepared product however better than LPBF product.
- ❑ Coercivity and permeability is strong function of grain size. Post deposition heat-treatment would elevate the obtained results.

Rapid Prototyping Journal, 25 (4) 699-707

Summary

- A first attempt of making Fe-Co-v alloy through WAAM process seemed successful as relatively good soft-magnetic properties has been achieved is as deposited condition.
- Orientation of substrate as well as substrate's design played important role to achieve crack free deposit.
- Control of deposition atmosphere's oxygen content below 500 ppm is critical for stopping oxidation of the alloy.
- Presence of cuboidal V-rich secondary phase is restricting the ductility by early onset of microcracks.

Thank you for listening!