Carpenter Additive

ROYAL ACADEMY OF ENGINEERING

Lancaster University

2nd Postgraduate Research Symposium on Ferrous Metallurgy

TRIP/TWIP steels produced by additive layer manufacturing

Hossein Eskandari Sabzi

Doctor Bij-Na Kim Lee

Doctor Wei Wen

Professor Pedro Rivera-Diaz-del-Castillo

Engineering Department of Lancaster University

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The aim of this work

PhD project

Carpenter Additive

Provide powder and ALM facilities

316 stainless steel

High Mn austenitic steels

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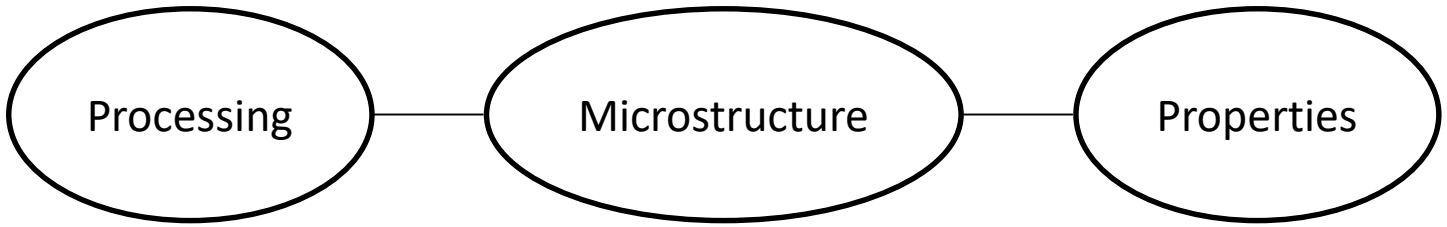
Thermodynamic modelling

Microstructure evolution, redesign and plasticity modelling of TRIP/TWIP steels for ALM

Microstructure evolution, redesign and plasticity modelling of TRIP/TWIP titanium alloys for ALM



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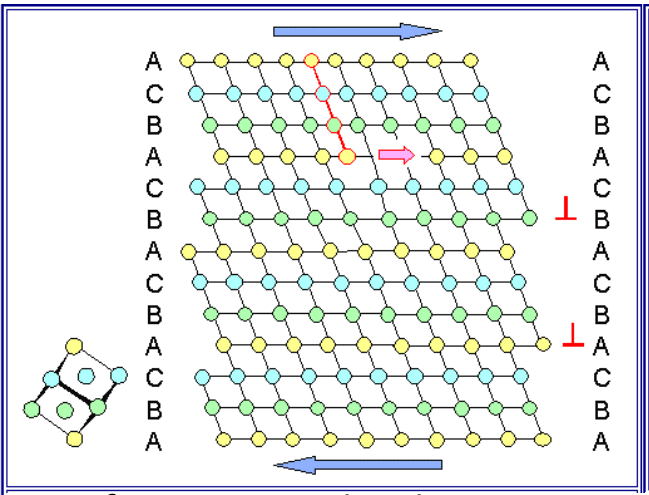
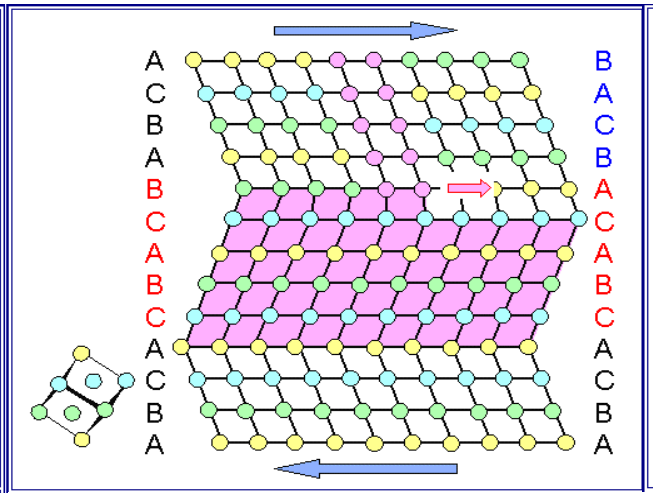
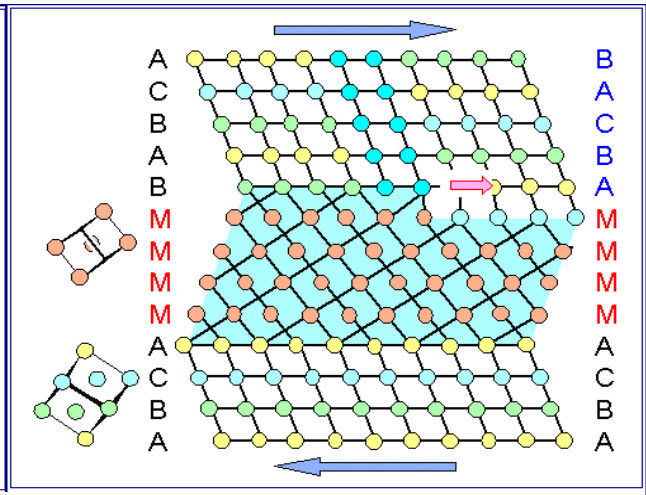
TRIP/TWIP in steels



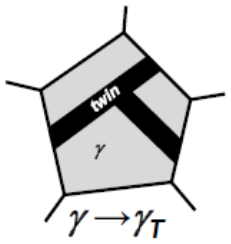
Deformation under shear stress with dislocation glide



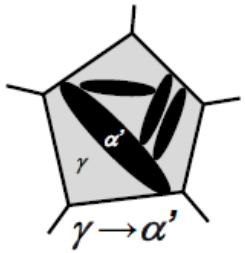
Deformation by twinning



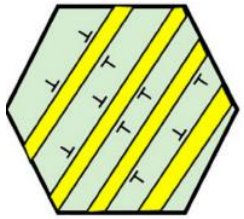
Martensite formation by shear



TWIP-effect

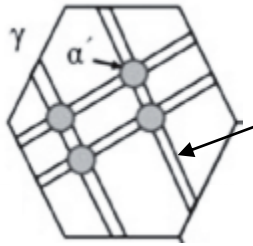


TRIP-effect



ε-martensitic transformtion

Decrease in stacking fault energy (SFE)



Ma, Yan. MATER SCI TECH 33.15 (2017): 1713-1727.

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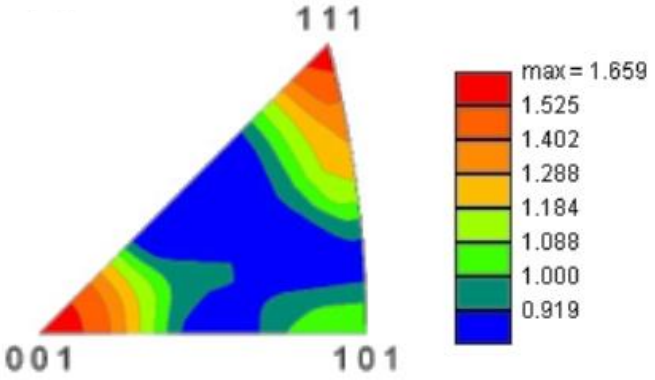
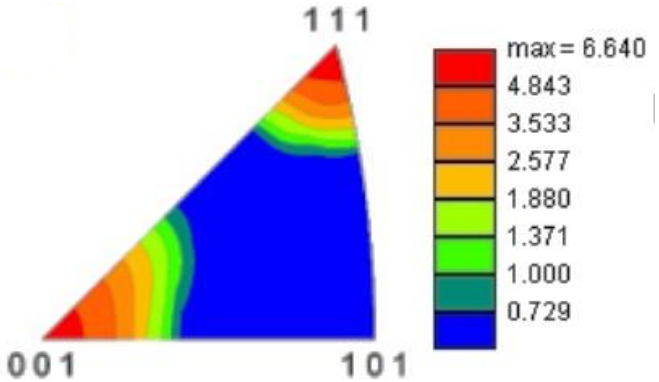
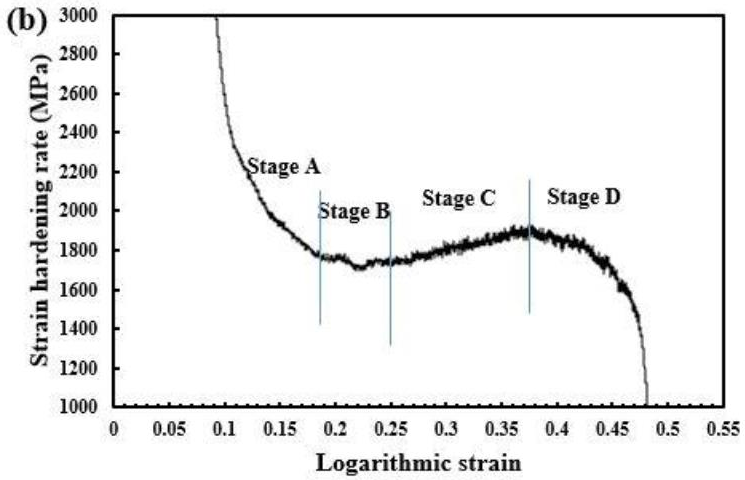
Orientation dependency of TRIP/TWIP

As-received
Austenitic low SFE steel



After tensile test
Austenitic low SFE steel





Sabzi, H. Eskandari, et al. *Mater Sci Eng A* (2018).

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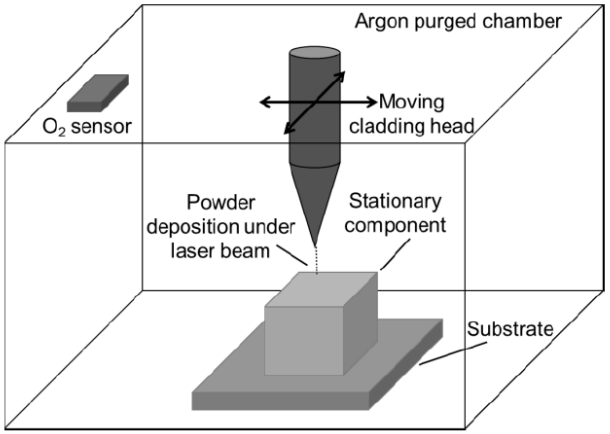
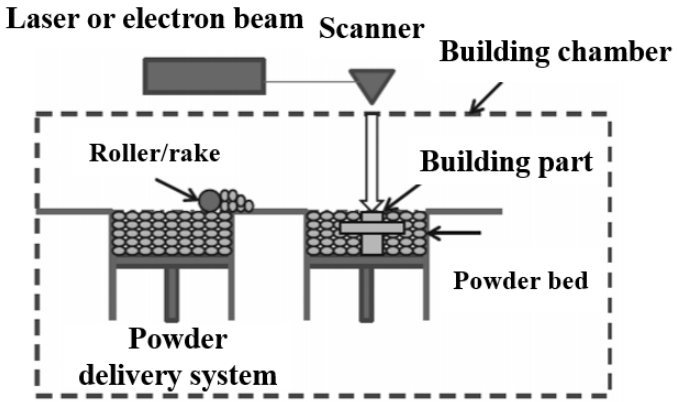
Additive layer manufacturing (ALM)

Directed energy deposition (DED)



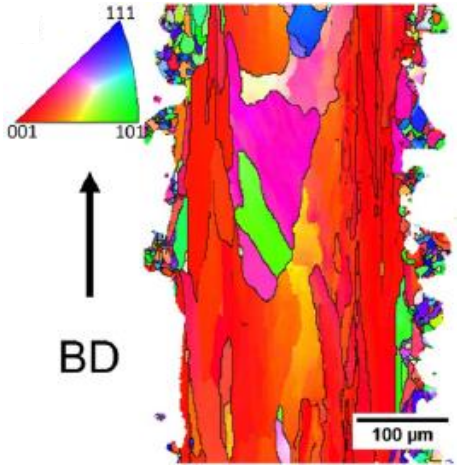
Powder bed fusion (PBF)



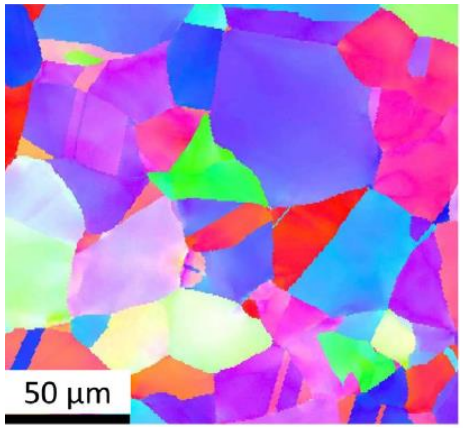
Directionally solidified grains
Dendritic microstructure

Wang, Xianglong, et al. *Mater Sci Eng A* 736 (2018): 27-40.

ALM produced



Conventionally rolled and annealed



Wang, et al. *Mater Sci Eng: A* 743 (2019): 824-831.
F. Kies et al. / Materials and Design 160 (2018) 1250–1264

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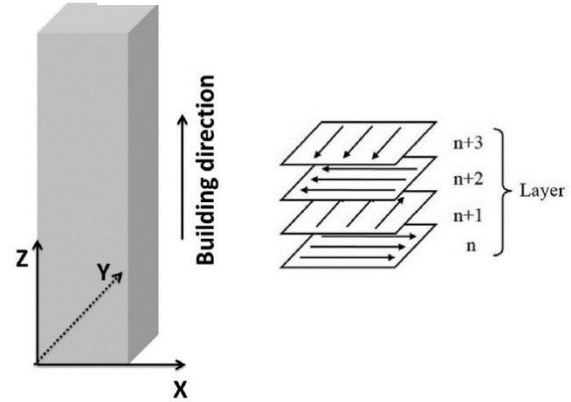
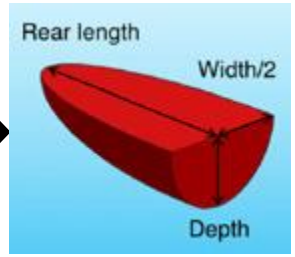
Overview of deformation mechanisms of ALMed TRIP/TWIP steels

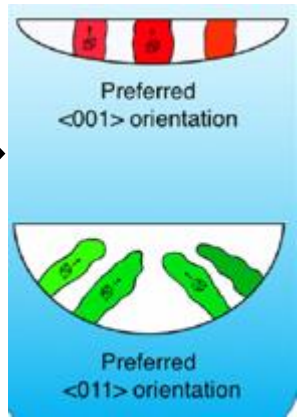
Scan strategies



Melt pool geometry

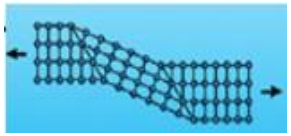


Preferred crystallographic texture

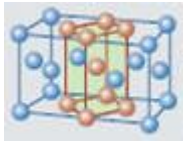


Deformation mechanisms

Dislocation slip

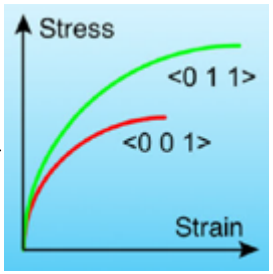


twinning



Strain induced martensitic transformation

Strong and tough metal parts



Sun et al. NPG Asia Materials (2018) 10: 127–136.

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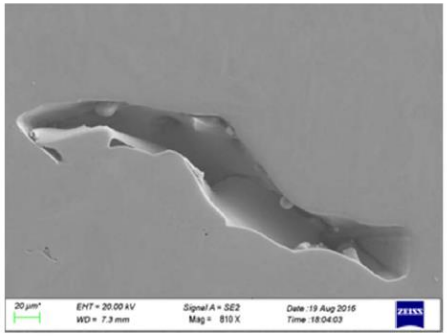
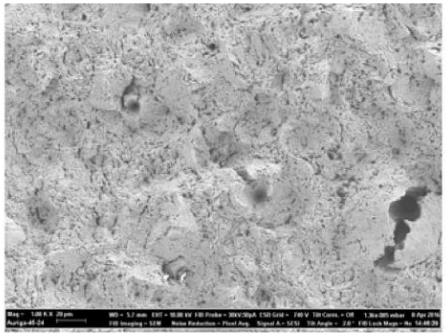
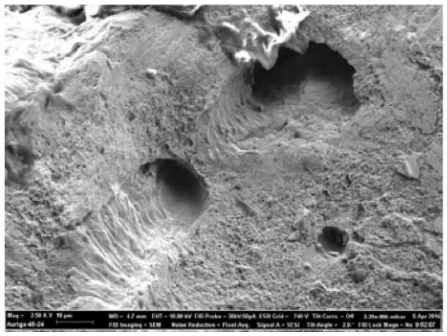
Issues in ALM



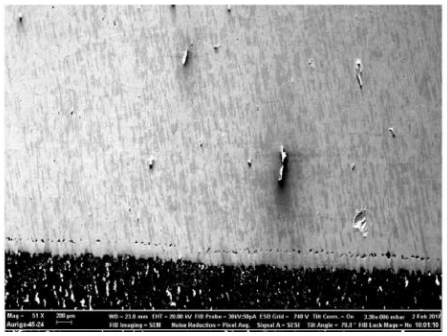
Lack of fusion



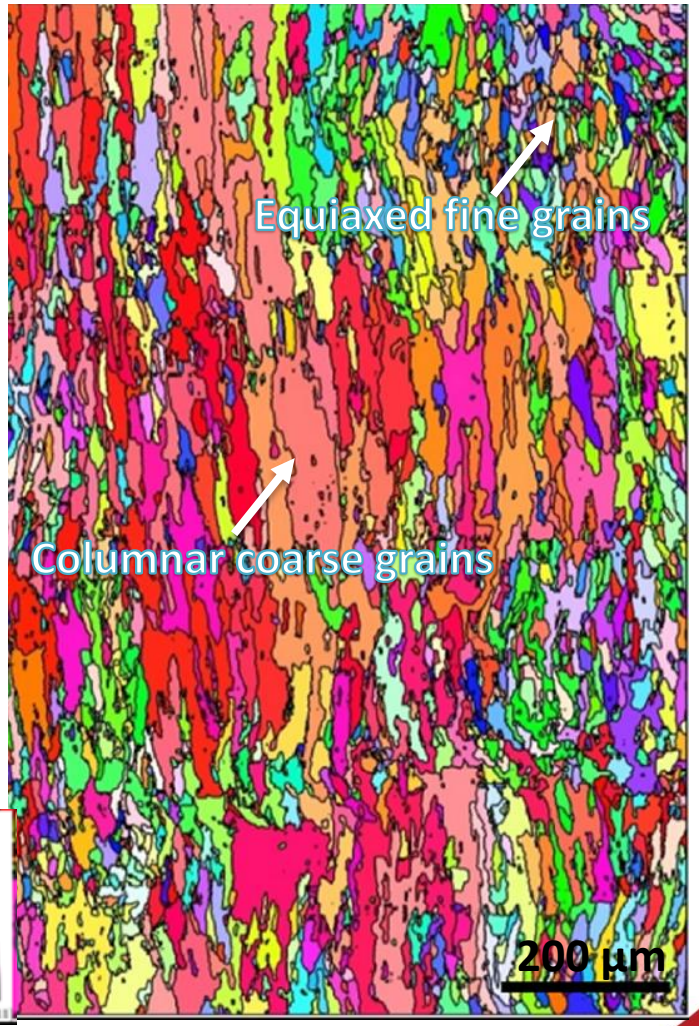
Entrapped gas in as-received powder

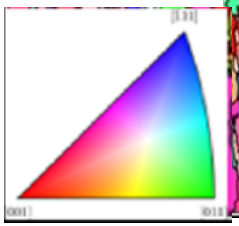


Keyholes in sub-surface regions



Surface pores





Sun, Zhongji, et al. *NPG Asia Mater* (2018): 1.

Pham, Minh-Son, and Paul Hooper. *AIP Conference Proceedings*. Vol. 1896. No. 1. AIP Publishing, 2017.

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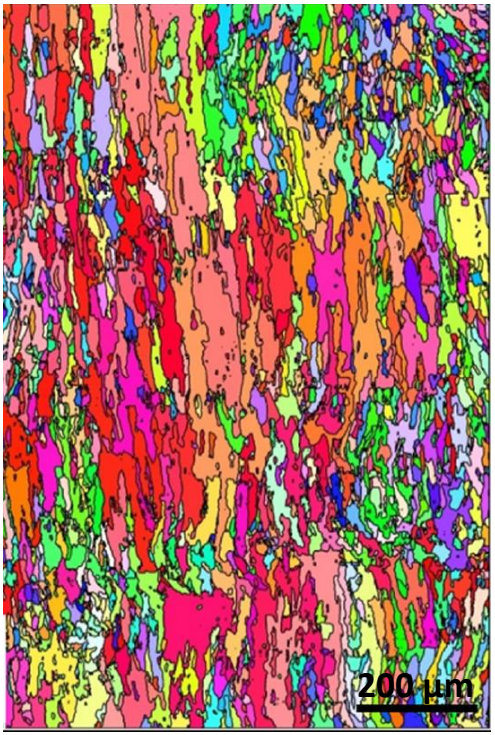
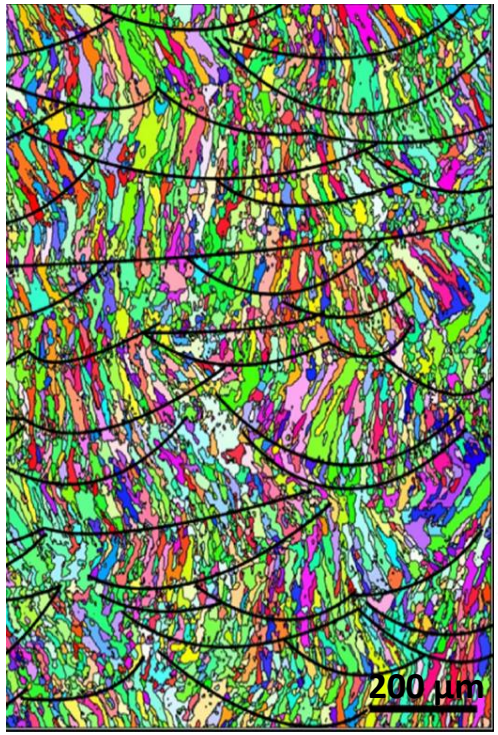
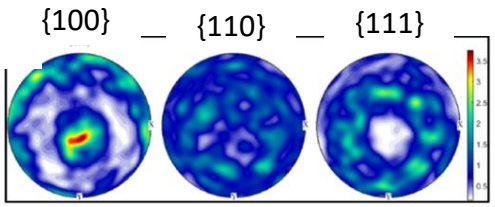
ALMed 316L stainless steel

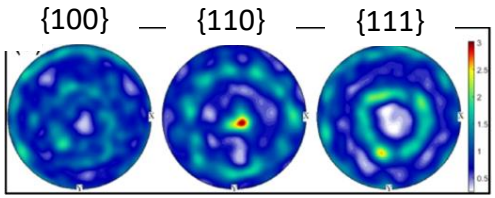
380 W

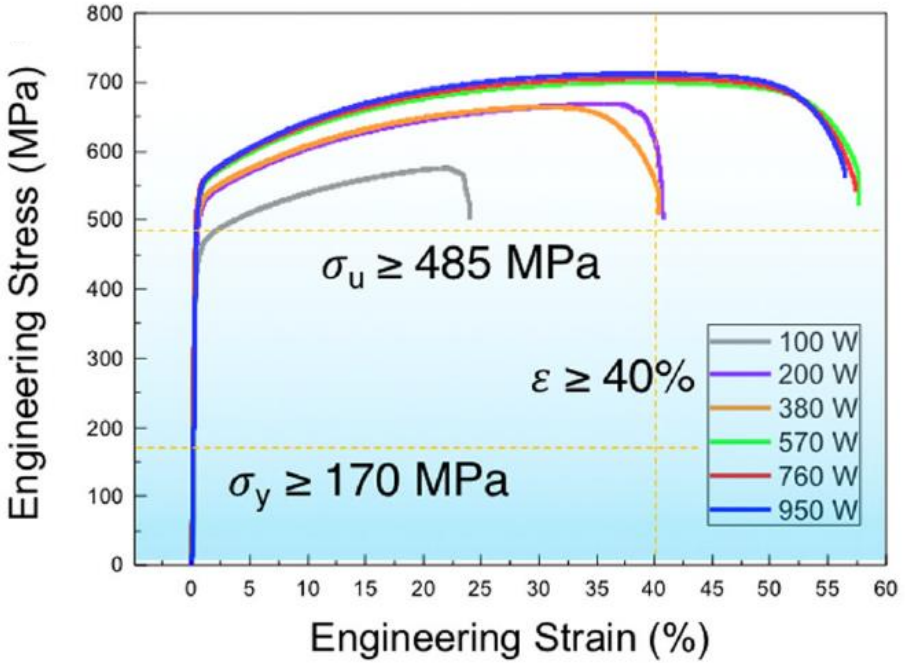


950 W









Sun, Zhongji, et al. *NPG Asia Mater* (2018): 1.

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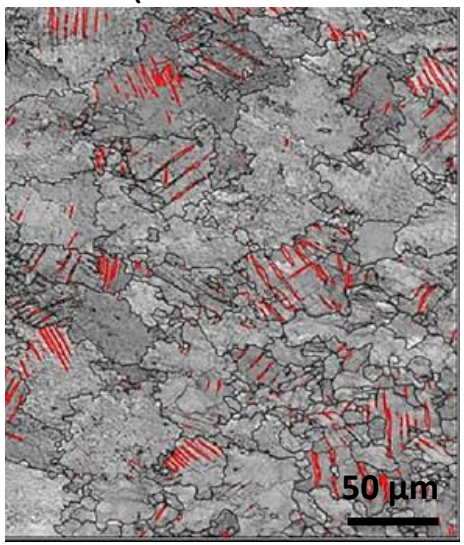
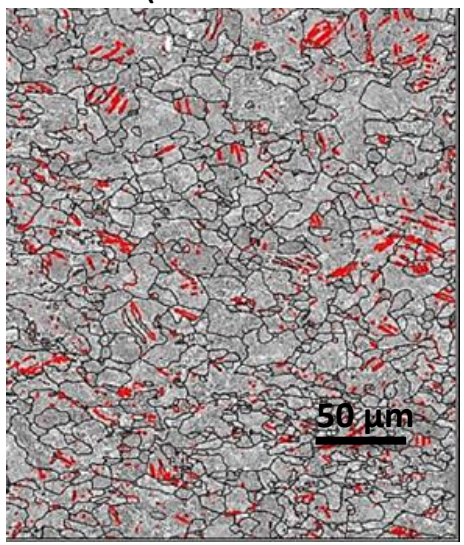
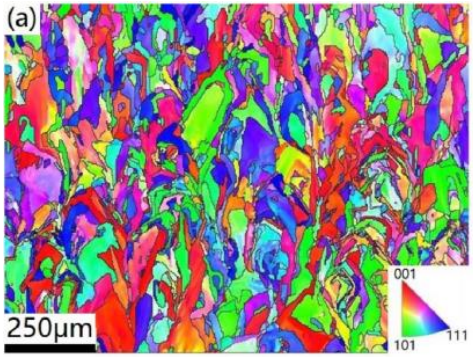
ALMed 316L stainless steel

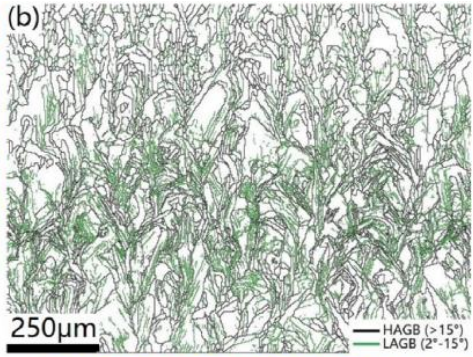
380 W (after tensile test)

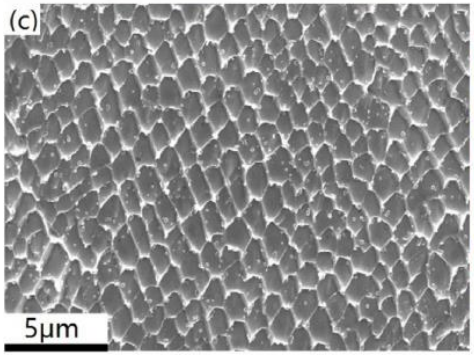


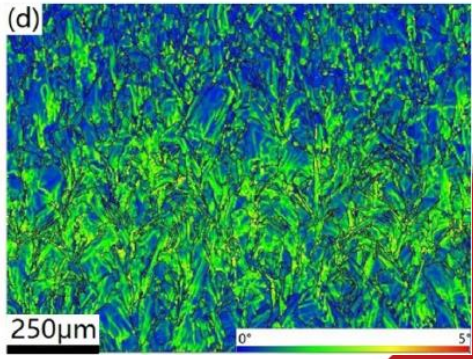
950 W (after tensile test)











High amounts of low angle grain boundaries
Cellular microstructure
High dislocation density

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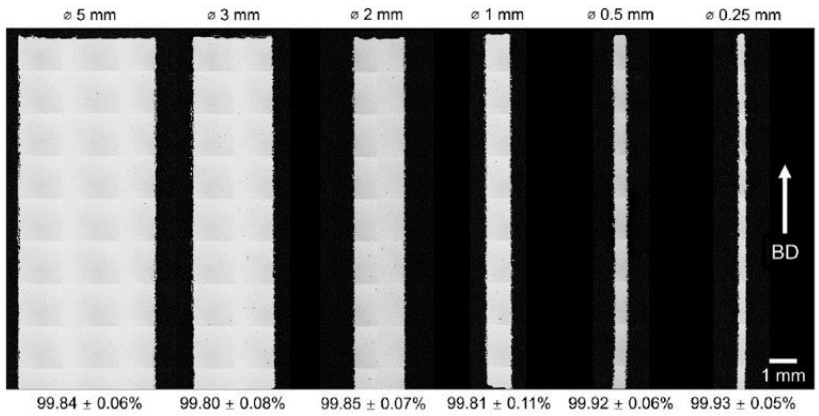
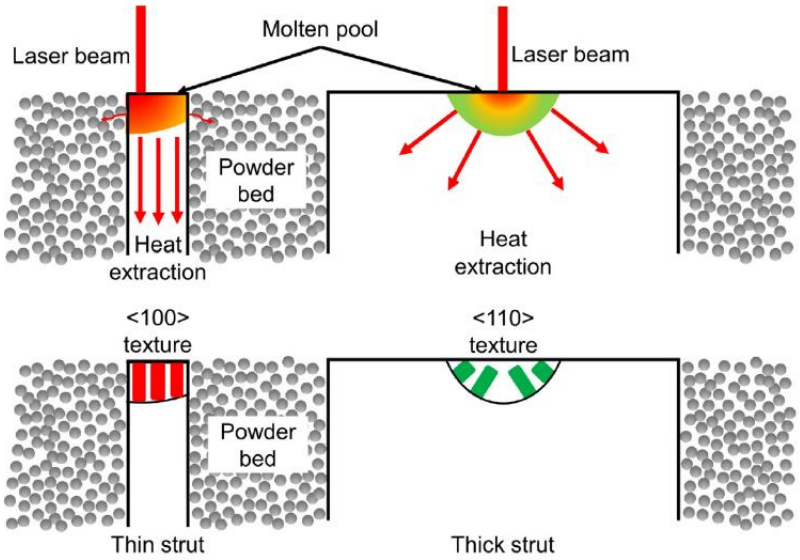
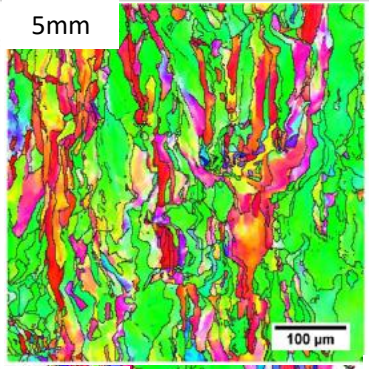
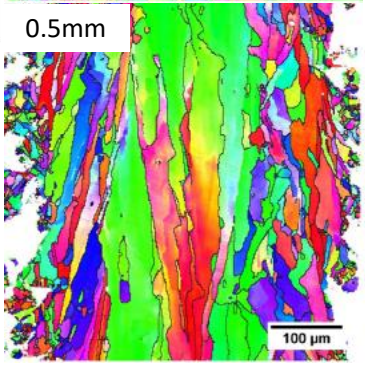
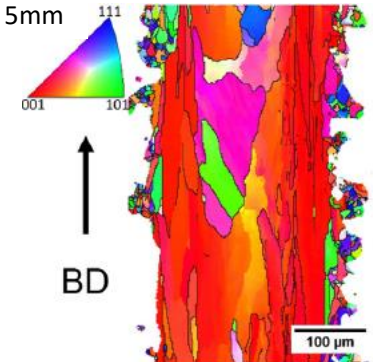
ALMed 316L stainless steel

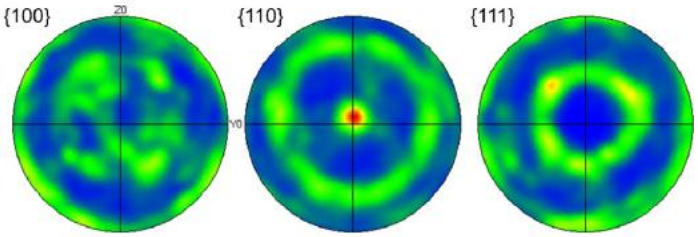


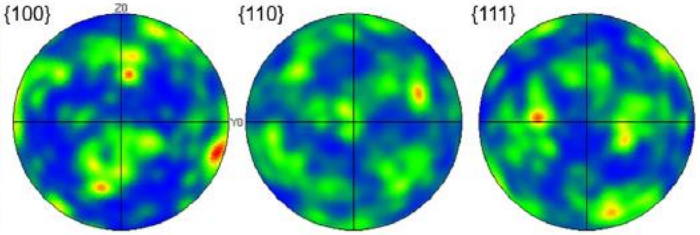


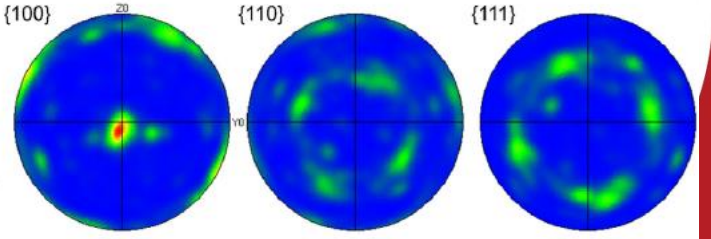












Wang, Xianglong, et al. *Mater Sci Eng A* 736 (2018): 27-40.

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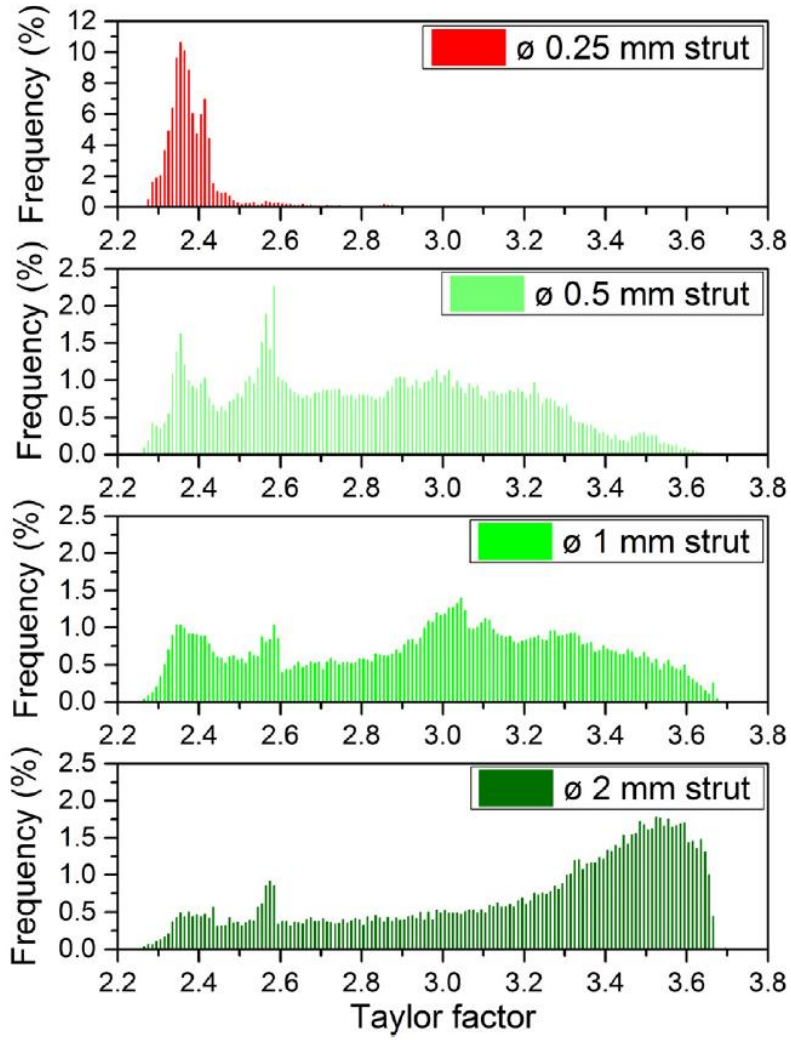
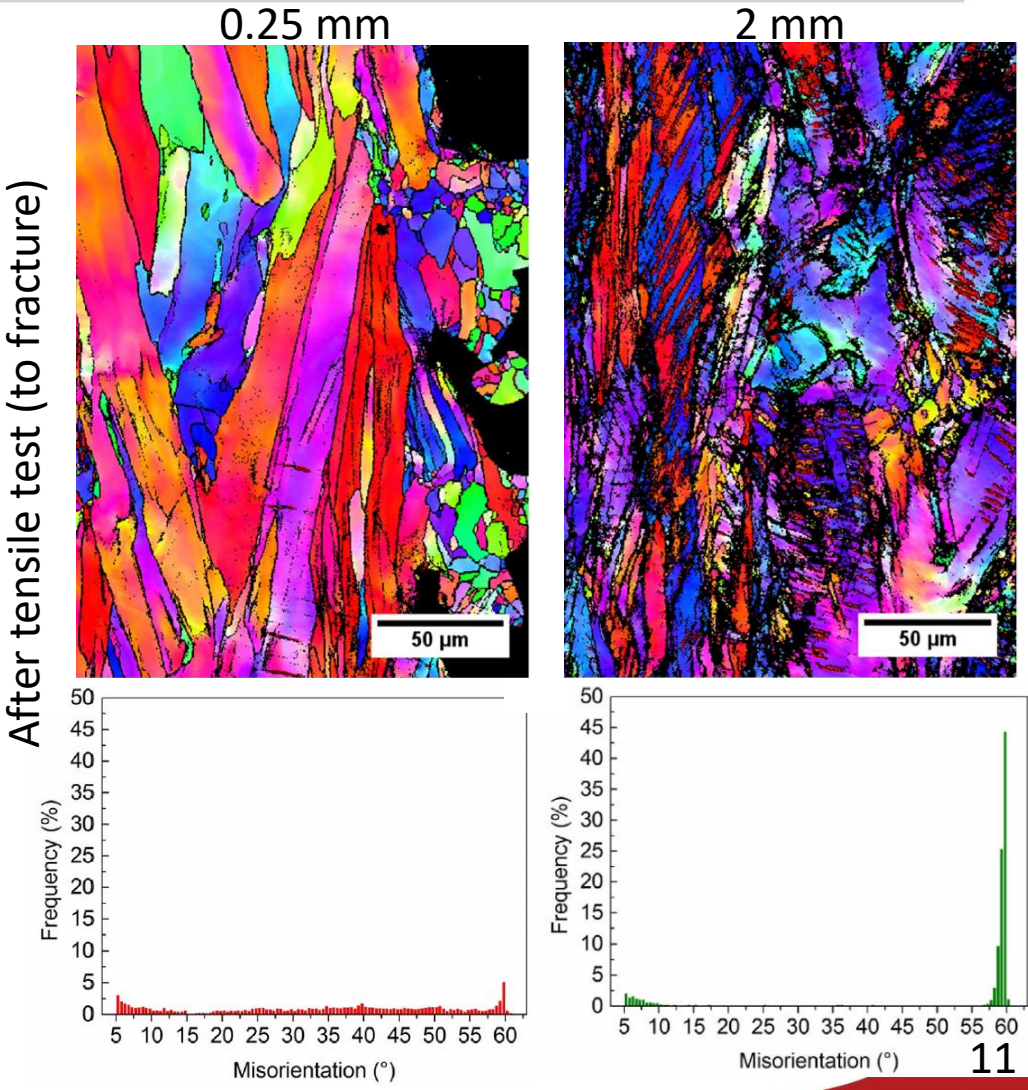
ALMed 316L stainless steel





Wang, Xianglong, et al. *Mater Sci Eng A* 736 (2018): 27-40.

Forthcoming research

Using computational methods

- Melt pool geometry
- Effect of processing parameters on defects (porosity and residual stresses)
- Texture evolution prediction
- Microstructural evolution
- Modelling yield strength
- Plasticity model for TWIP after deformation

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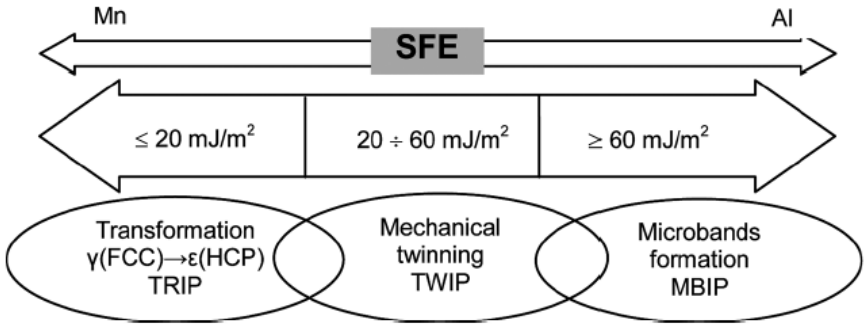
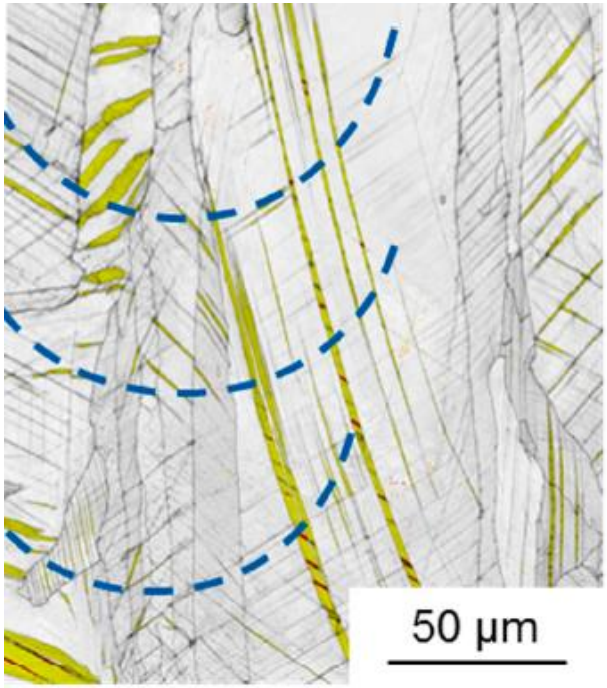
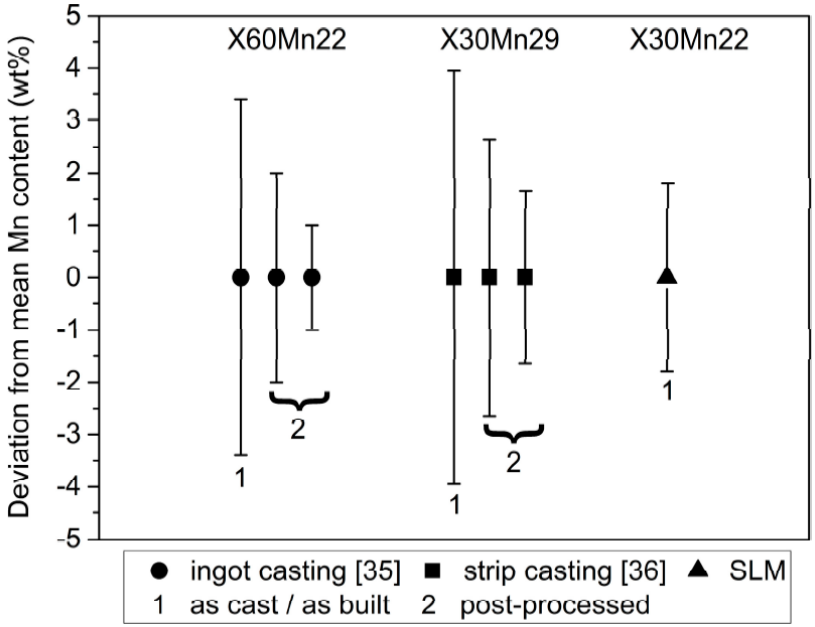
ALMed high Mn austenitic steels



State	Fe	Mn	C
Ingot-cast	bal.	21.67	0.293
After SLM	bal.	20.15	0.274



SFE $\sim 10 \mathrm{mJ}/m^2$



Haase, Christian, et al. *Materials* 10.1 (2017): 56.

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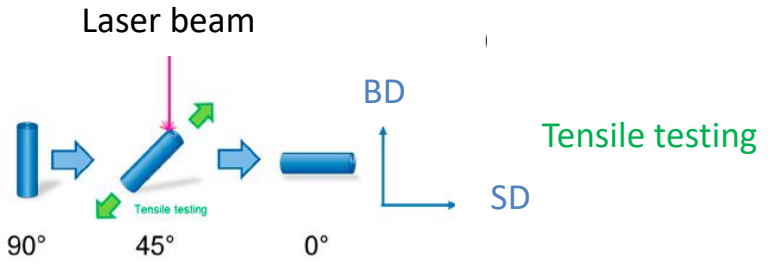
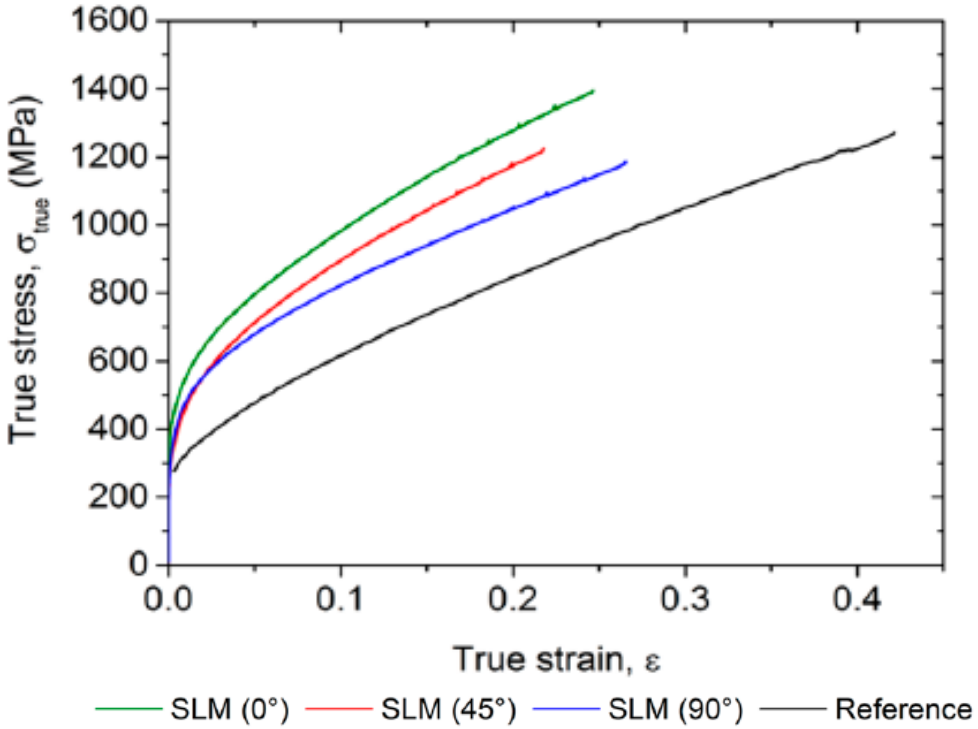
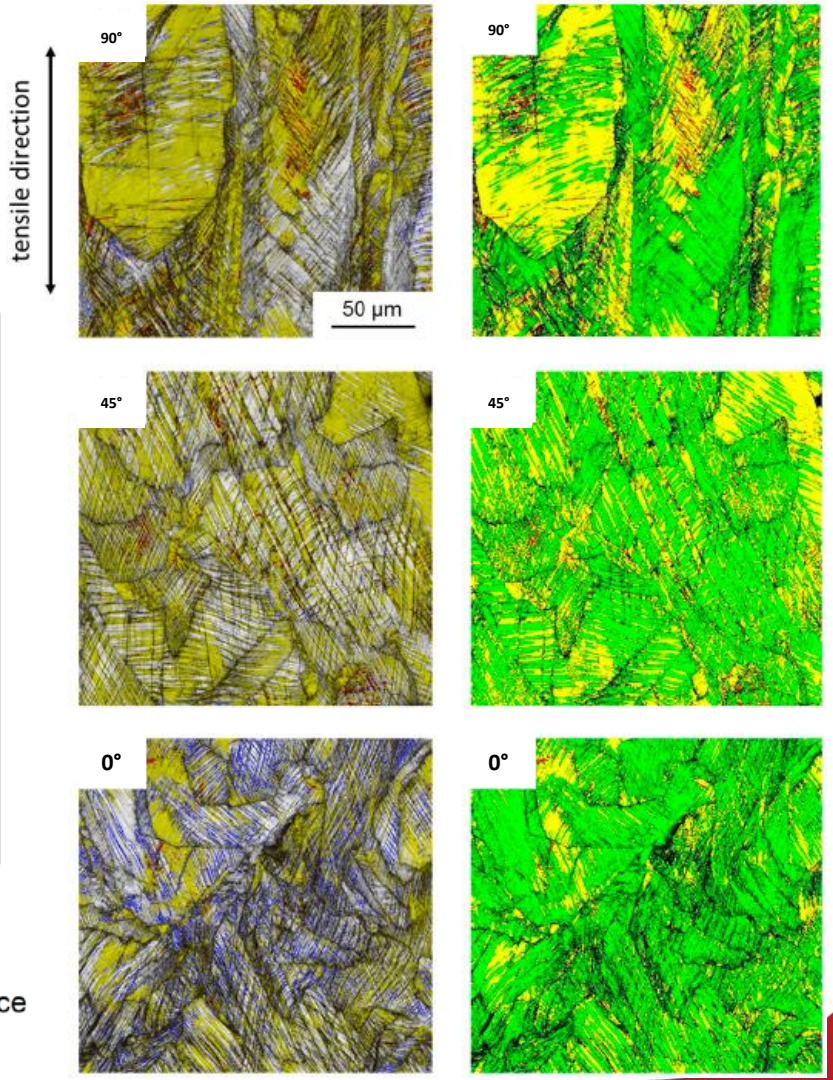
ALMed high Mn austenitic steels





After fracture



Haase, Christian, et al. *Materials* 10.1 (2017): 56.

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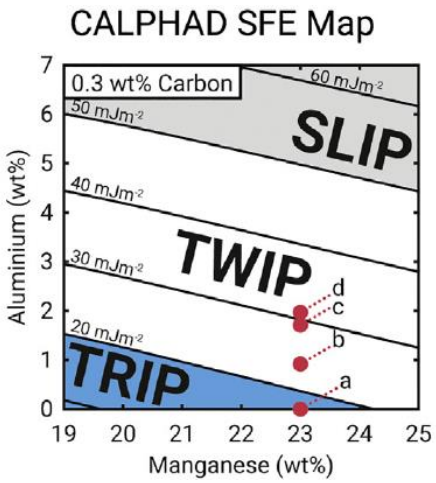
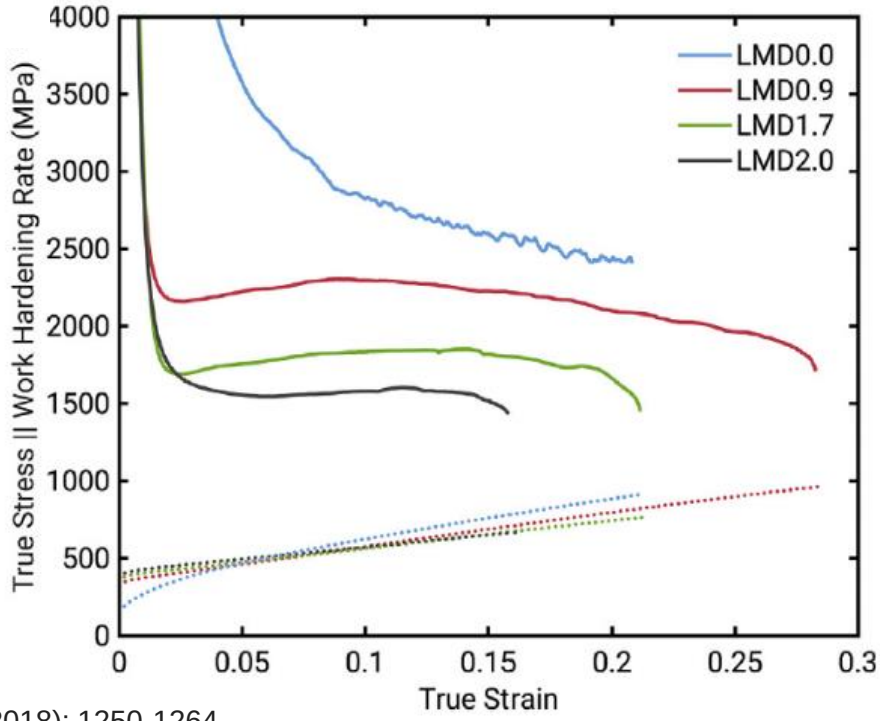
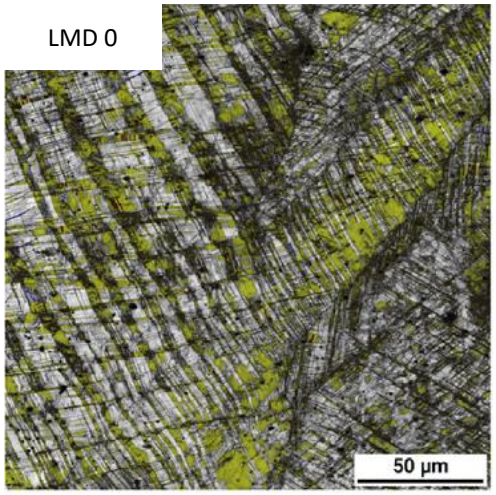
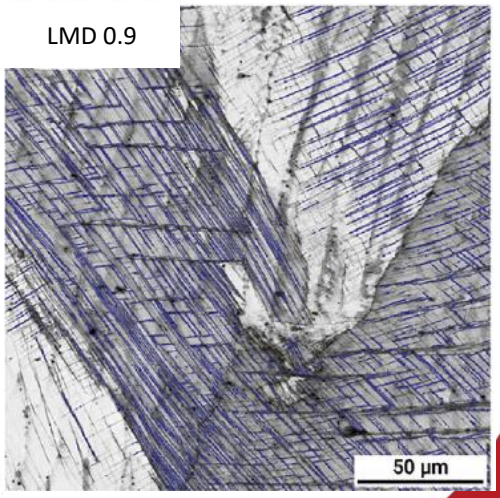
ALMed high Mn austenitic steels

sample	Fe	C (wt%)	Mn (wt%)	Al (wt%)	SFE (mJ/m2)
Steel powder	Bal.	0.33	21.9	0.01	-
LMD0.0	Bal.	0.27	23.1	<0.005	16.4
LMD0.9	Bal.	0.32	23.6	0.92	25.9
LMD1.7	Bal.	0.32	23.6	1.71	31.2
LMD2.0	Bal.	0.32	23.8	1.97	33.3









Kies, Fabian, et al. *Mater. Des.* 160 (2018): 1250-1264.

Forthcoming research

Using computational methods

- Redesign printable high Mn austenitic steels
- Melt pool geometry
- Effect of processing parameters on defects (porosity and residual stresses)
- Texture evolution prediction (lowering anisotropy)
- Microstructural evolution
- Modelling and optimisation of yield strength
- Plasticity model for TRIP and TWIP after deformation

Thank you for your attention

Contact
h.eskandarisabzi@lancaster.ac.uk