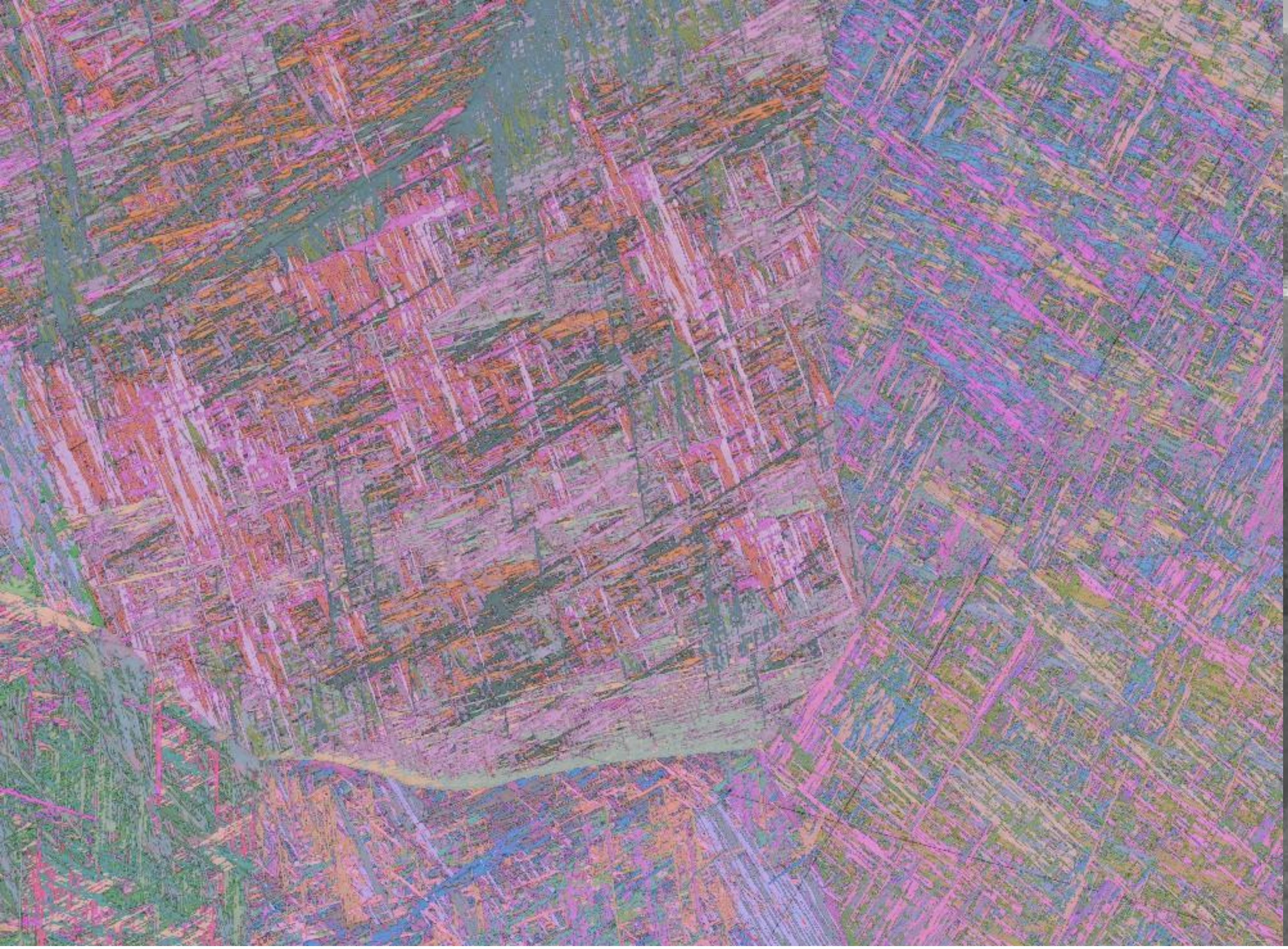

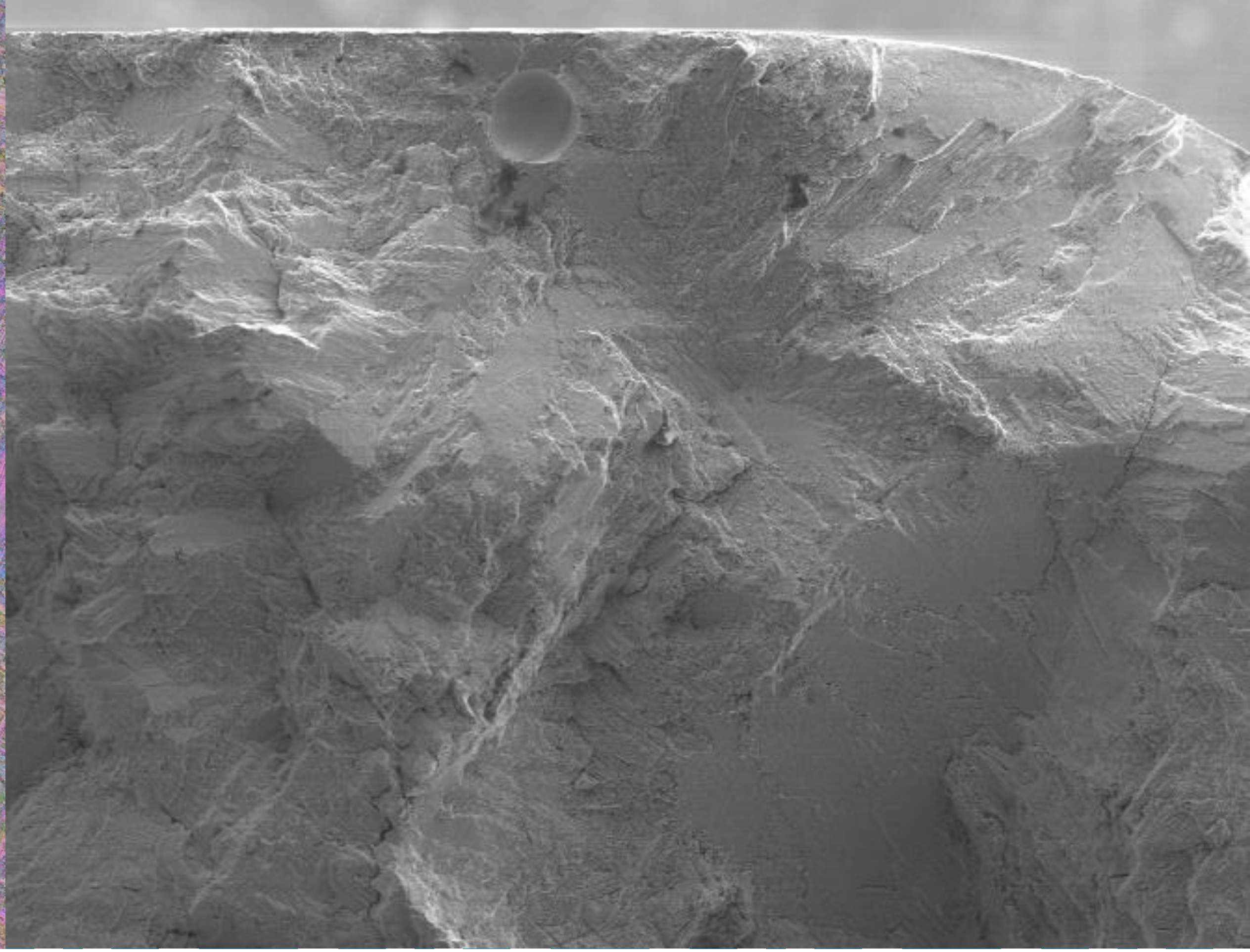

THE EFFECT OF MICROSTRUCTURE AND DEFECTS ON MECHANICAL PROPERTIES OF TI6AL4V WELDS PRODUCED BY DIFFERENT PROCESSES

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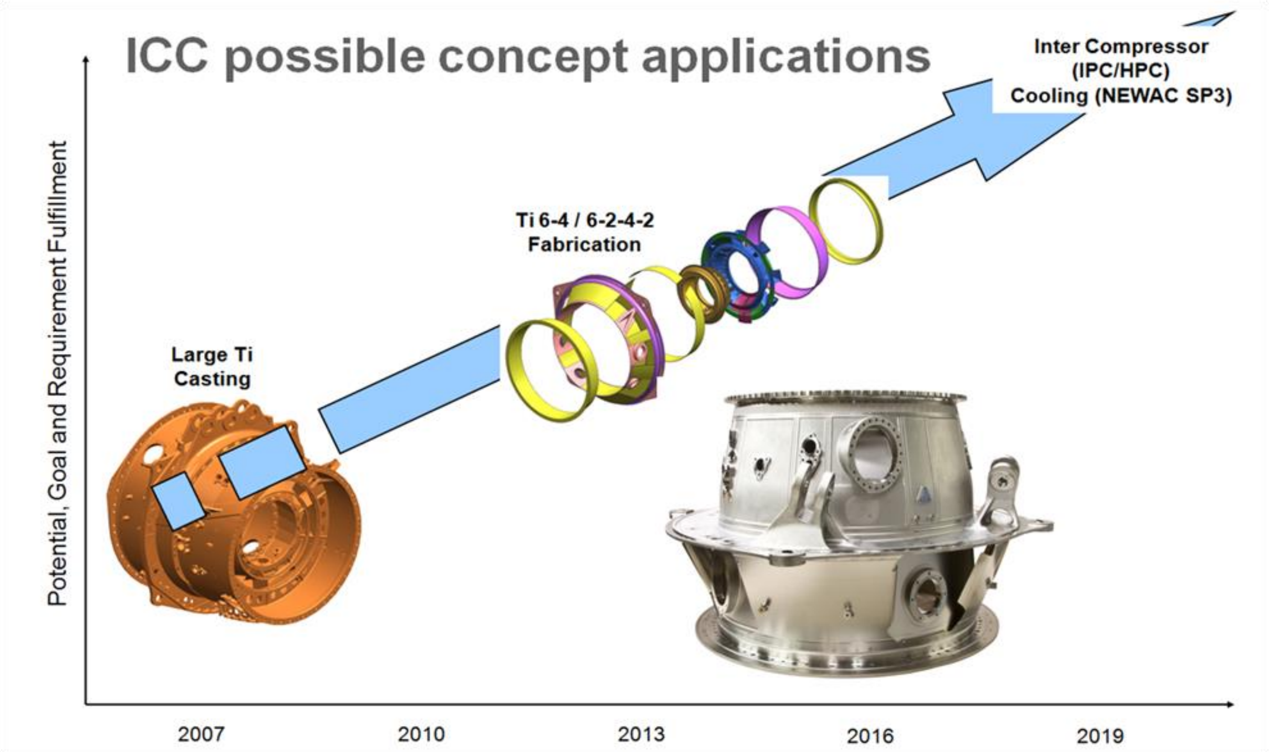
Robert Pederson
Uta Klement

CHALMERS
UNIVERSITY OF TECHNOLOGY

GKN AEROSPACE

BACKGROUND



Fabricated aeroengine components enable

1. design of lighter aeroengines with improved performance
2. Lower buy-to-fly ratio

Lower environmental impact and economical benefits

High quality welds are prerequisite for fabrication technologies

WELDING OF TITANIUM ALLOYS – TI6AL4V

Most used titanium alloy in aerospace industry

Reactivity at elevated temperatures

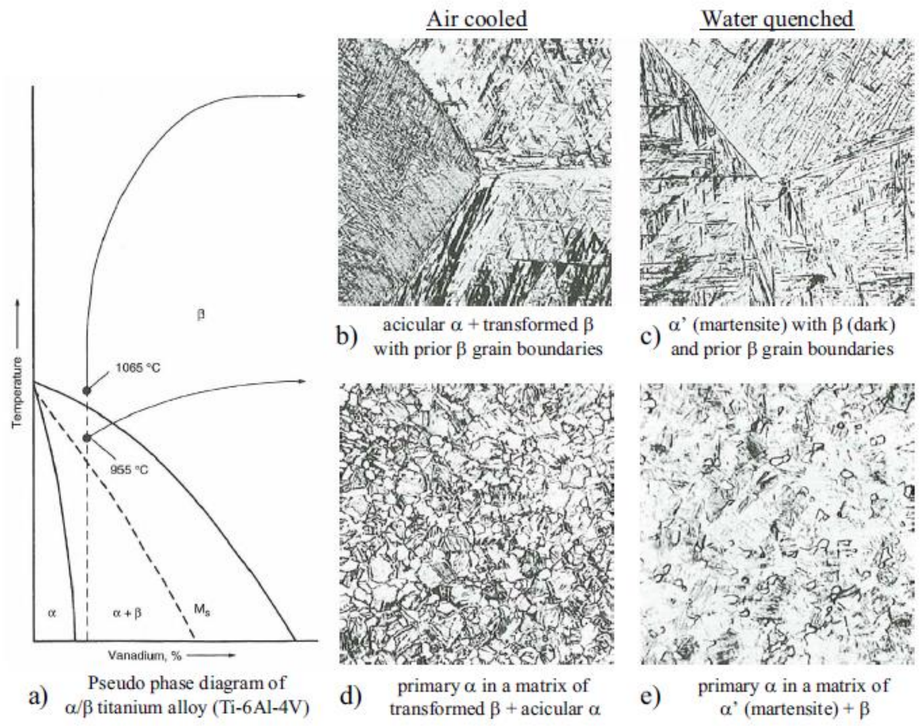
Has the best weldability of α+β alloys

Single phase solidification

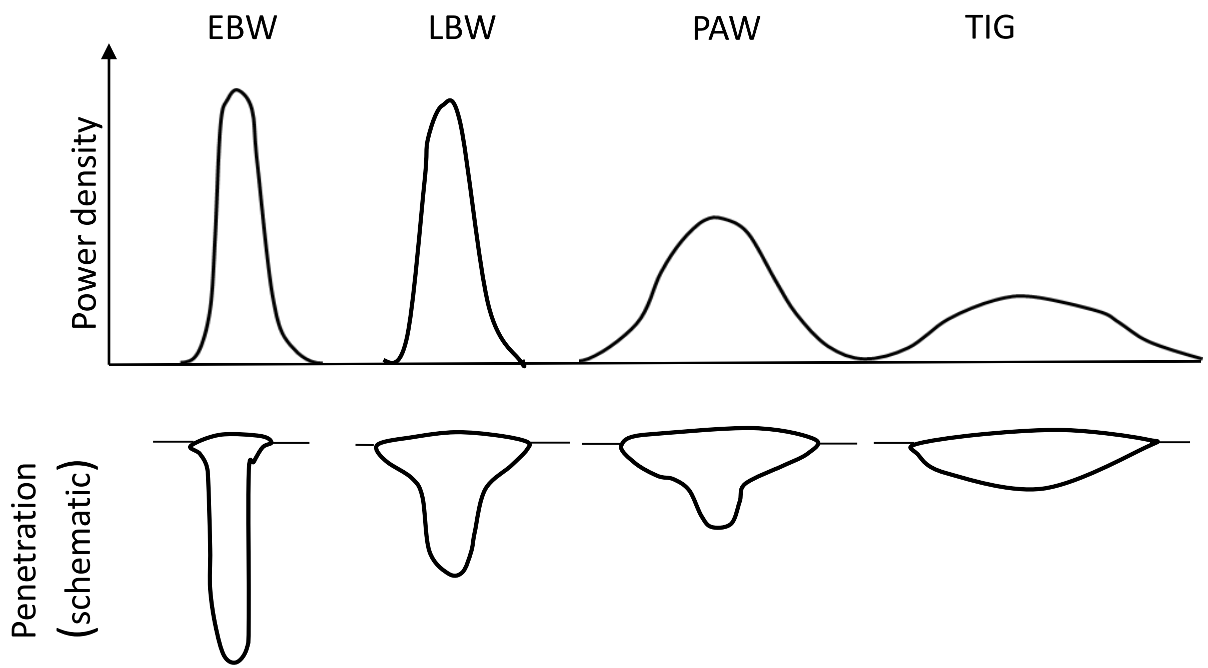
- Highly resistant to solidification and liquation cracking related cracking

Complex microstructures in continuous cooling

Porosity



WELDING PROCESSES

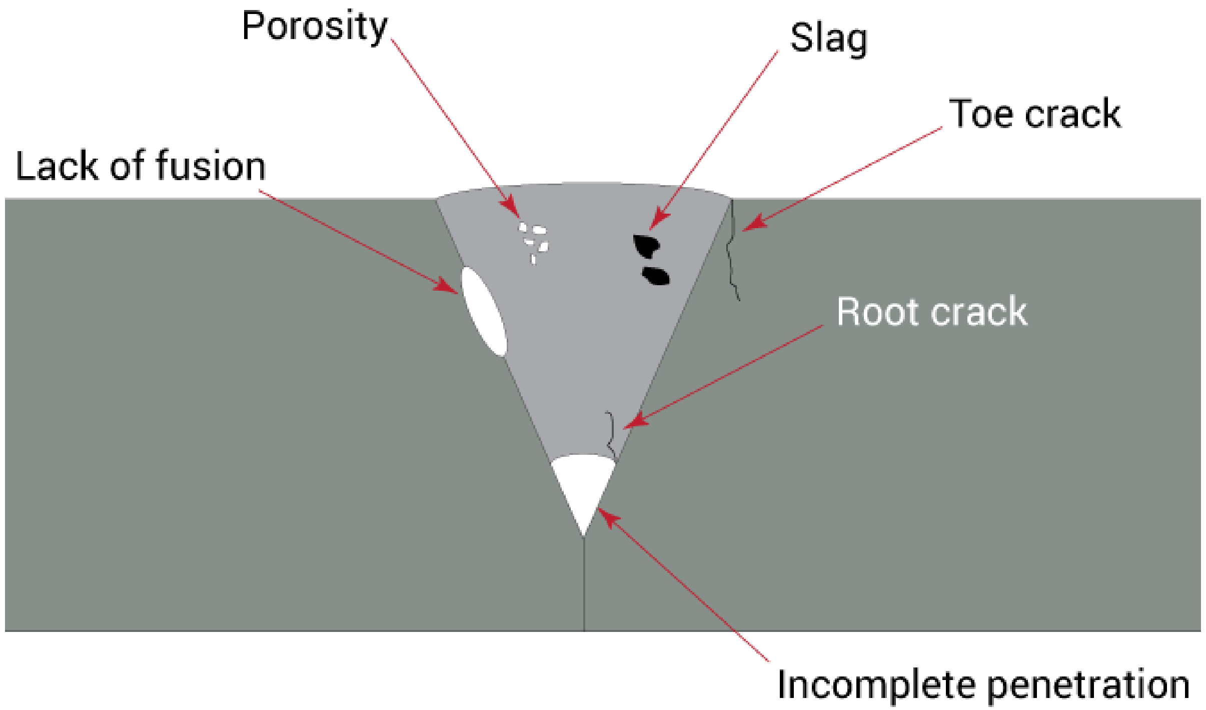


	EBW	LBW	PAW	TIG
Power density (W/cm^2)	10^5-10^8	10^5-10^7	10^3-10^6	10^2-10^4
Penetration depth (mm)	6-75	15	15	3-4

FATIGUE IN WELDS

Lower fatigue performance and high scatter due to

- Discontinuations
- Defects
- Brittle phases
- Distortions
- Residual stresses
- Stress concentrations



AIM OF THE WORK

What kind of microstructures are produced with different weld processes?

What kind of defects exist for different processes(/parameters)?

How do different microstructures effect on mechanical properties?

What size and distribution of defects effect mechanical properties?

EXPERIMENTAL PROCEDURE

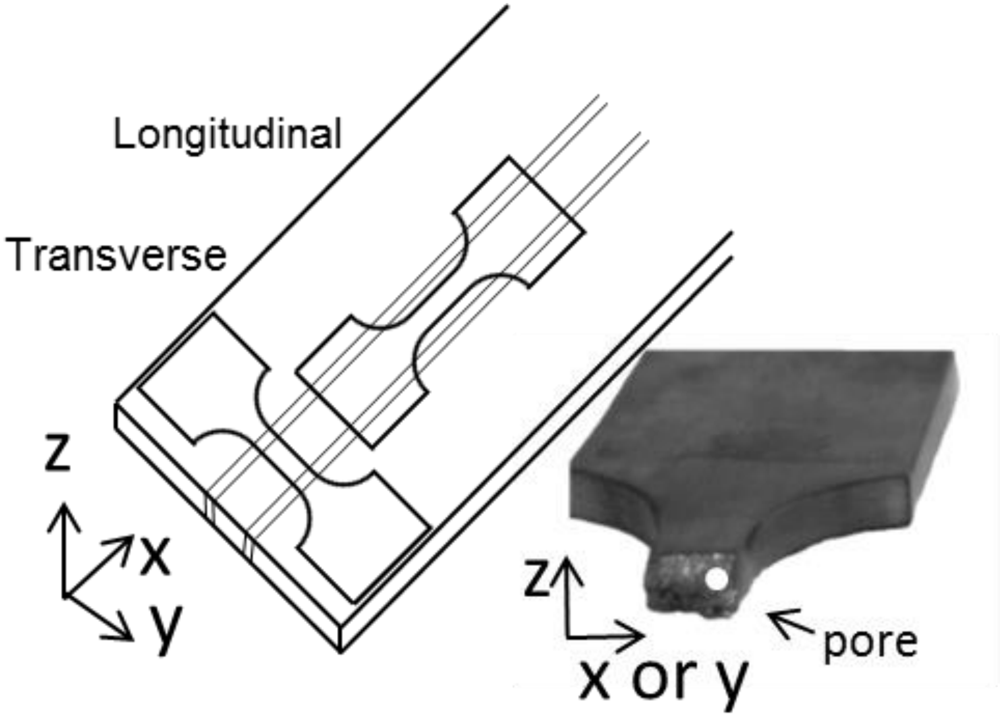
Material
- 4 mm thick AMS4911 Ti-6Al-4V sheet

Welding
- TIG, PAW, LBW, EBW
- Post weld heat treatment at 704°C for 2h
- Machining

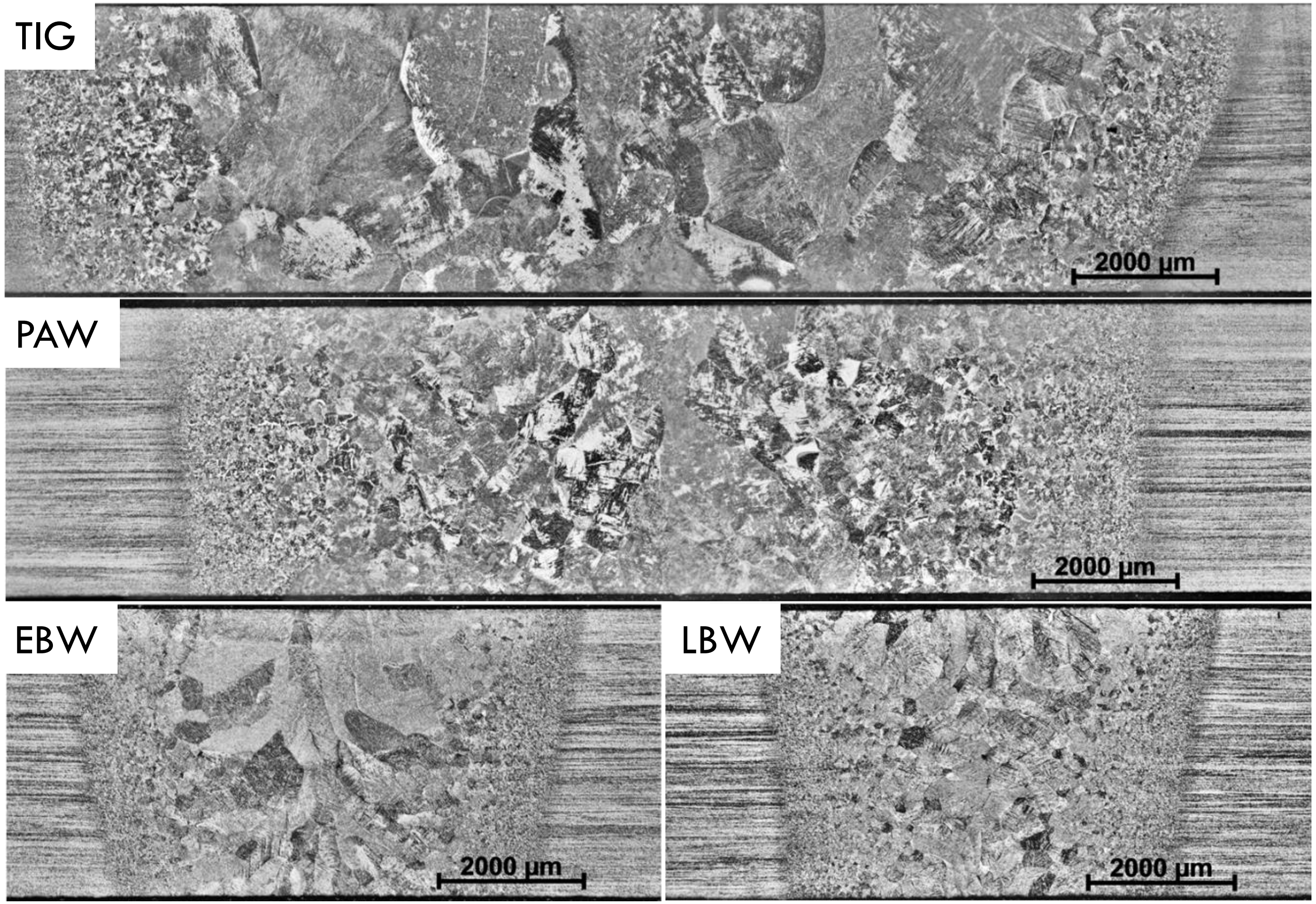
Mechanical testing
- Tensile testing
- Fatigue testing
  - Load controlled at at RT and 250°C in air
  - R=0

Microstructure
- OM, SEM, microhardness

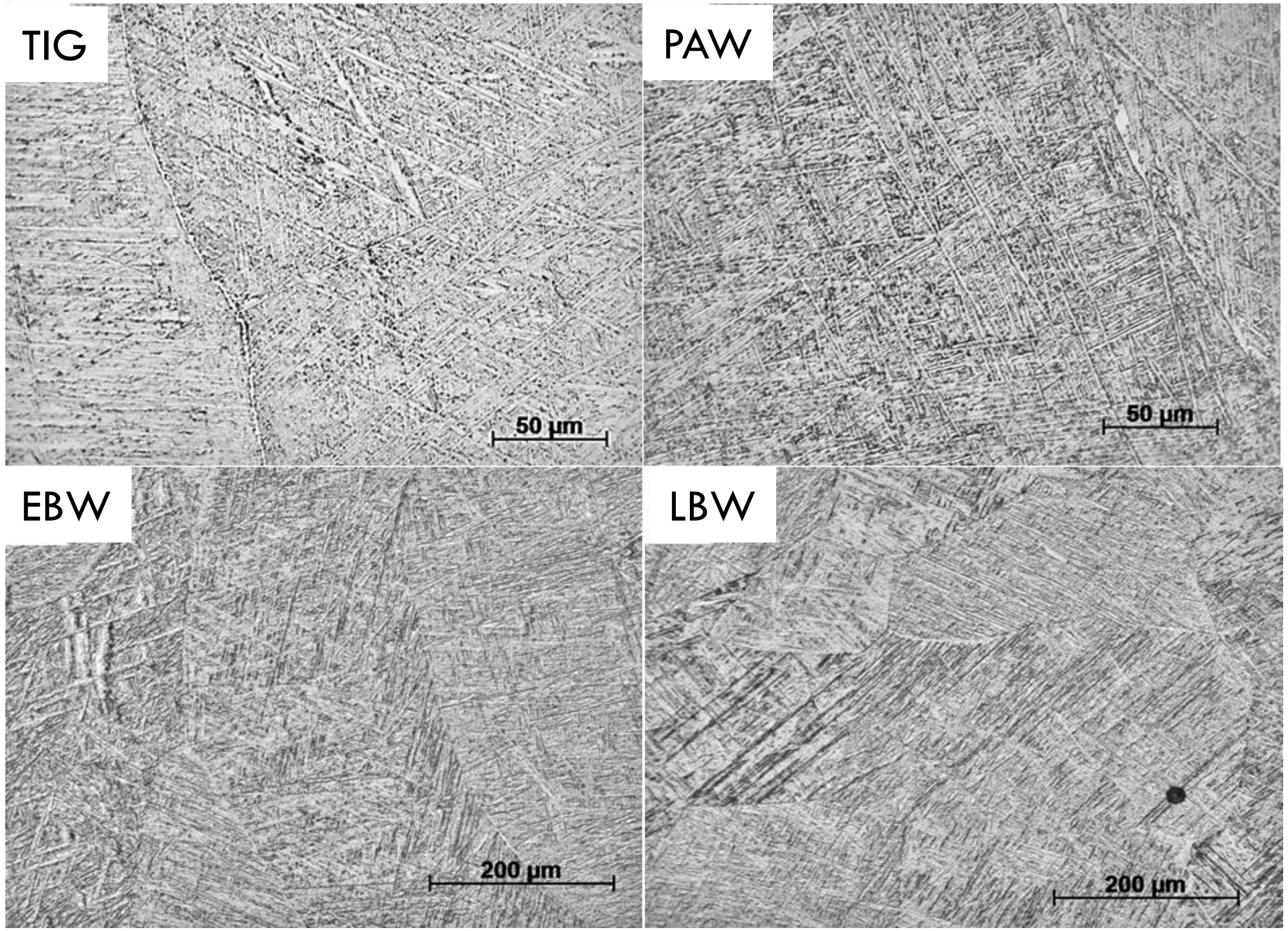
Fractography
- Location and size of crack initiation sites



MACROSTRUCTURE



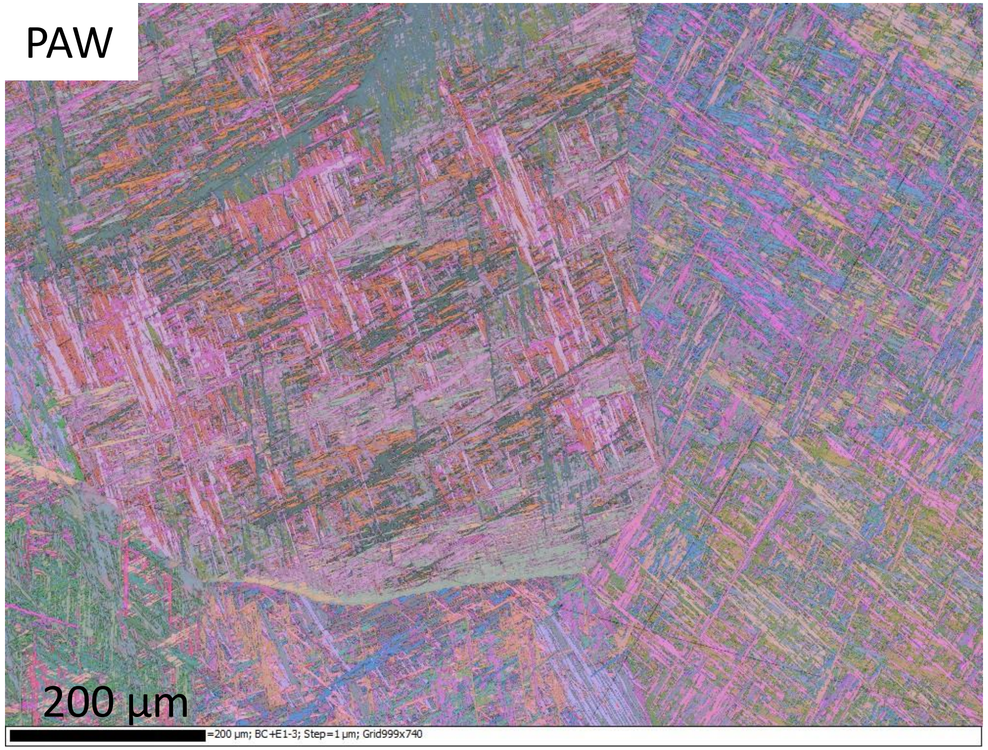
FUSION ZONE MICROSTRUCTURE

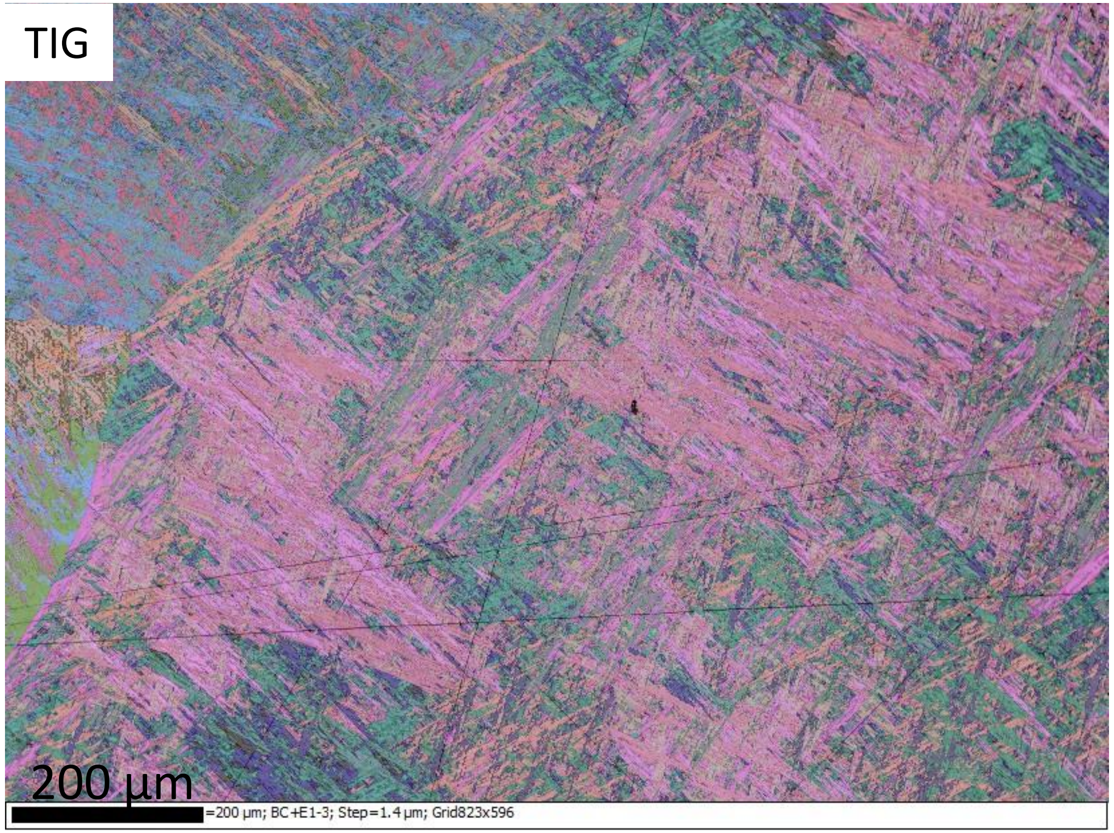


	TIG	PAW	EBW	LBW
FZ width top/bottom	12.3/7.5mm	7.3/5.8 mm	3/3 mm	3/1.8 mm
HAZ width	2 mm	1.8 mm	1.8 mm	1.6 mm
Prior-β grain size	3 mm	2 mm	1. 5 mm	1 mm
GB-α	1 µm/continuous	1 µm/continuous	Thin/uncontinuous	Thin/uncontinuous
α lath spacing	1.2-1.3 µm	1.2-1.3 µm	0.8-1 µm	0.8-1 µm

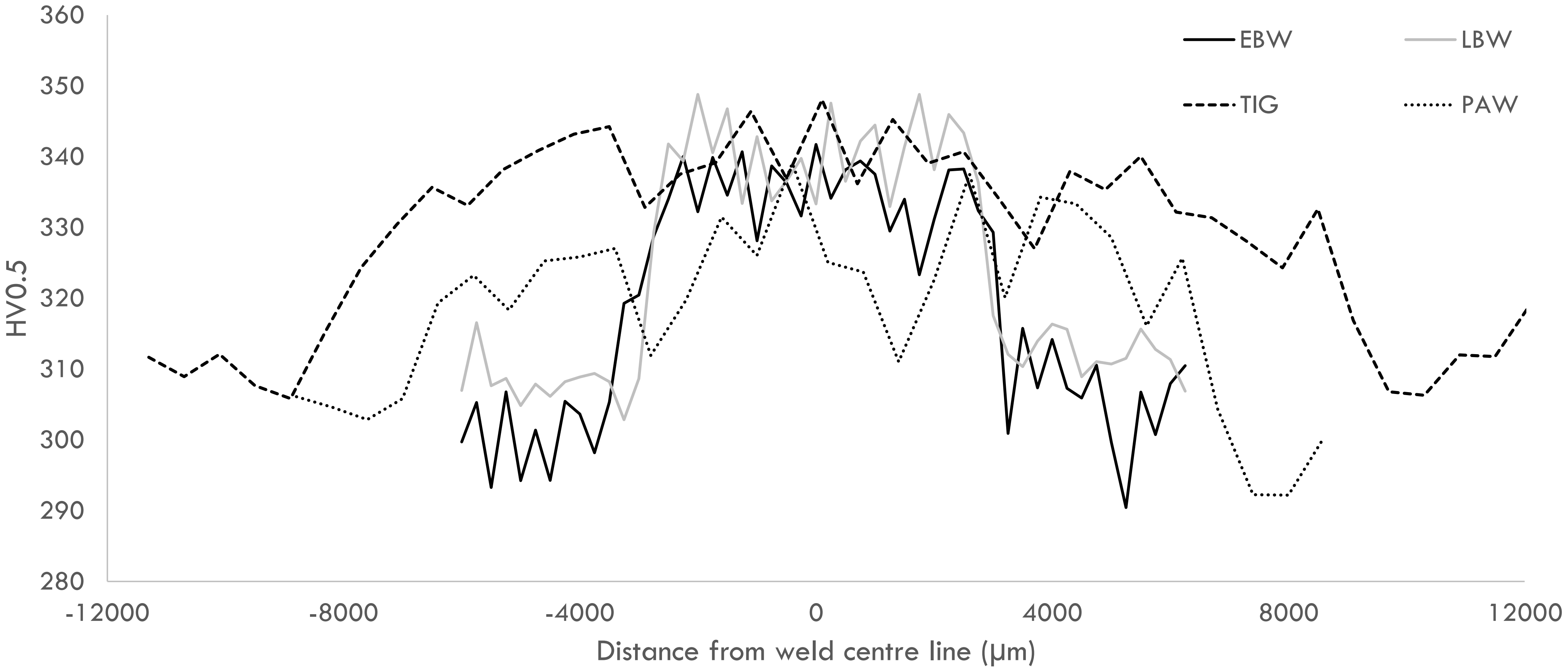
MICROSTRUCTURE - EBSD

- Euler angle presentation
- PAW basket weave
- TIG combination of colony and basket weave structure



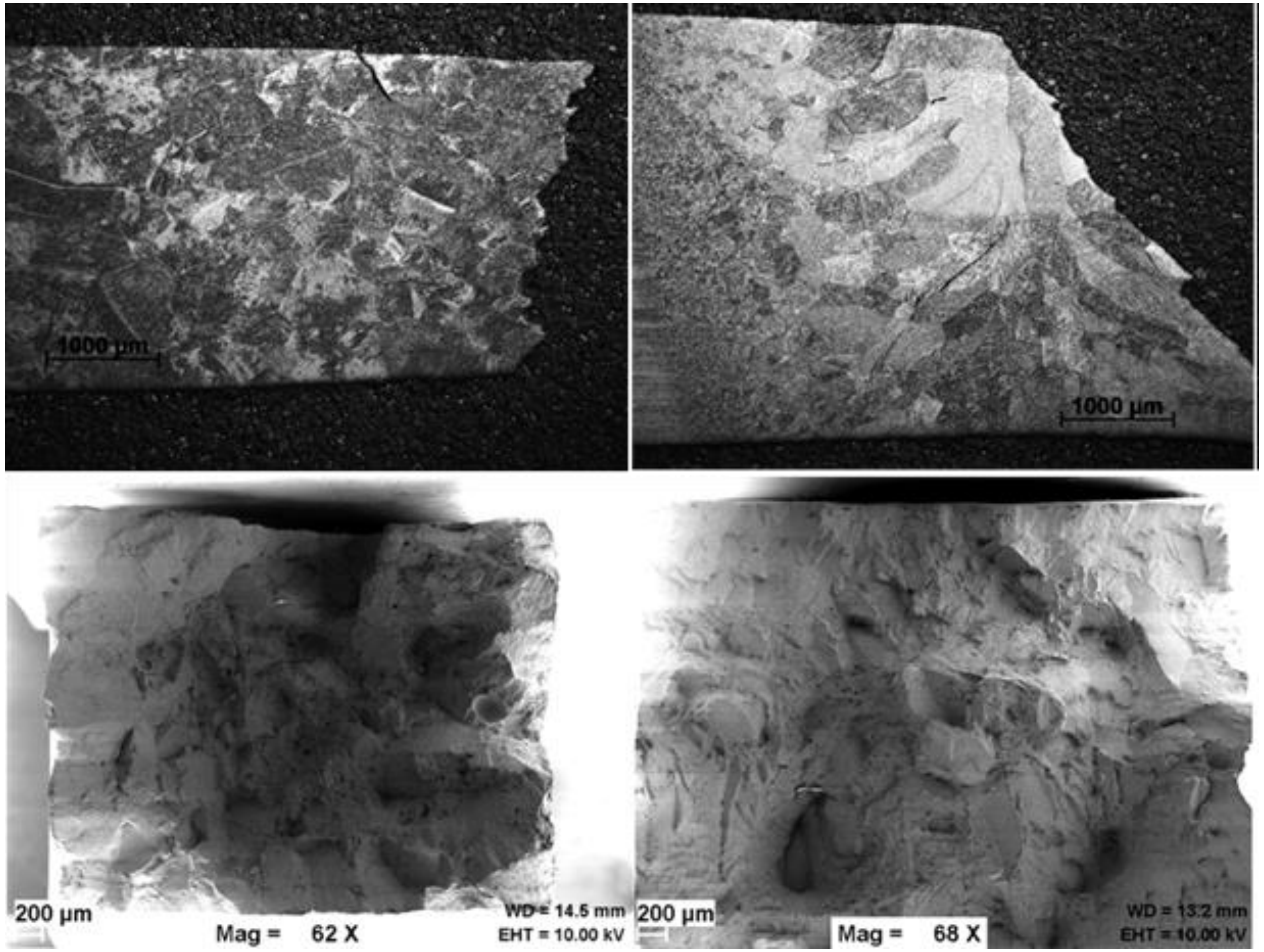


MICROHARDNESS



TENSILE PROPERTIES

Process	Test temp (°C)	Yield strength (normalized)	UTS (normalized)	Elongation on A4 (%)
Base material	20	0.95	1.00	16,4
Base material	250	0.72	0.78	17,8
EBW	20	0.92	0.99	10
EBW	250	0.67	0.78	15
LBW	20	0.91	0.97	10
LBW	250	0.66	0.76	12
TIG	20	0.85	0.94	7
TIG	250	0.58	0.73	14
PAW	20	0.84	0.93	9
PAW	250	0.58	0.71	14

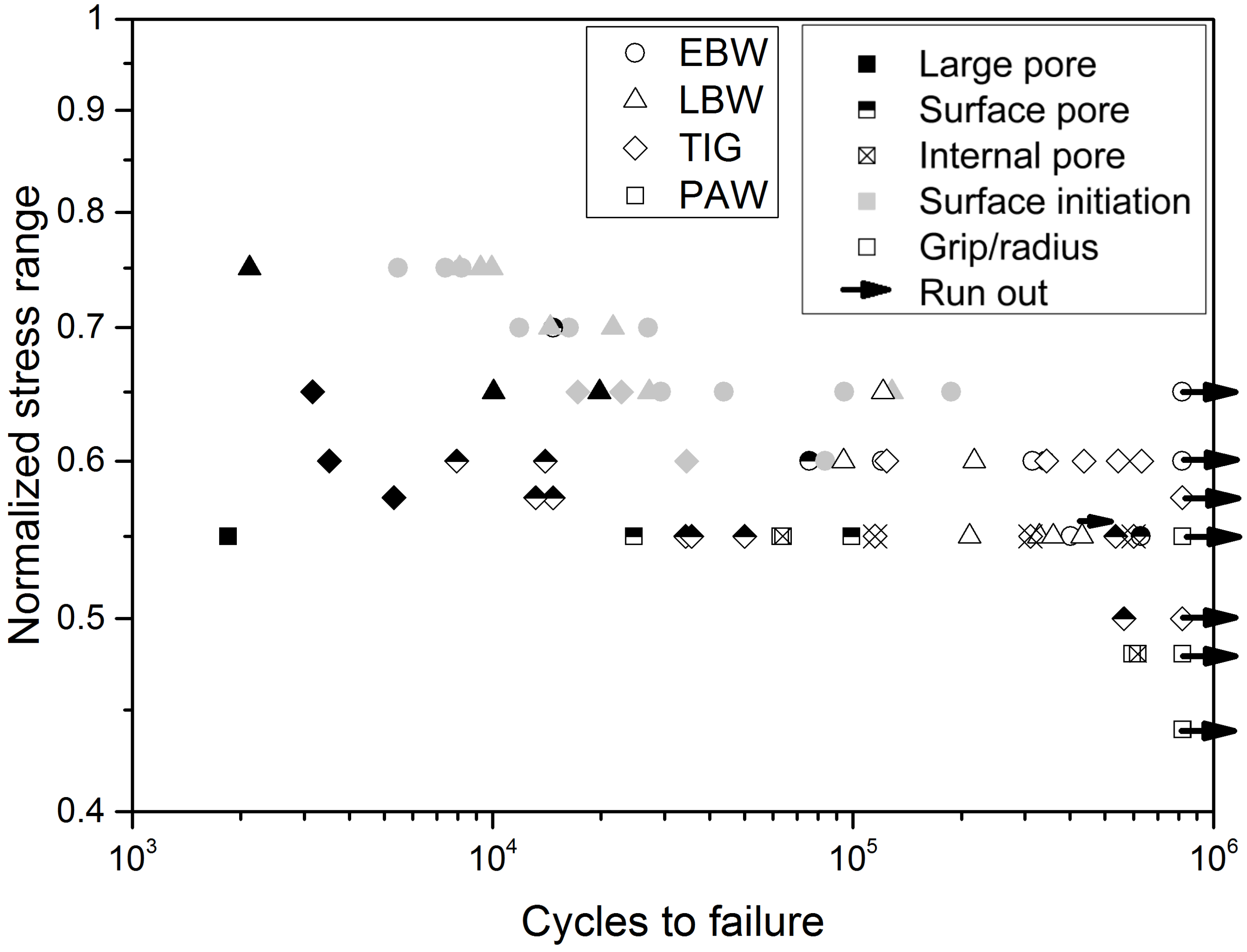


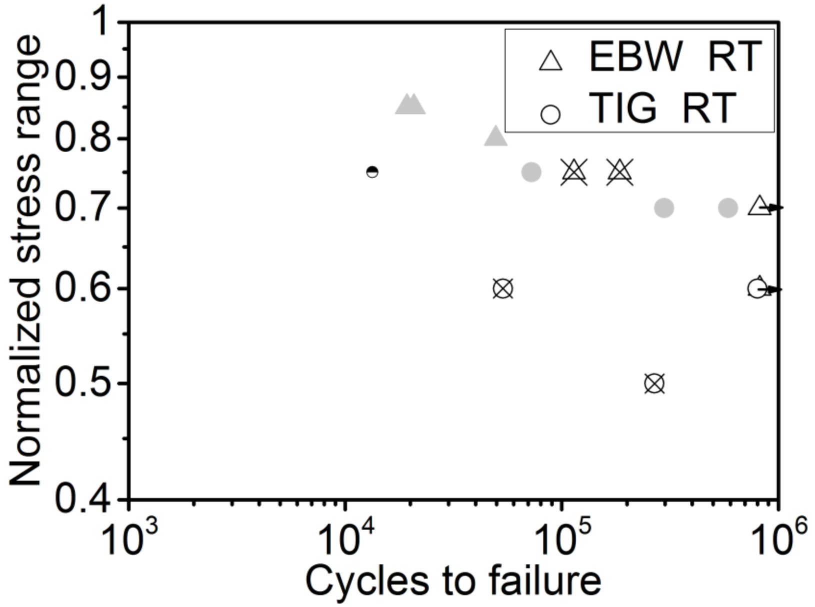
LOW CYCLE FATIGUE

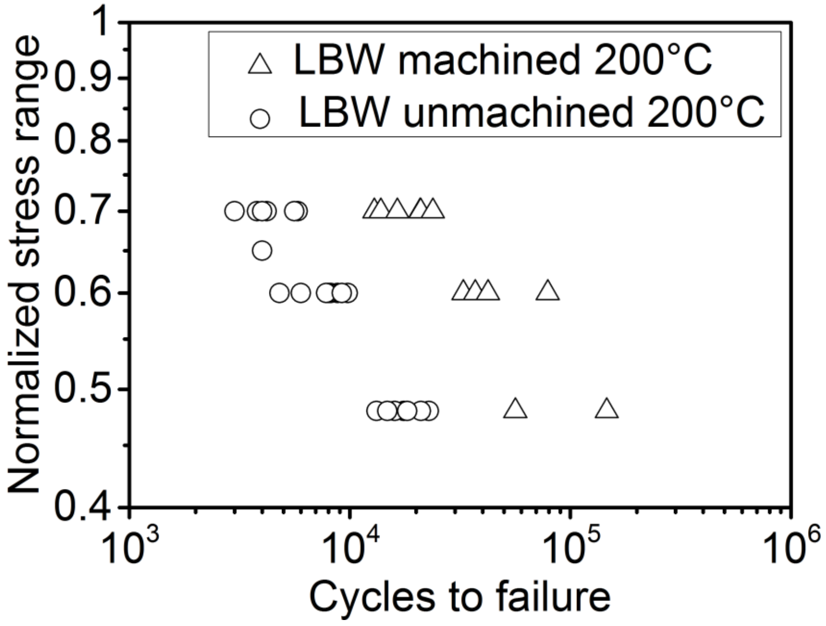
How do different microstructures effect on mechanical properties?

What size and distribution of defects effect mechanical/LCF properties?

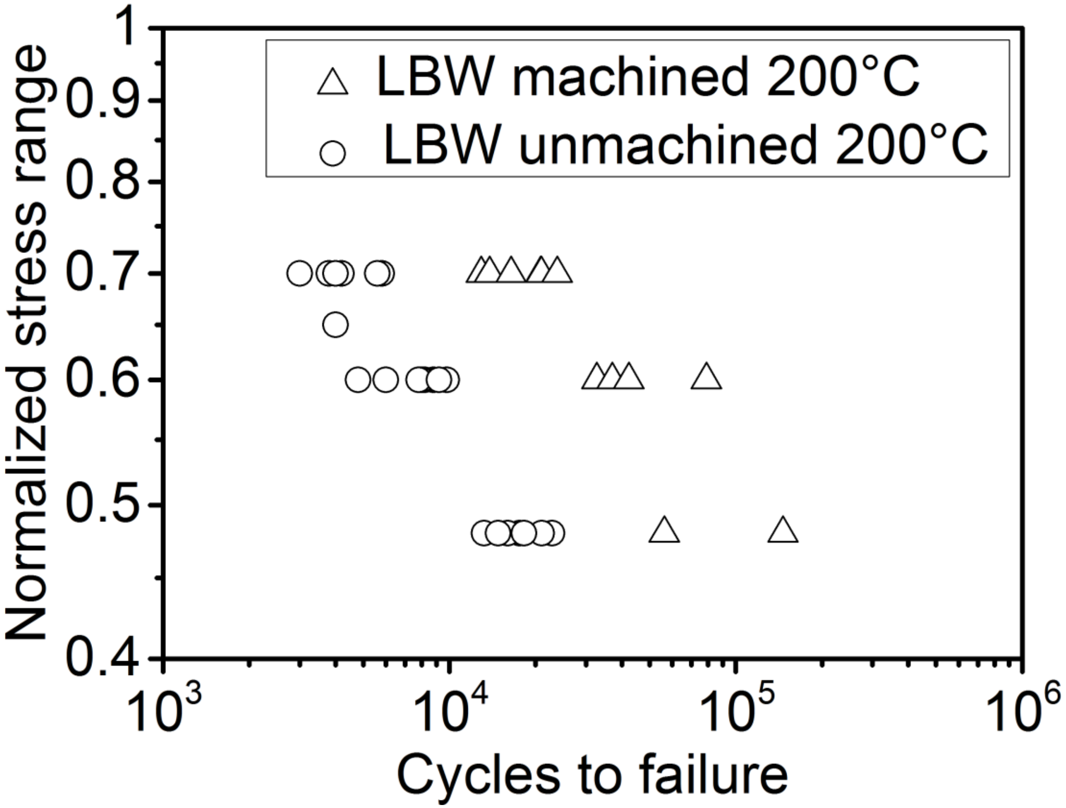
FATIGUE TEST RESULTS

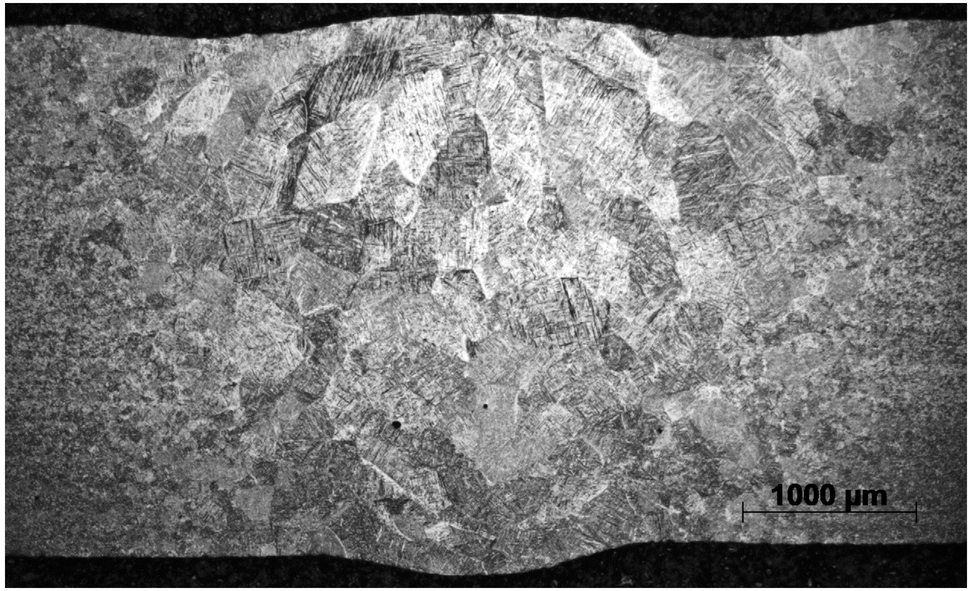


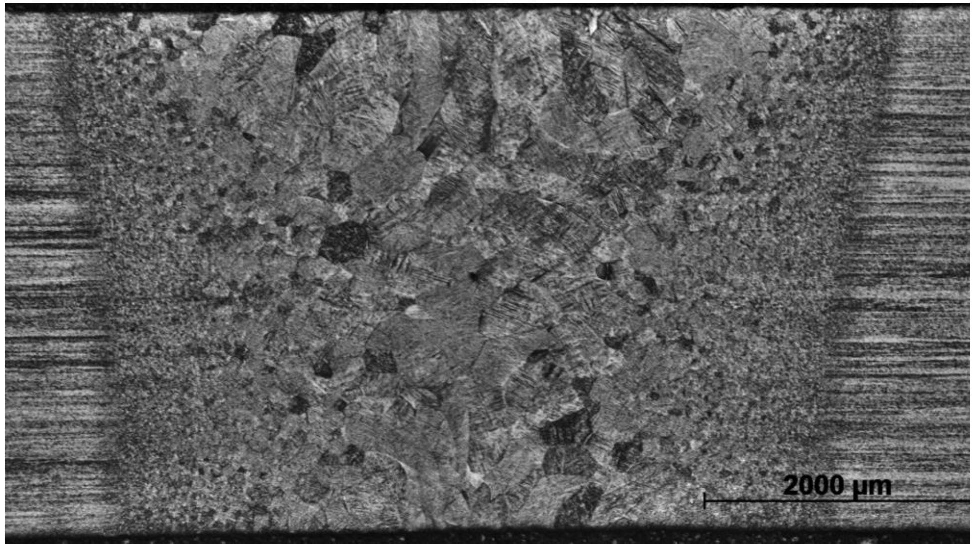




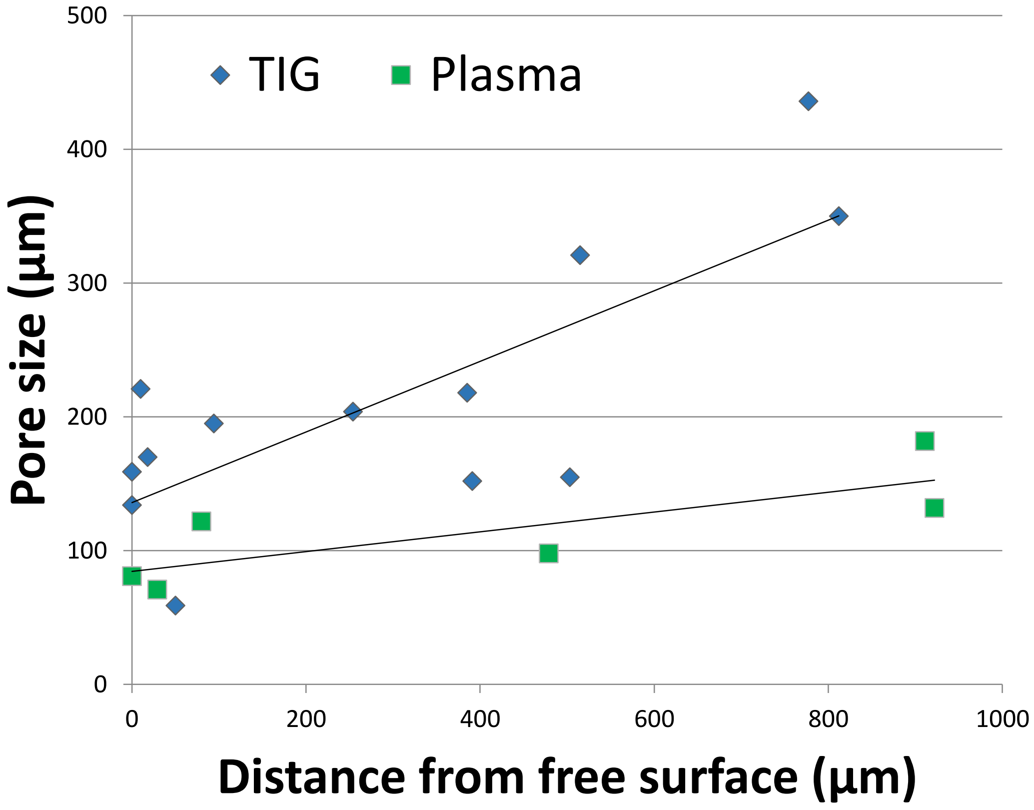
EFFECT OF WELD GEOMETRY

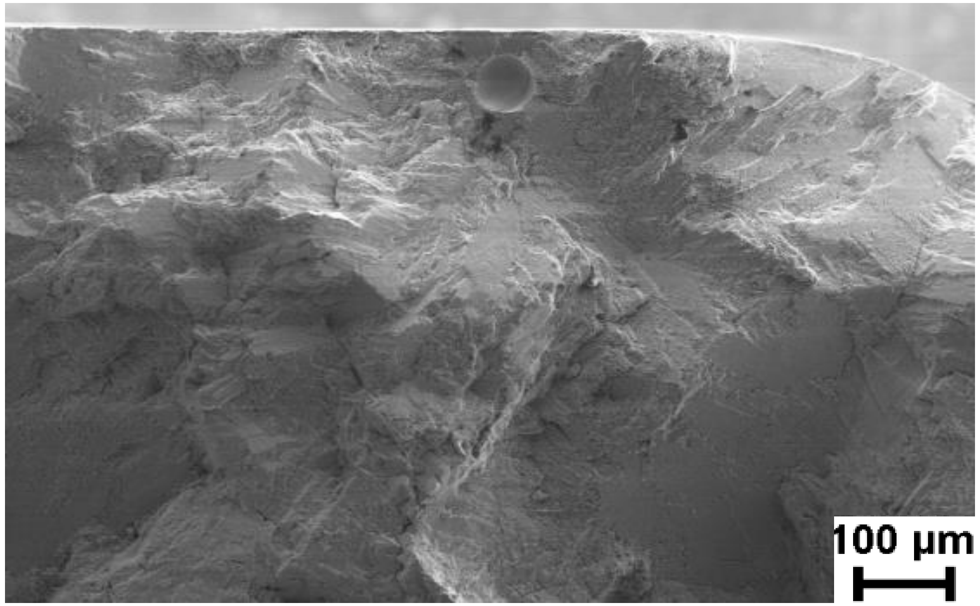


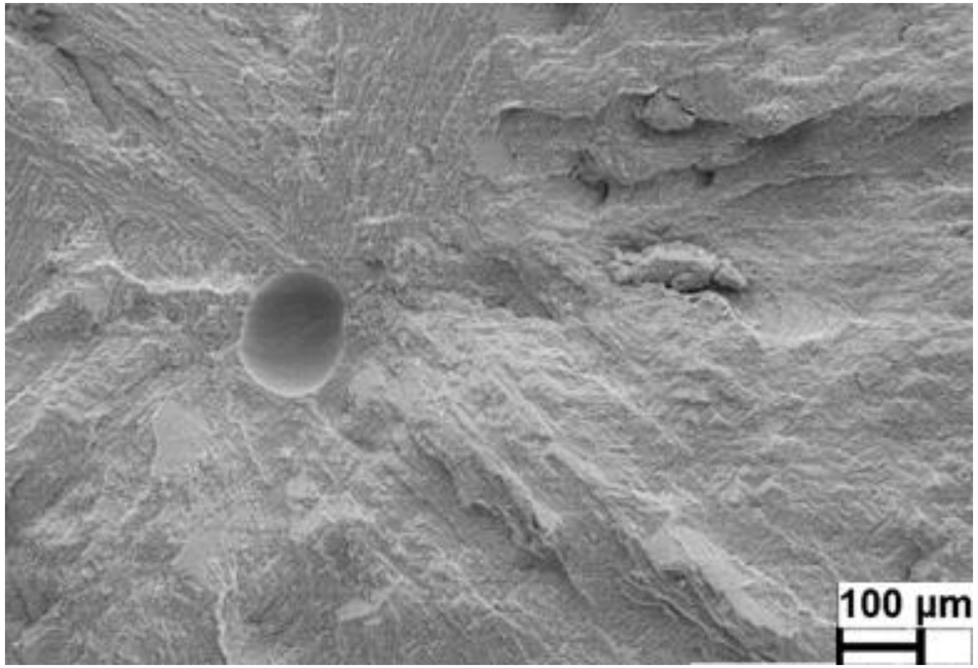




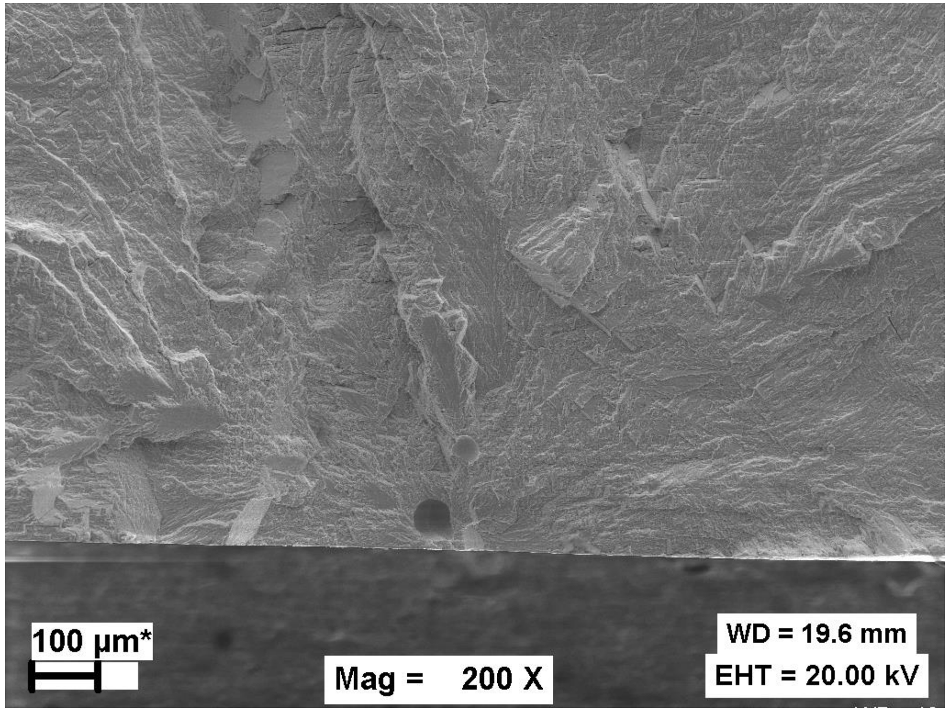
FRACTOGRAPHY TIG&PAW

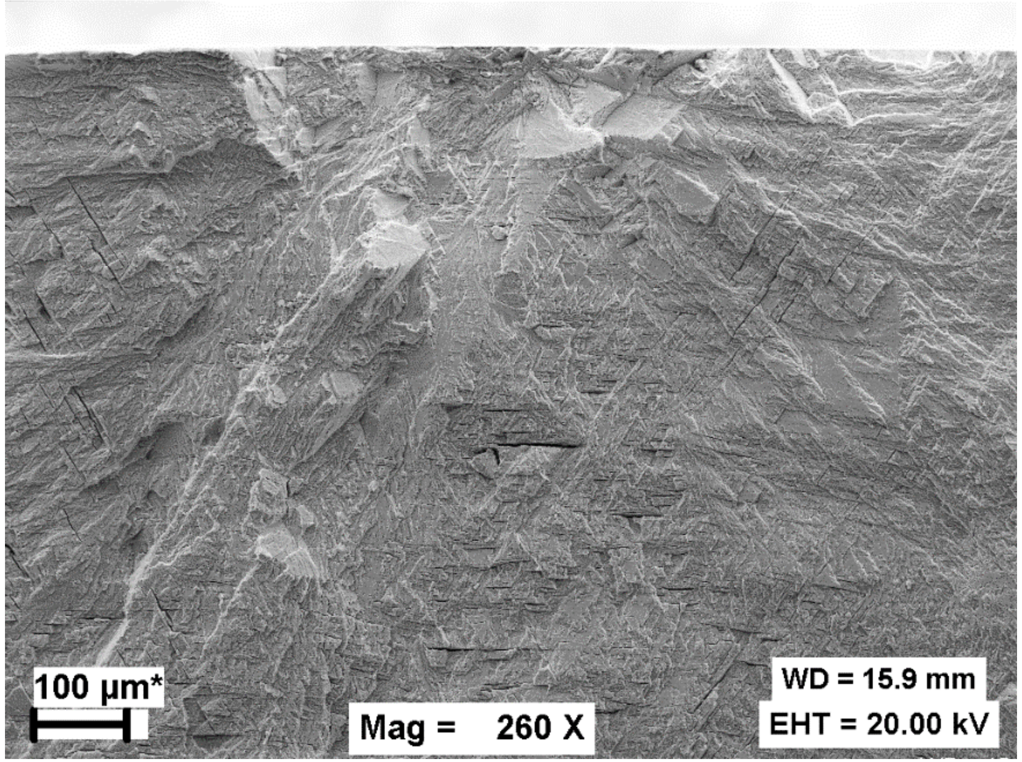




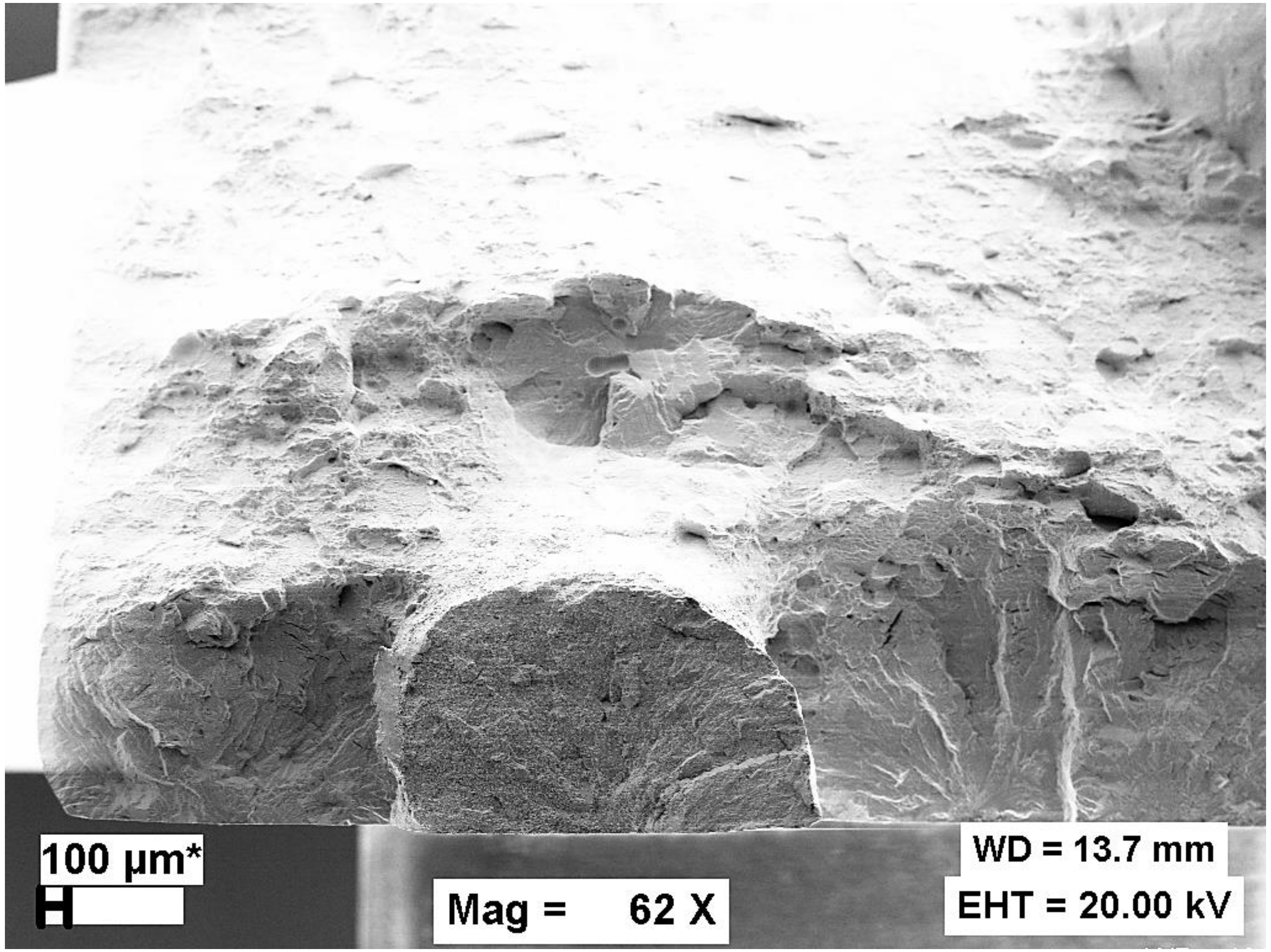


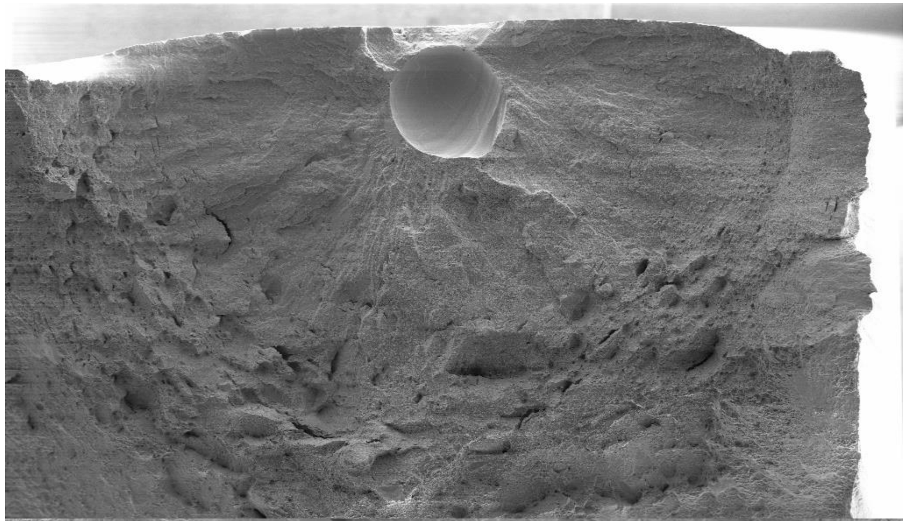
FRACTOGRAPHY EB

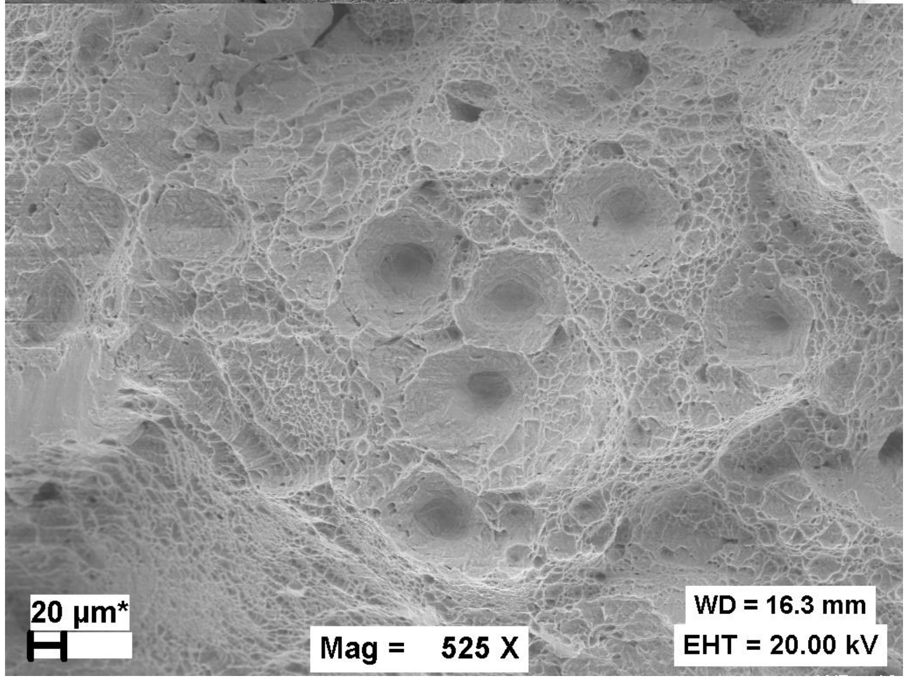




FRACTOGRAPHY LBW

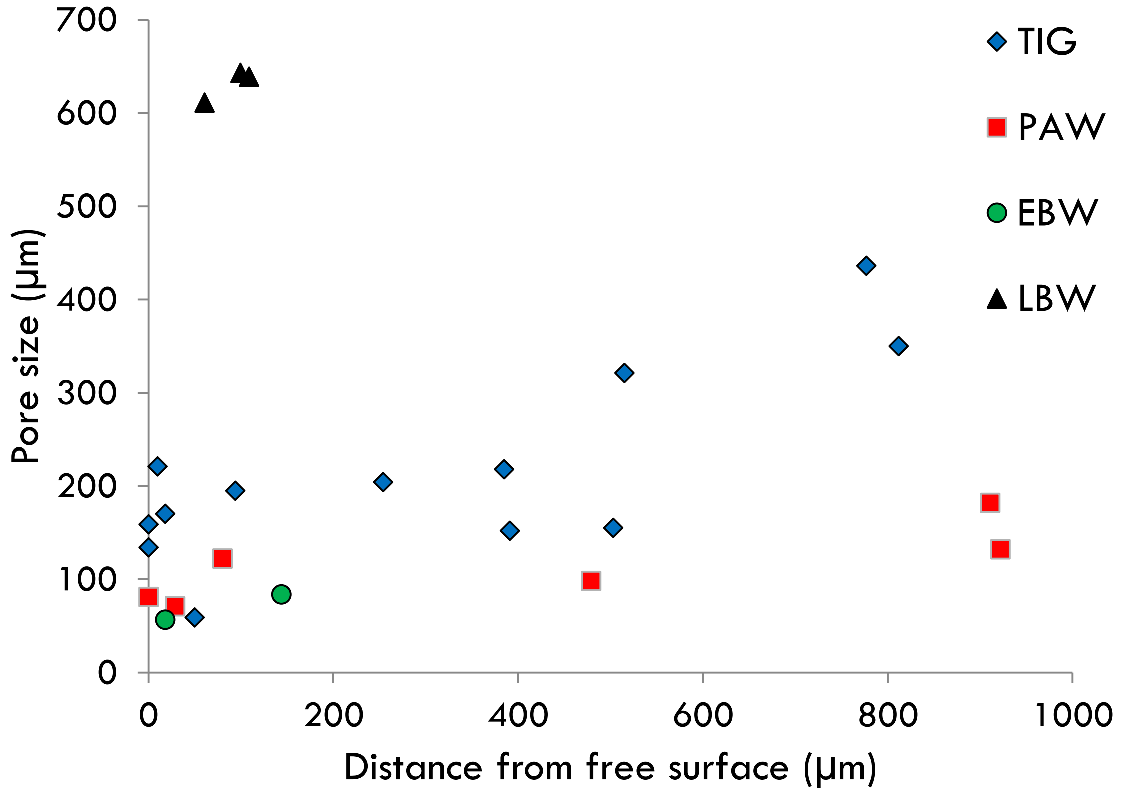




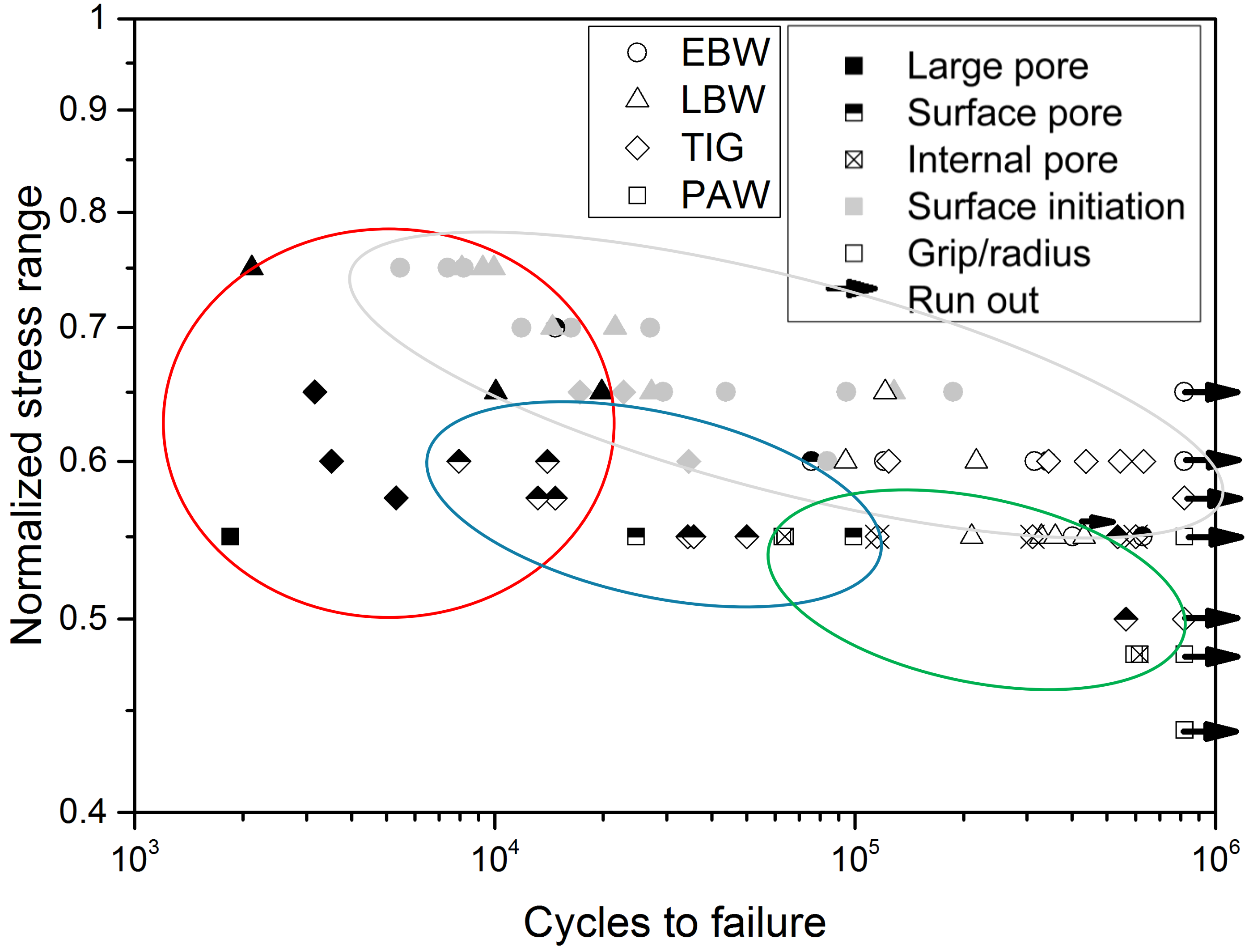


FRACTOGRAPHY SUMMARY

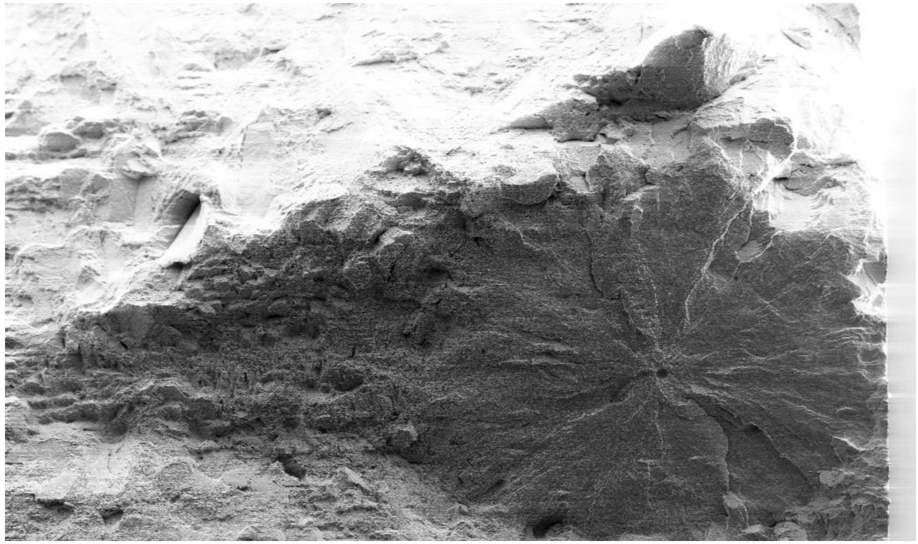
Size [μm]	TIG	PAW	EBW	LBW
Surface initiation	3	2	24	9
0-100	3	3	4	15
100-200	10	3	-	3
200-300	6	-	-	-
300-400	4	-	-	-
400-500	1	-	-	-
600-700	-	LOF	-	3

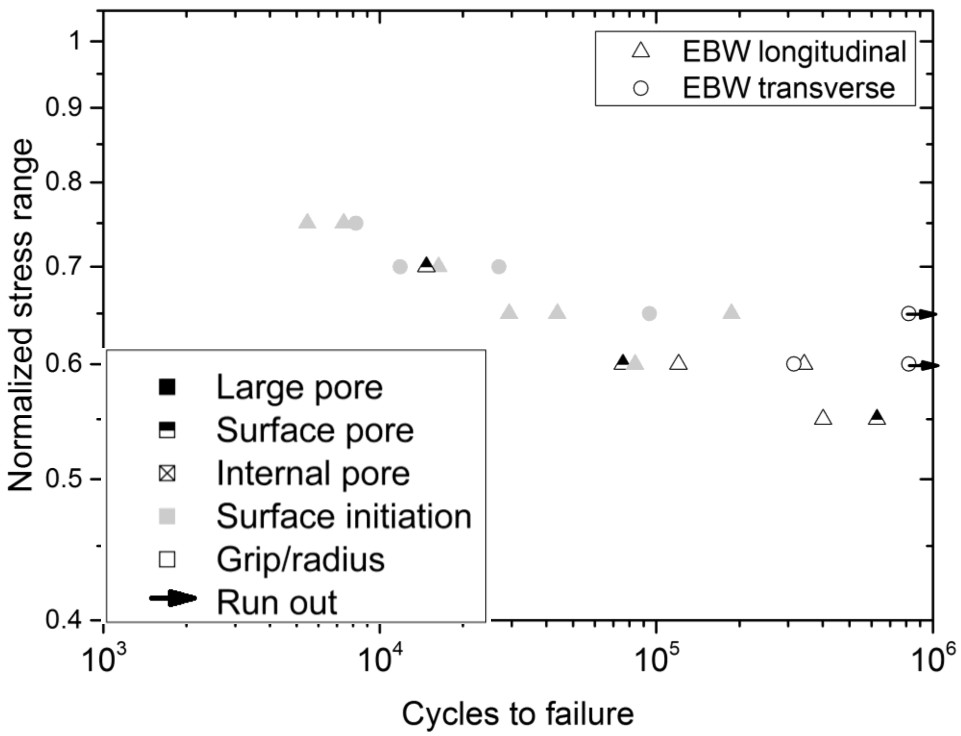


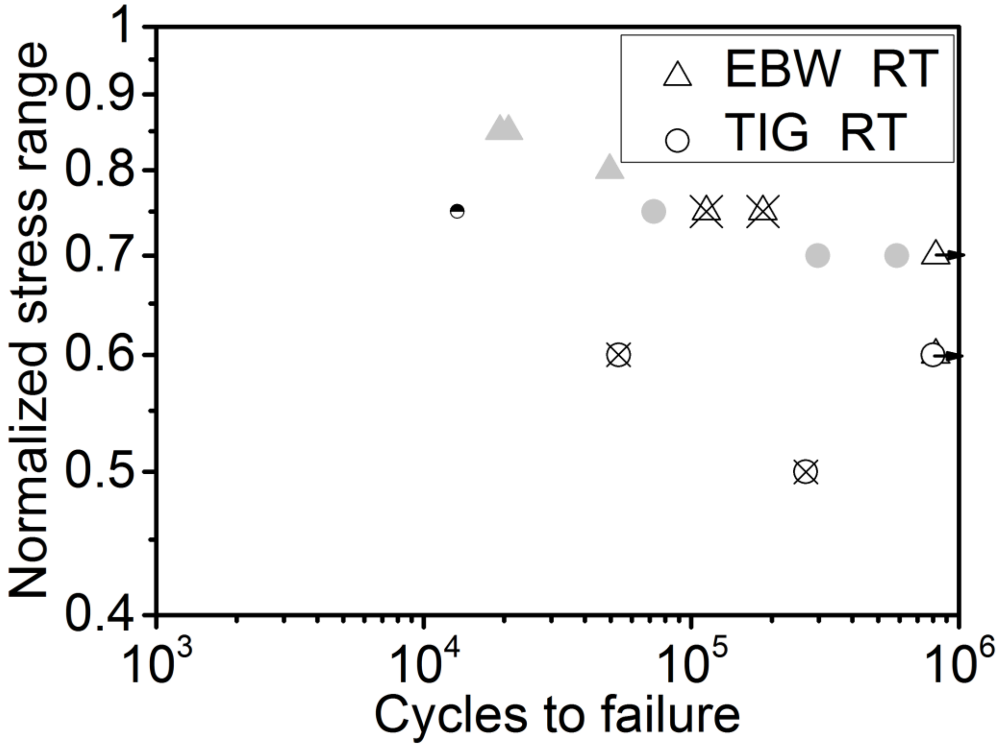
EFFECT OF PORE SIZE AND LOCATION



EFFECT OF TEMPERATURE





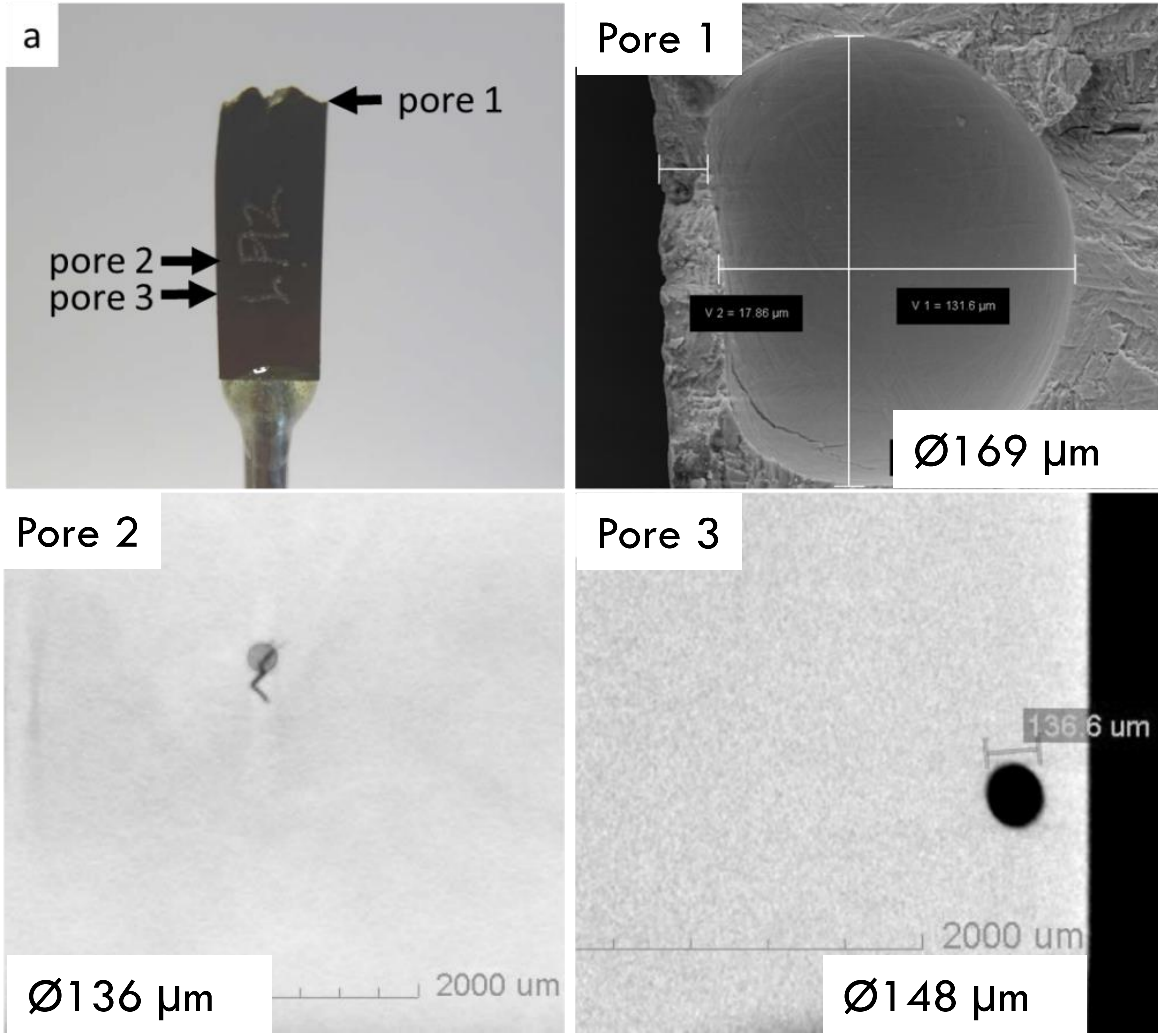


X-RAY MICROSCOPY

Zeiss Xradia Versa 520

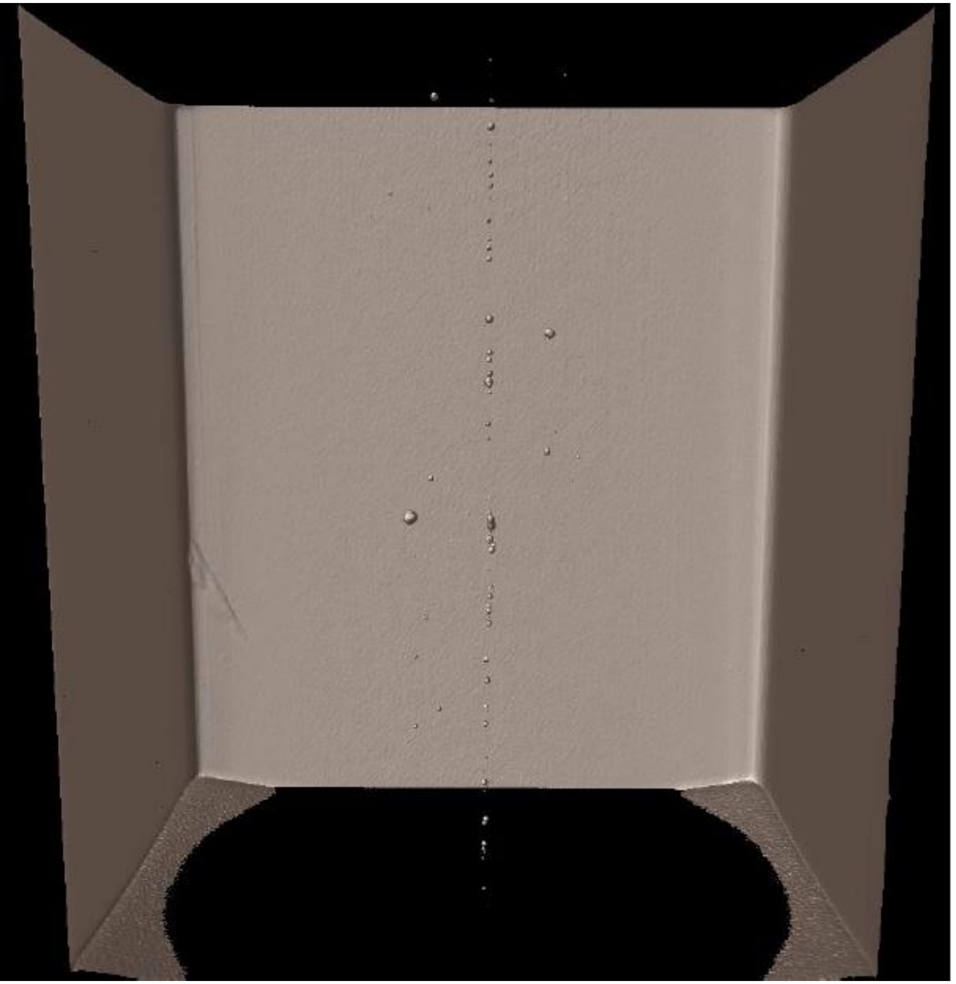
- Optical magnification system (in contrast to x-ray tomography)
- Scan times in examples 4-12 hrs
- Voxel size down to 70 nm

CASE: TIG WELD FATIGUE SAMPLE



- Cycles to failure 13166

CASE: LASER WELD SAMPLE

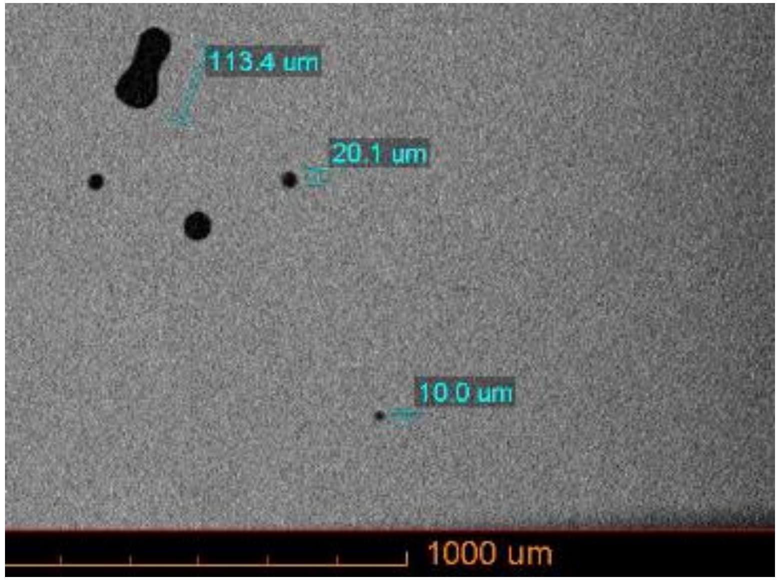


Discontinued after 432 000 cycles

No failure

Largest pore 114 µm

Smallest pore detected



CONCLUSIONS

Pores initiated cracks on nearly all the samples in PAW and TIG welds whereas in LB and EB welds most samples had crack initiation at the surface

Large pores and pores close to surface were the most detrimental to fatigue life

Microstructure & hardness have an effect on fatigue performance

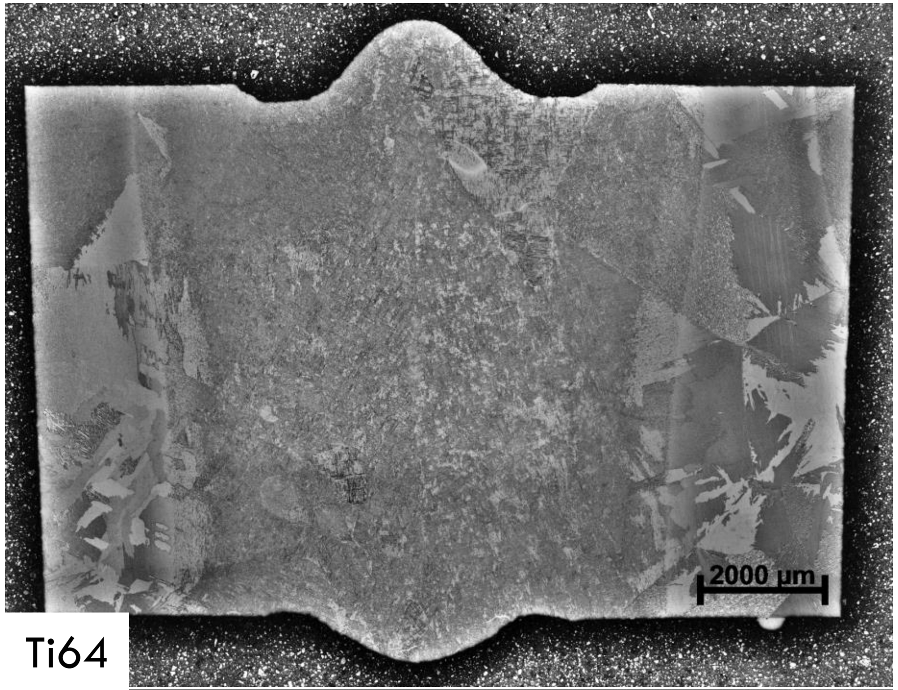
- EB&LBW had better fatigue performance than TIG&PAW
- LBW had lot of porosity but only large pores initiated crack

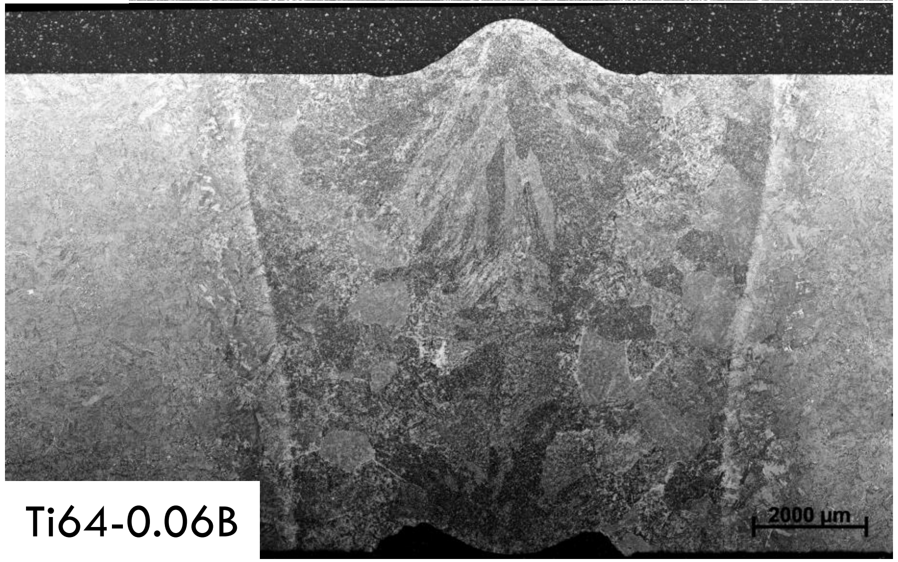
FUTURE WORK

Predict fatigue life using LEFM

XCT to identify critical defects

Effect of small boron addition in microstructure of Ti64 welds





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