AUT UNIVERSITY ENGINEERING

Latest Metals Research Outcomes at AUT University and CAMTEC

Neitzert, T., Chen, Z., Pasang,T., Singamneni, S.

Manufacturing Methods applied to Light Metals

Forming (of Mg)

Machining (of Ti)

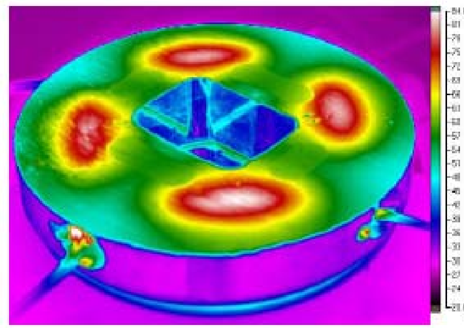
Welding (of Ti)

Friction Stir Lap Welding (of Al, Ti)

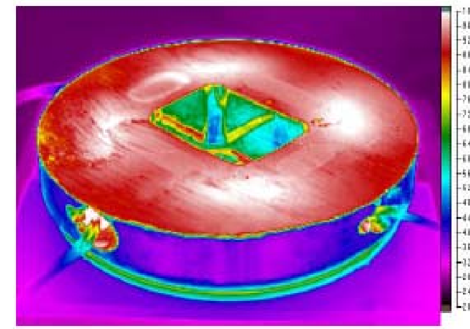
Rapid Casting (of Al, Mg)

Metal Forming of Mg ZE10 at elevated temperatures

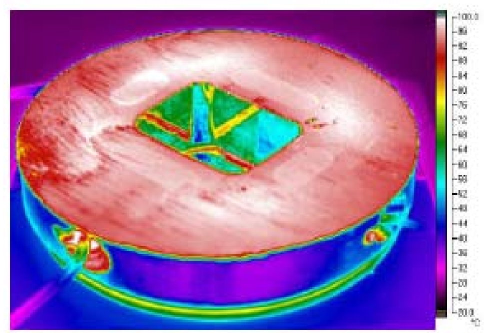
ZE 10: 1% Zn
0.17 Rare Earths
Rest Mg

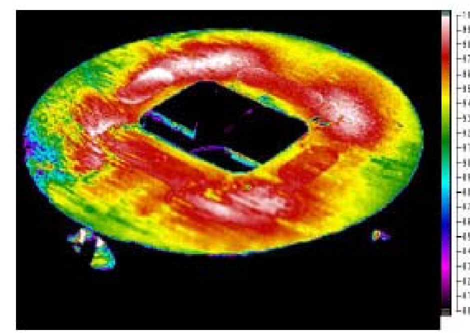


4 minutes



10 minutes





16 minutes

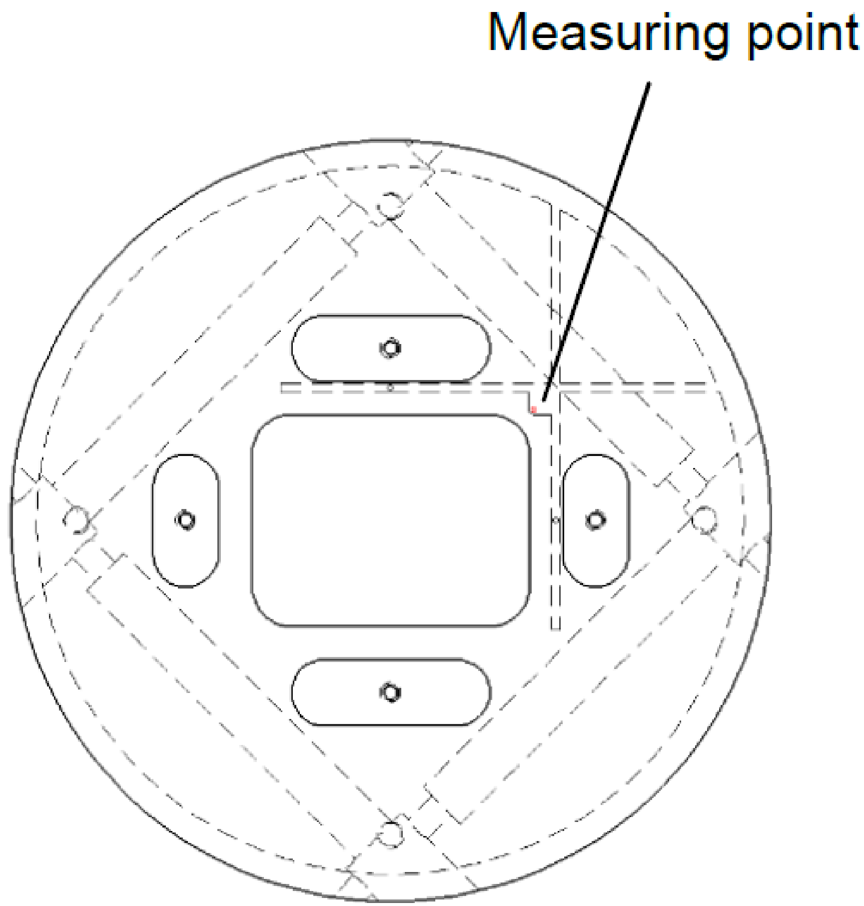
Development of heated, rectangular tool

Die

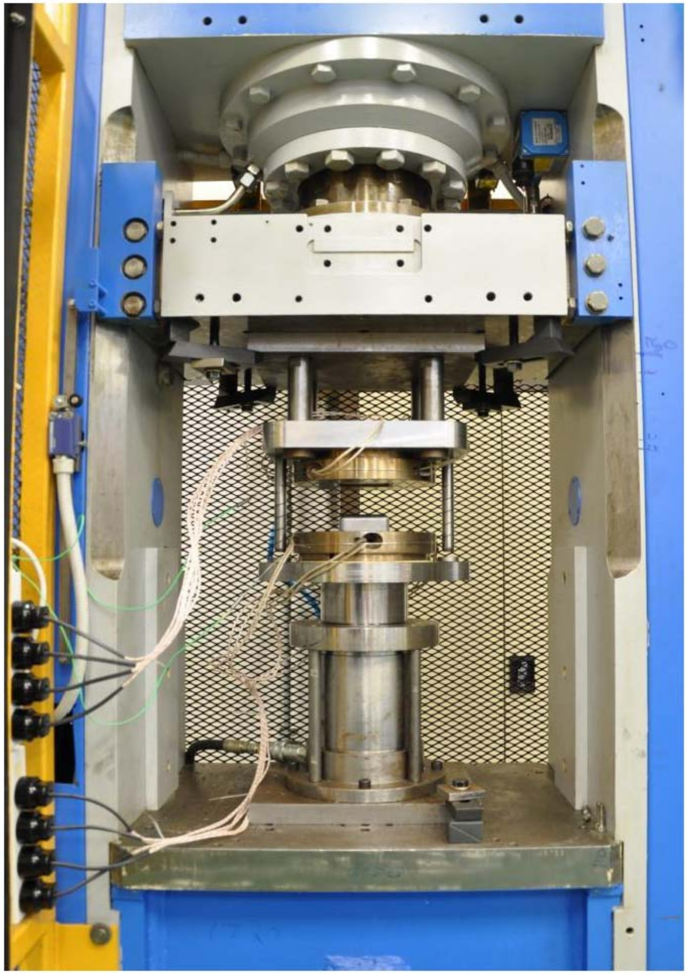
Blankholder

Punch

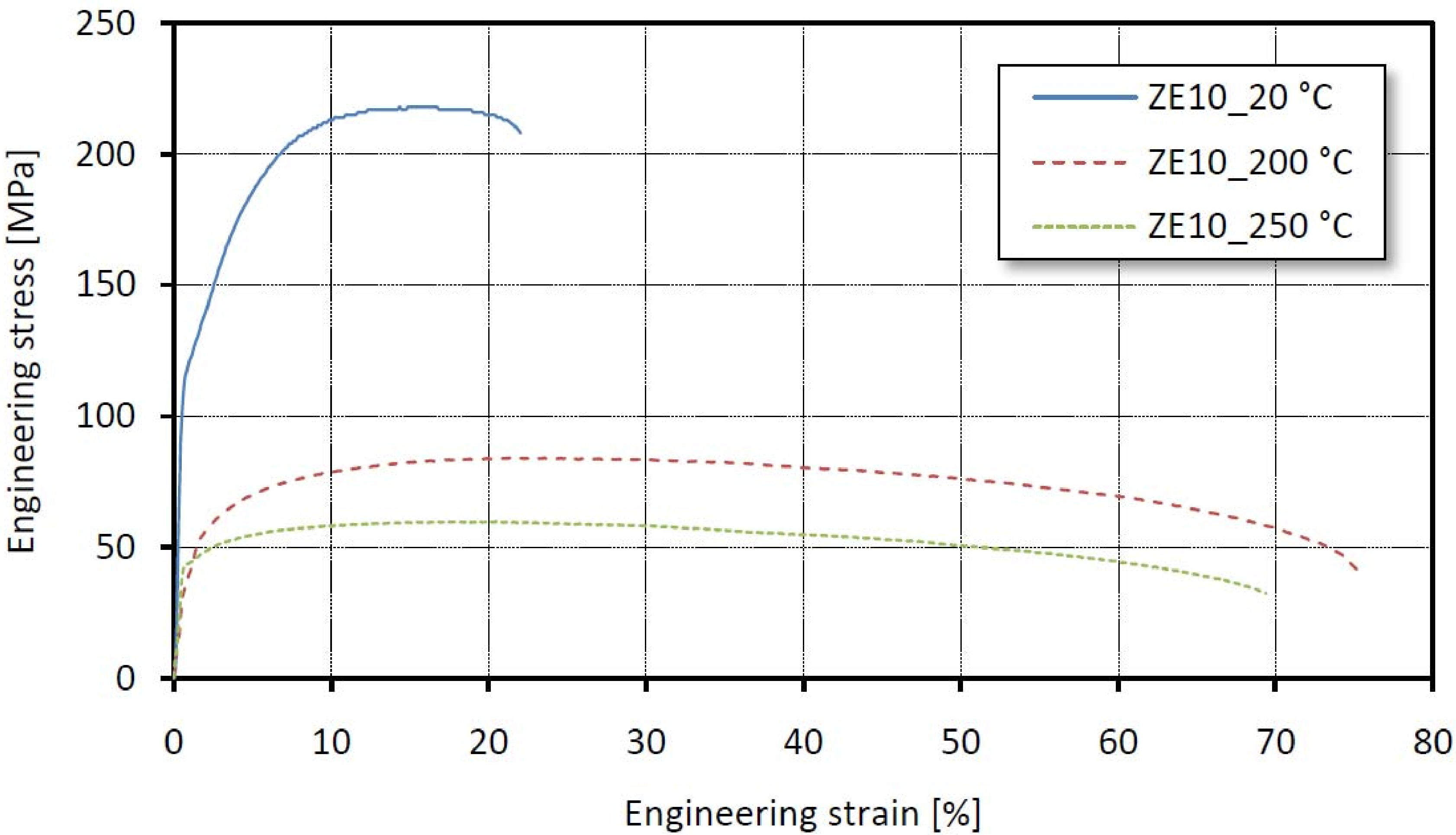
Details of placement of heaters, thermocouples and draw-beads



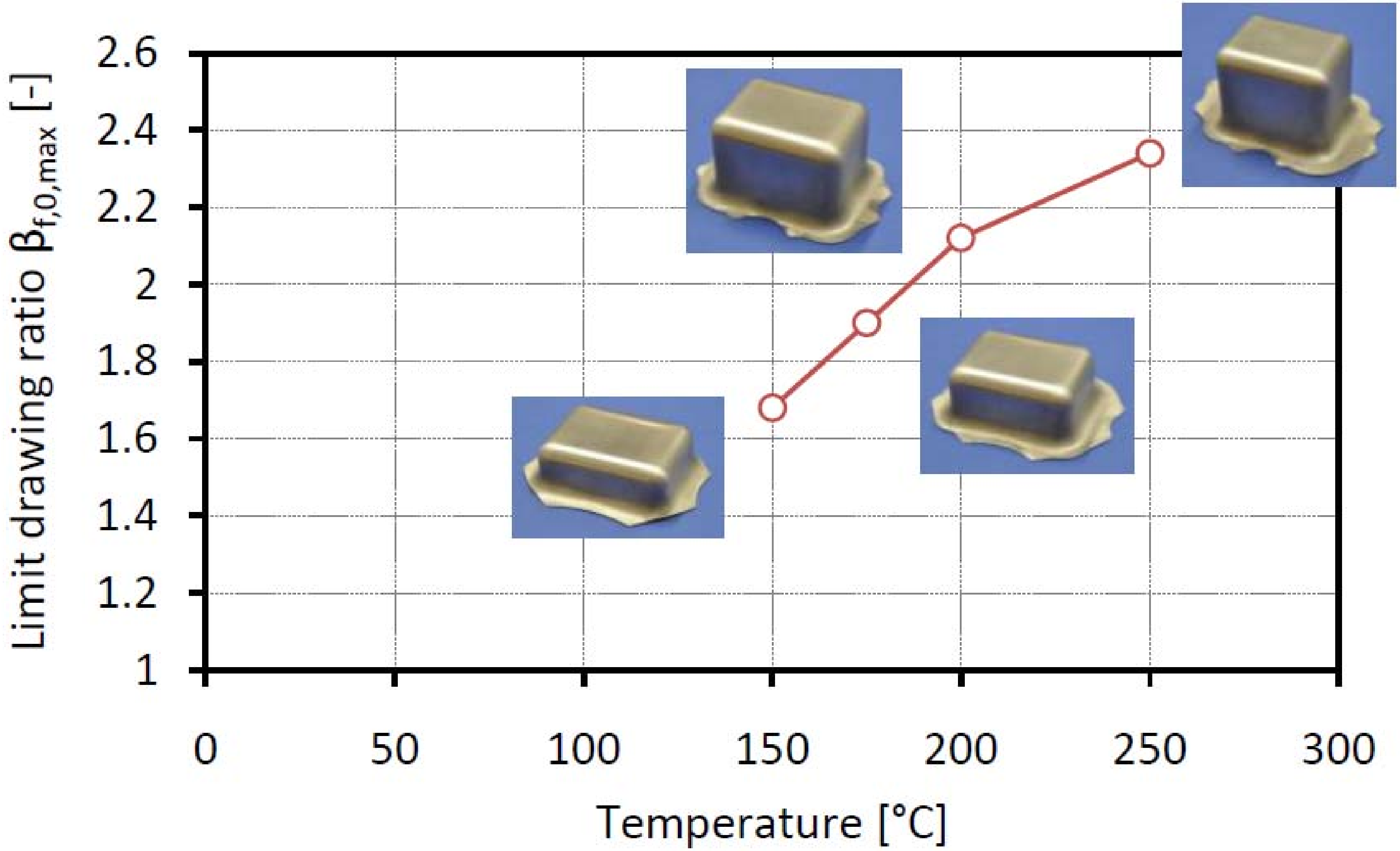
Tool assembled inside press



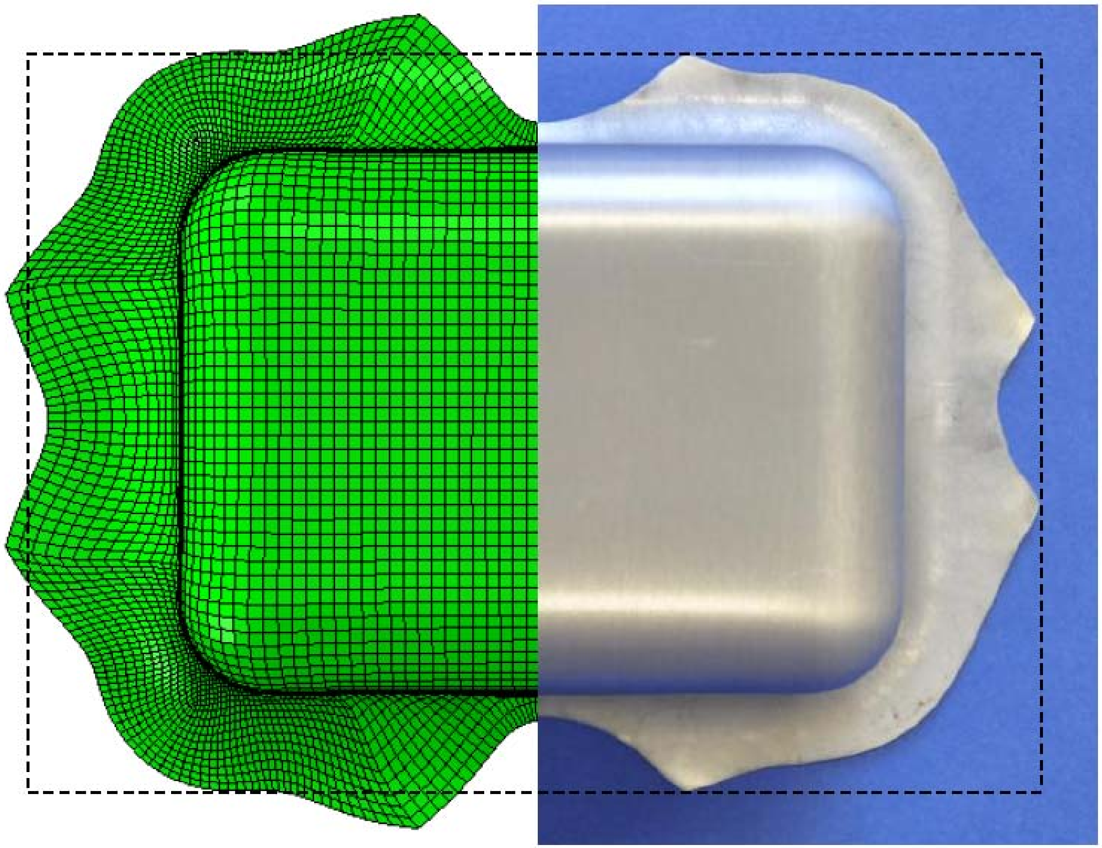
Stress-Strain curve of ZE 10 at elevated temperatures



Limit drawing ratios



Comparison of FEA model with experiment



AUT UNIVERSITY ENGINEERING

Future work

Investigation of draw-beads

Investigation of higher temperatures

Improvements of simulation model

Metallographic analysis

Investigation of other Mg alloys

AUT UNIVERSITY ENGINEERING

Materials for Landing Gears
(transition from steels to titanium)

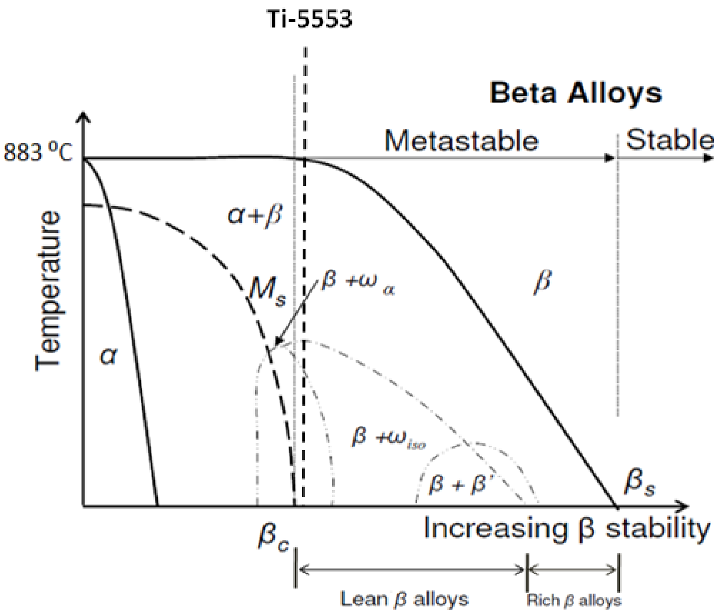
- *Boeing 747: 4340M high strength steels*

- Boeing 777: Ti-10V-2Fe-3Al

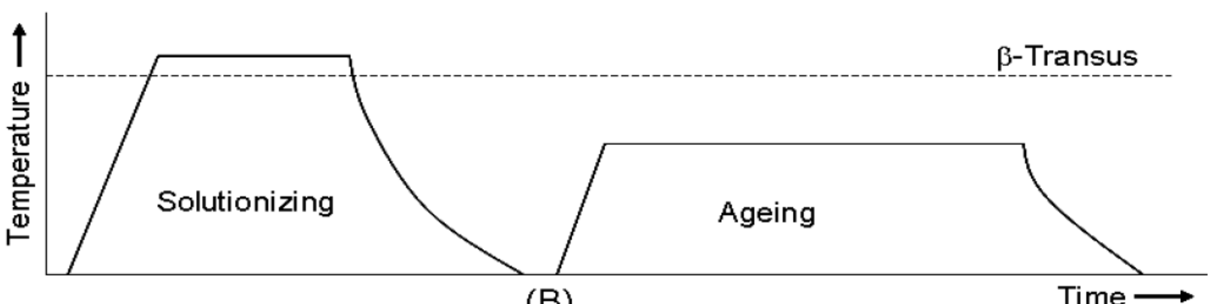
- Boeing 787: Ti-5Al-5V-5Mo-3Cr

Machining of Ti 5553

Phase Transformation during Heat Treatment of Ti-5553 Landing Gear Components



- Beta transus around 880°C
- Ageing quenched Ti-5553 at 350 °C, phase transformation occurred and ω phase formed
- ω phase
  - Brittle
  - Reduce fatigue life
  - Hardness (500HB, hard to machine)
- Elimination of ω phase to improve Ti-5553 machinability

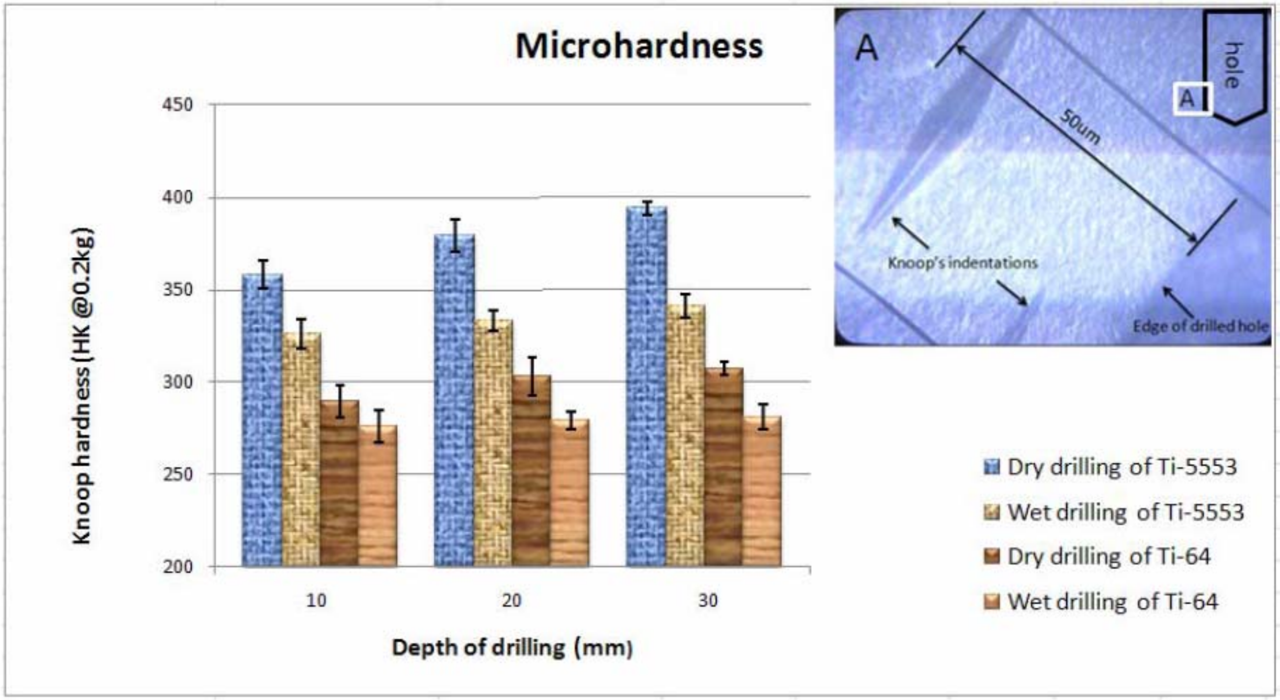


(B)

AUT UNIVERSITY ENGINEERING

Micro-hardness alteration

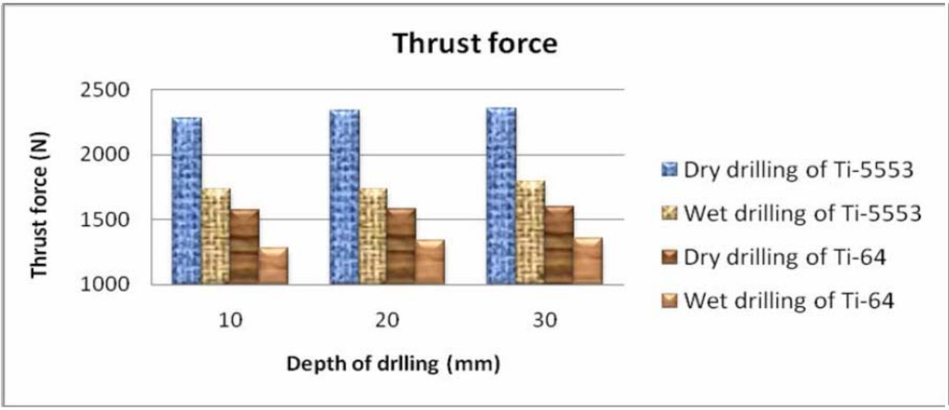
- Hardness measured at a distance about 50μm from edge of drilled hole (original is 320 and 273 HK for Ti-5553 and Ti-64)

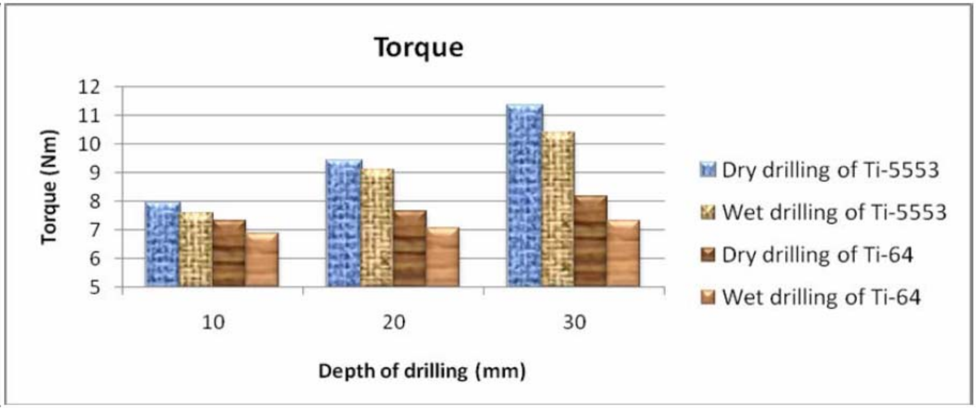


- Hardness increase as drilling depth increase, higher hardness in dry than wet drilling
- Max. 15% of increase between dry and wet drilling of Ti-5553 at depth of 30mm
- Max. 10% of increase between depth of 10 and 30mm during dry drilling Ti-5553
- Max. 394HK obtained during dry drilling of Ti-5553, 23% greater than before drilling
- Higher temp. at deeper depth of drilling, phases change results in alteration of hardness

Analysis of experimental cutting force and torque

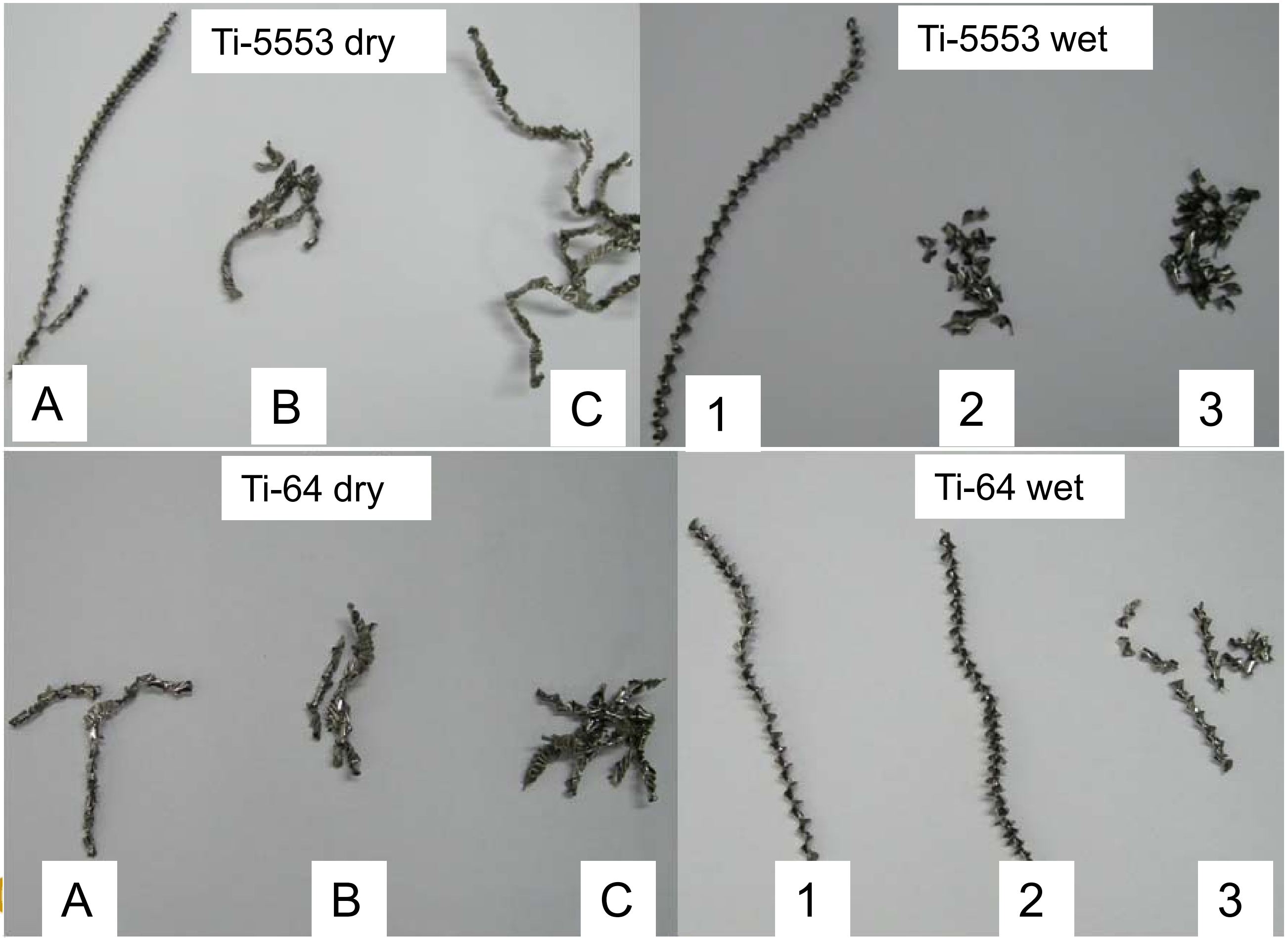
- Comparing dry and wet drilling, thrust forces increase 34% and 23%, torque increase 10% and 11% for Ti-5553 and Ti-64 respectively
- In dry drilling, high cutting temp. leads to harder subsurface layer formed as a result of phase transformation
- Ti-5553 produced a higher thrust force and torque than Ti-64 in all drilling tests
- Comparing drilling of Ti-5553 and Ti-64, thrust forces increase 45% and 30%, torque increase 27% and 20% for dry and wet drilling respectively
- Results are closely associated with mechanical properties of alloys (higher hardness for Ti-5553 than Ti-64)
- Effect of depth of drilling on variation of thrust force is insignificant





Chip morphology analysis

- Overall continuous chip with three regions initial spiral cone, steady -state spiral cone (from contact to full engagement of cutting edge) and folded long ribbon (deeper drilling increase resistance to eject chip) was found
- Continuous chip obtained in dry drilling of Ti-5553, discontinuous chip produced under wet drilling of Ti-5553



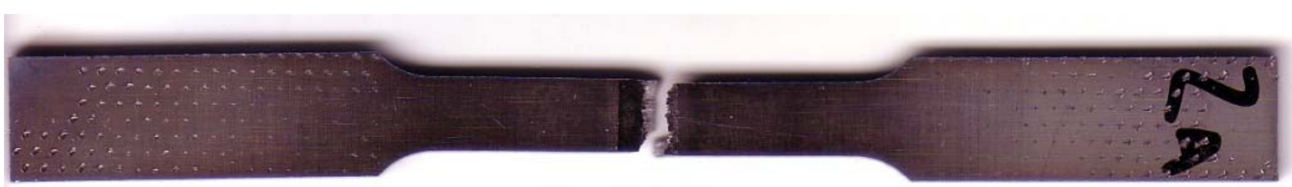
ELECTRON BEAM WELDING OF Ti

Welding combinations:

CPTi/CPTi
Ti64/Ti64
Ti5553/Ti5553 → Similar Titanium

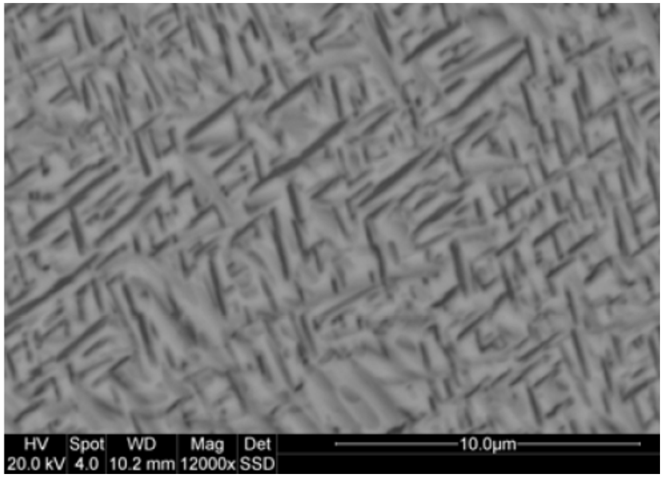
CPTi/Ti64
CPTi/Ti5553
Ti64/Ti5553 → Dissimilar Titanium

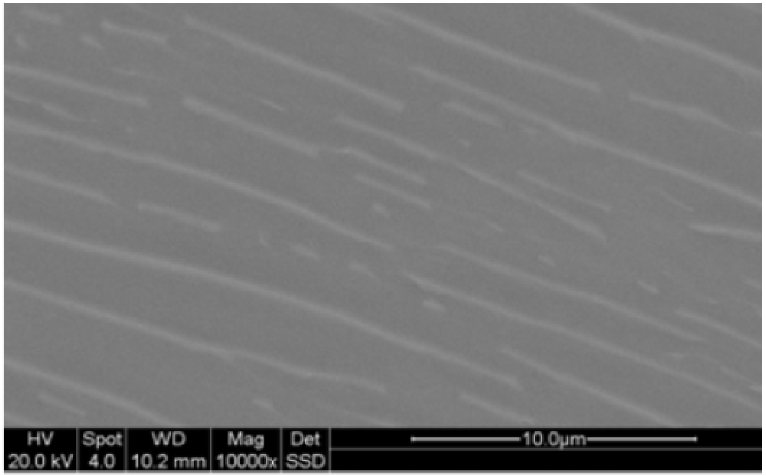
2 mm thick



Initial characterization of Ti5553 and Ti64

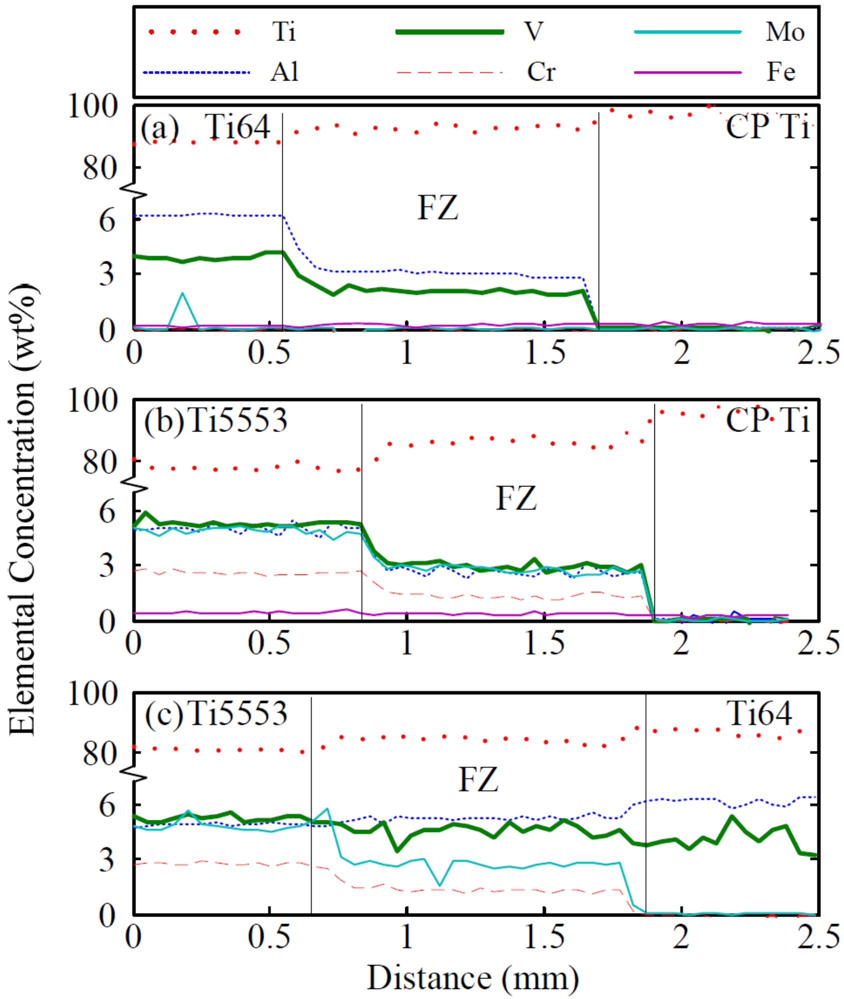
	Ti5553	Ti64
Strength	1100 MPa	850 MPa
Hardness	310 Hv	260 Hv





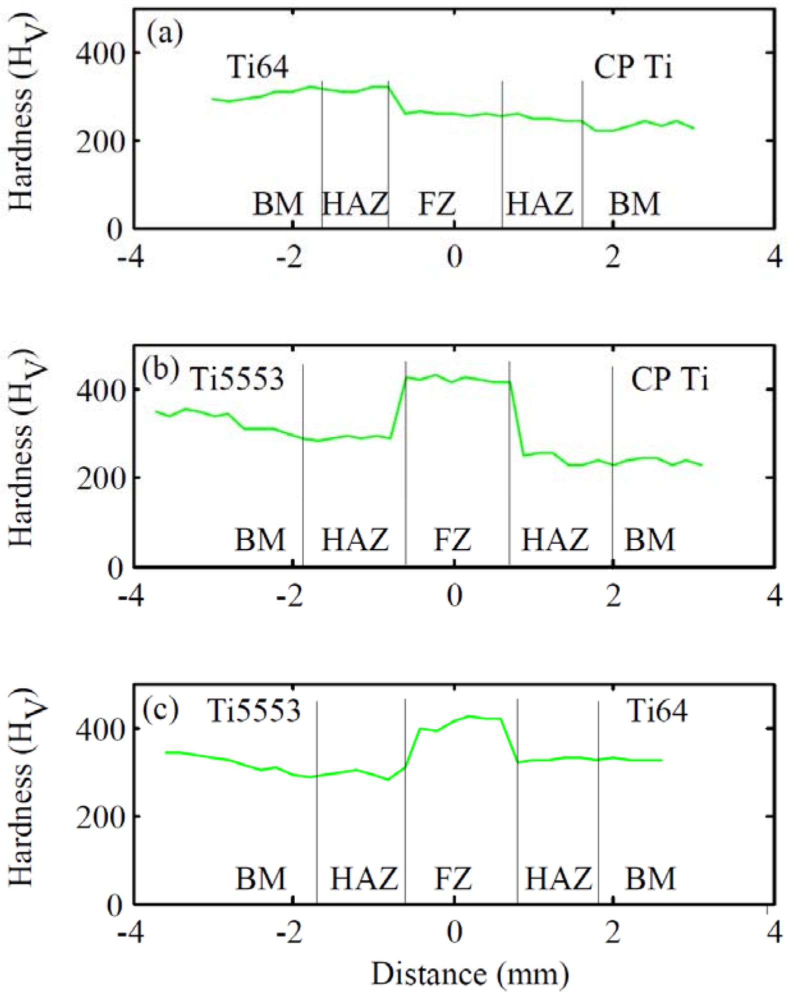
AUT UNIVERSITY ENGINEERING

Chemical Composition across Weld

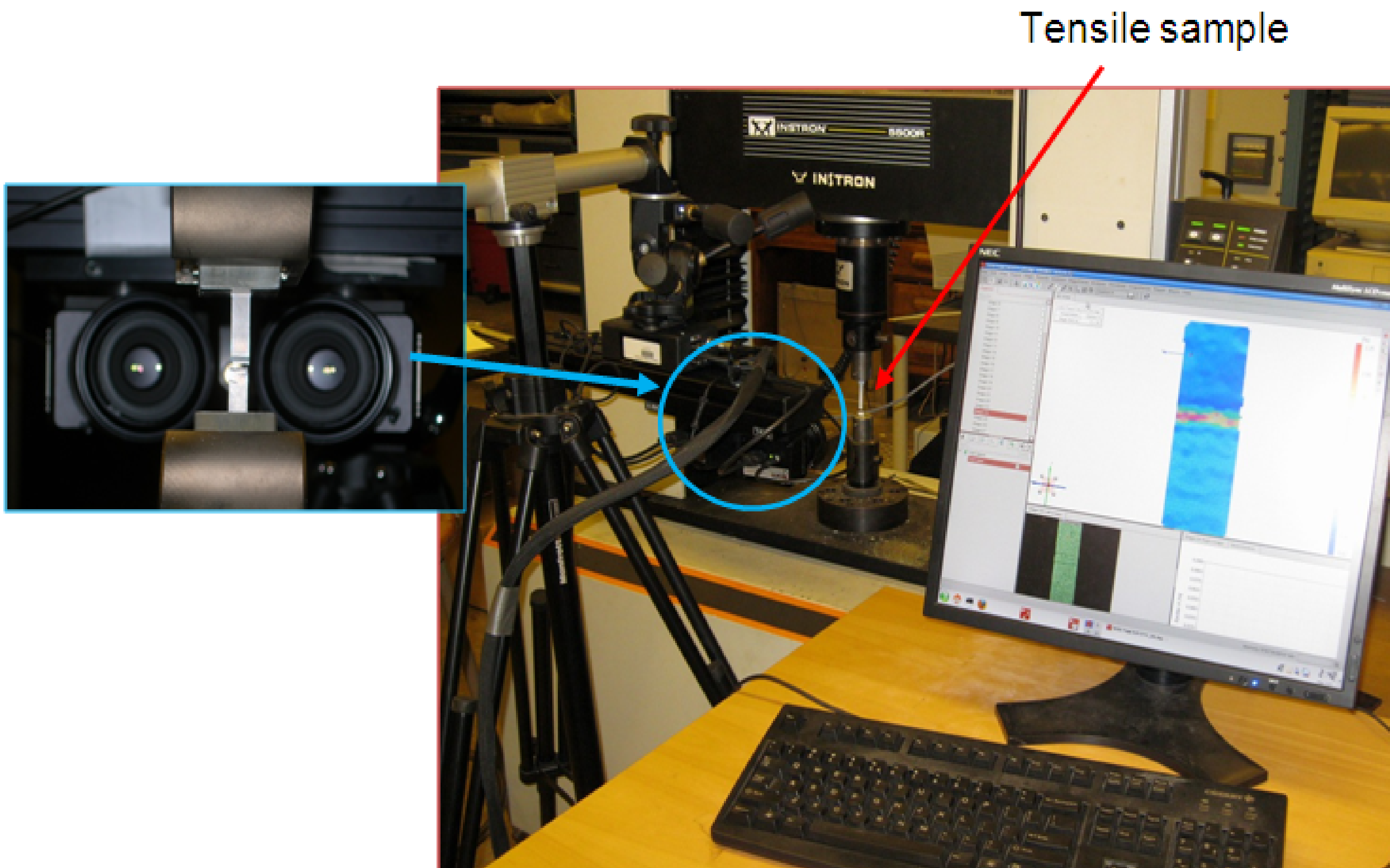


AUT UNIVERSITY ENGINEERING

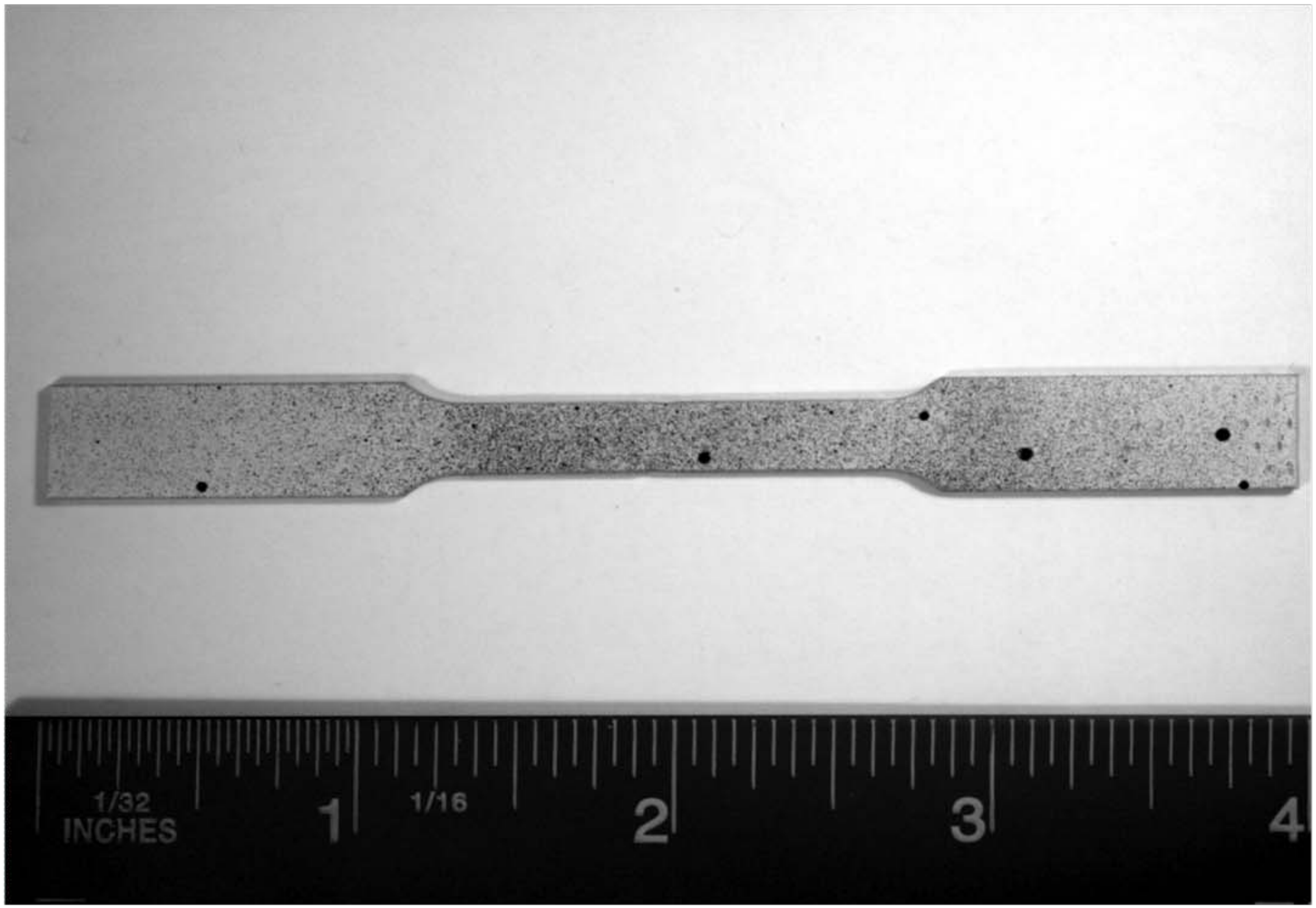
Hardness Distribution across Weld



Tensile Testing using Aramis System



Sample Preparation



AUT UNIVERSITY ENGINEERING

Preliminary Tensile Test Data

Welding Combination	UTS or premature Fracture Strength (MPa)	Yield Strength (MPa)	Total Elongation at Fracture (%)	Localized Deformation in the Vicinity of the weld (%)	Fracture Location ***
CP Ti/CP Ti	552	430	35.9	21.0	BM – CP Ti
CP Ti/Ti64	505	400	26.3	1.5	BM – CP Ti
CP Ti/Ti5553	505*	400	17.5**	1.8	WZ
Ti64/Ti64	796*	740	15.0	10.2	WZ
Ti64/Ti5553	744*	715	12.0	10.1	WZ
Ti5553/Ti5553	678*	N/A	10.5	4.2	WZ

* Indicates premature fracture before necking
** Indicates adjustment of strain due to grip settling
*** WZ = weld zone; BM =base metal

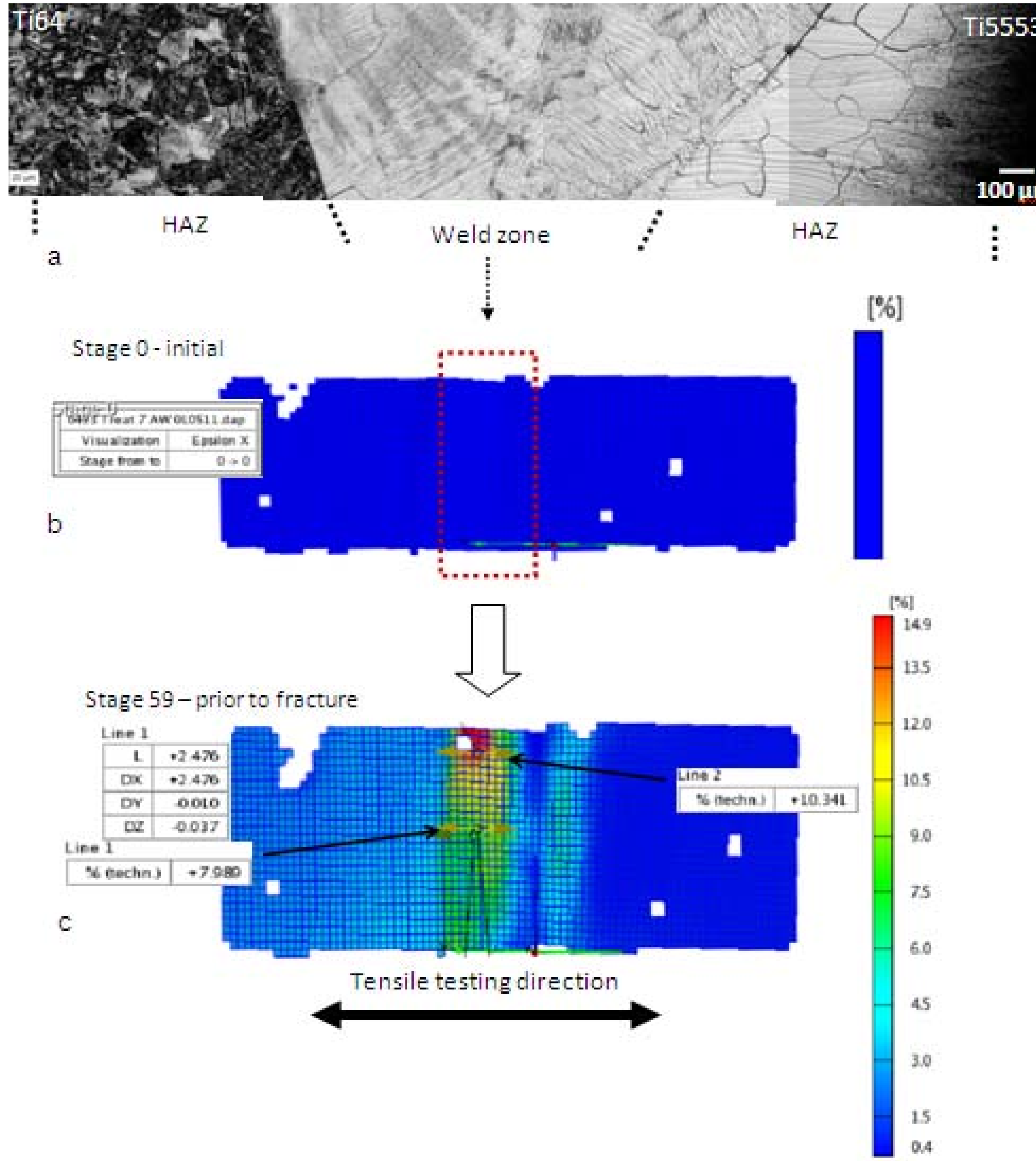
AUT UNIVERSITY ENGINEERING

Tensile Testing and Characterization

a) Weld profile

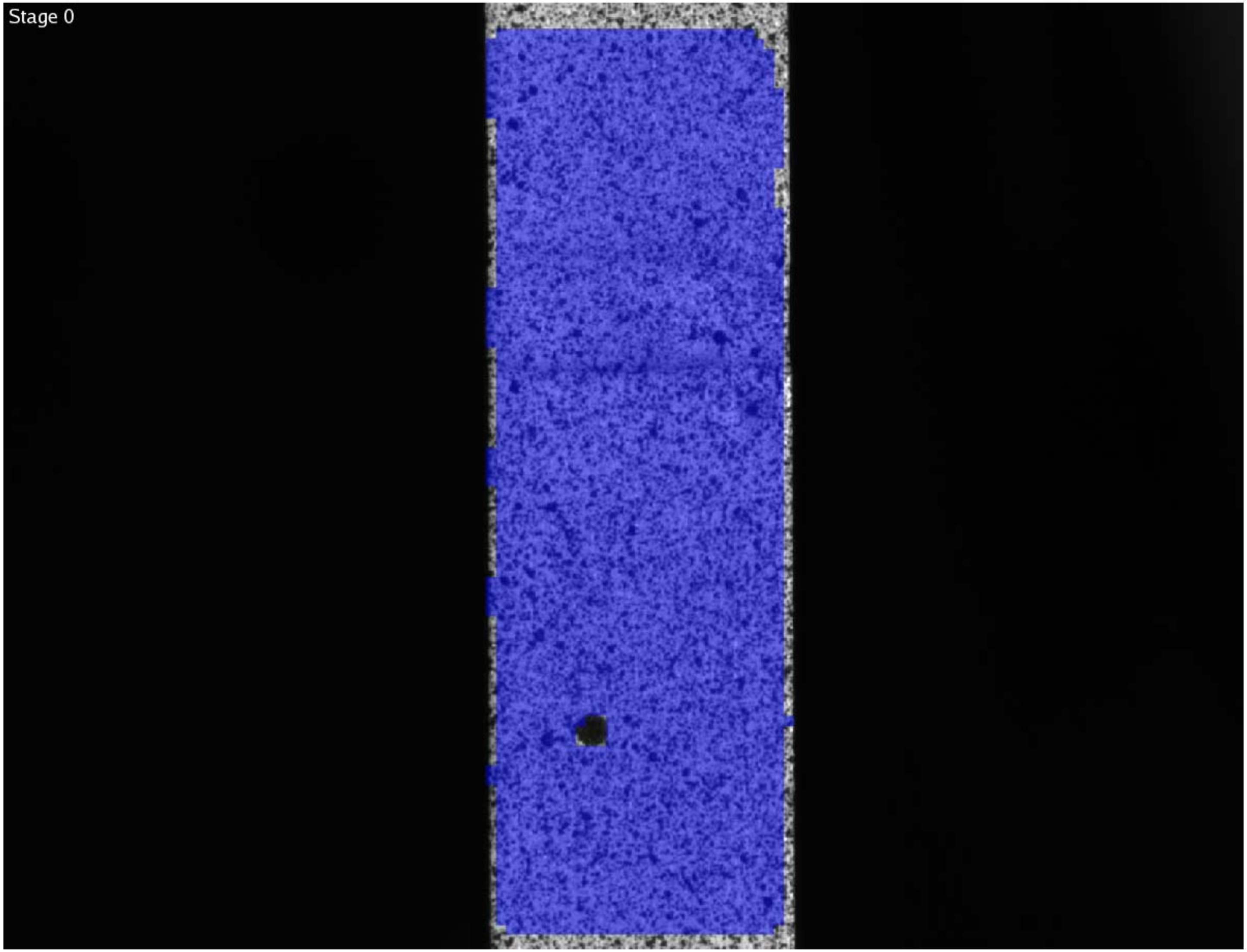
b) Initial stage before sample is tested

c) Highly localized strain in the weld zone



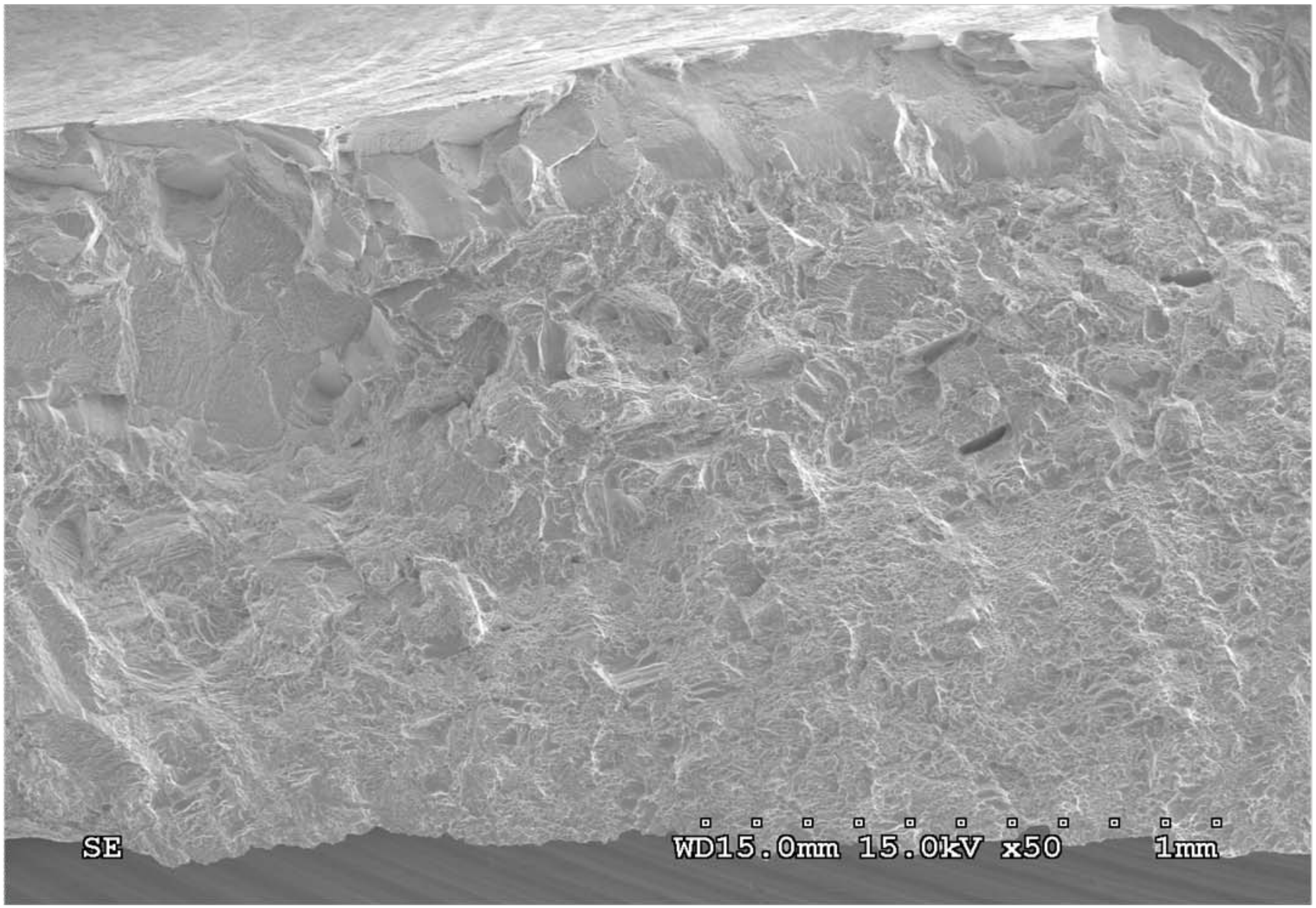
AUT UNIVERSITY ENGINEERING

Aramis Results Ti53/Ti53



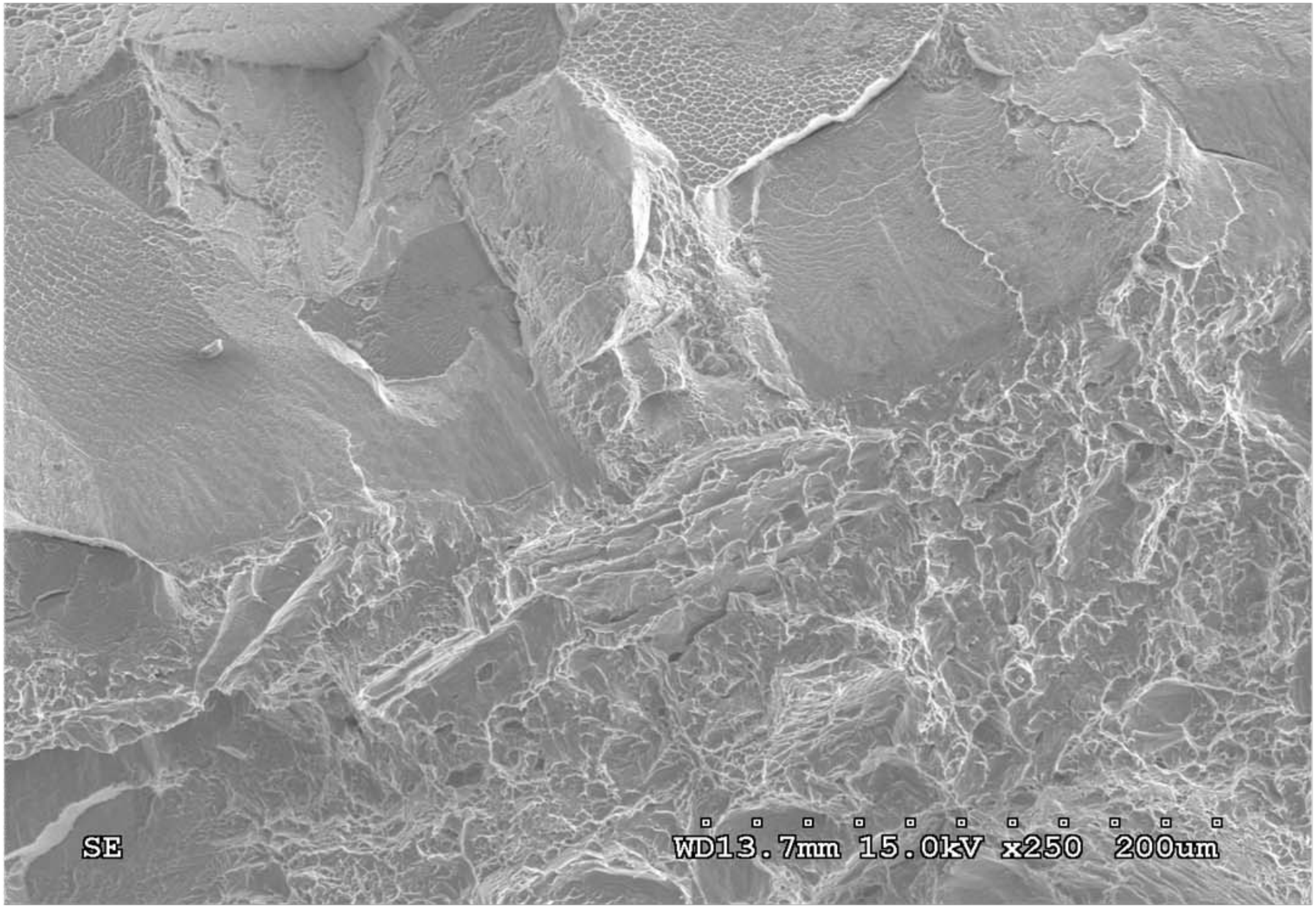
AUT UNIVERSITY ENGINEERING

Fracture Surface Ti64/Ti53

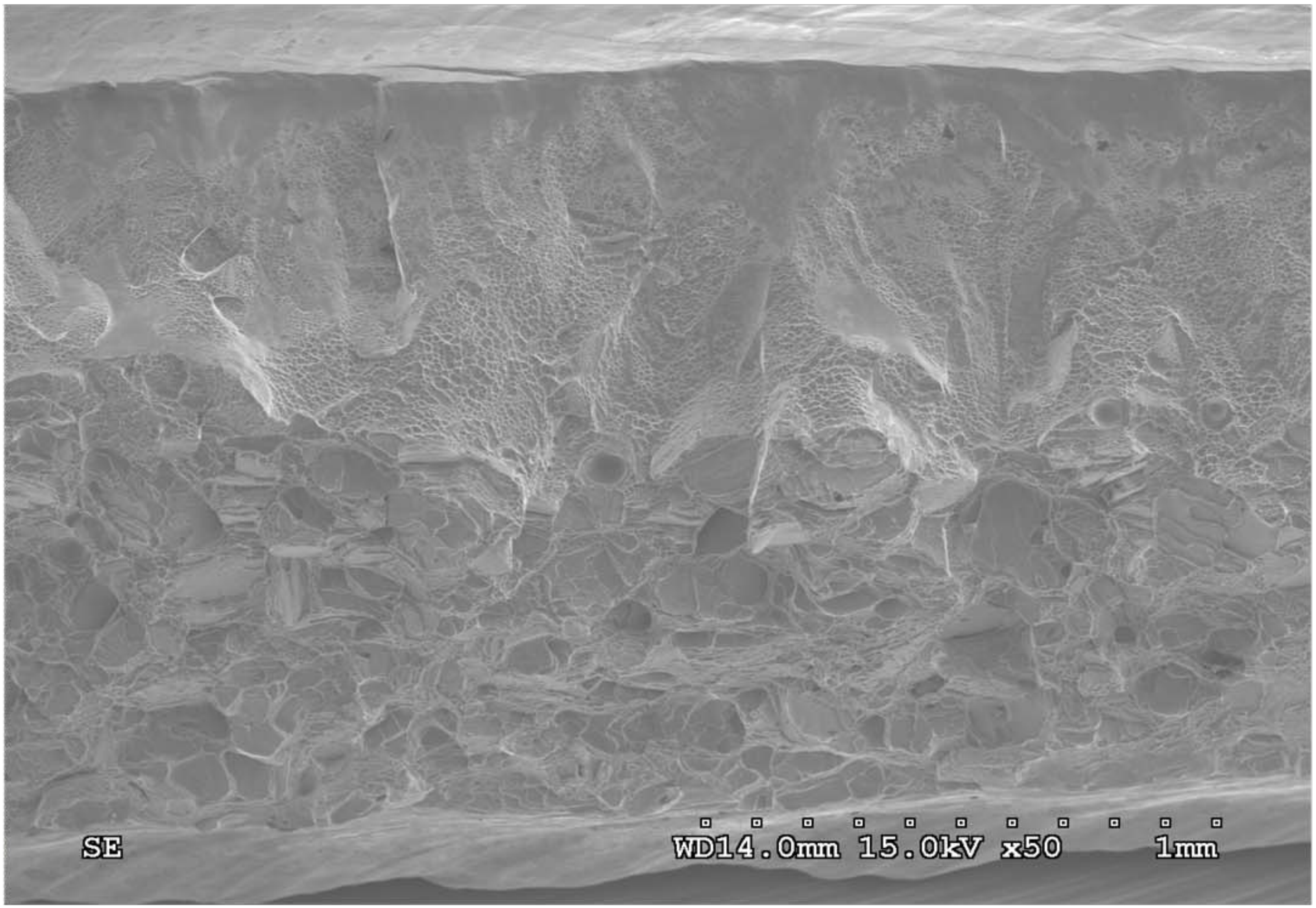


AUT UNIVERSITY ENGINEERING

Ti64/Ti53



Ti CP / Ti 53



AUT UNIVERSITY ENGINEERING

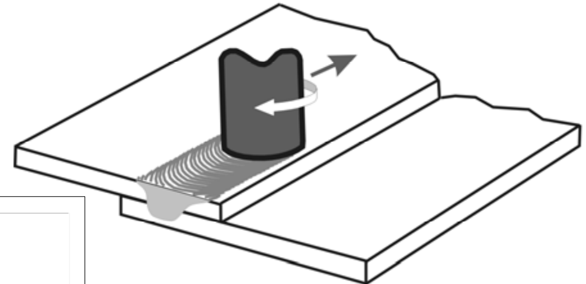
Summary

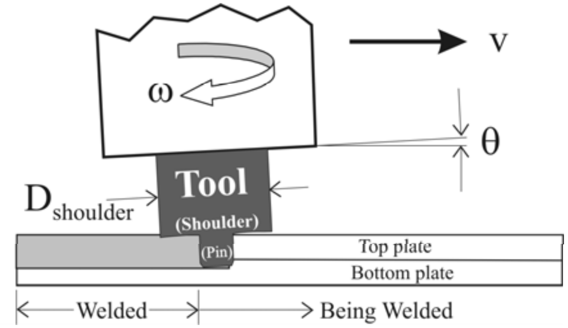
Based on our preliminary investigations we have formulated the following conclusions:

- Noticeable ductility within weld reaching up to around 10% was possible to be measured with the Aramis system
- Comparison between total and local elongation shows a high degree of complexity in the deformation pattern
- Additional testing and analysis are needed and are underway

AUT UNIVERSITY ENGINEERING

Friction Stir Lap Welding





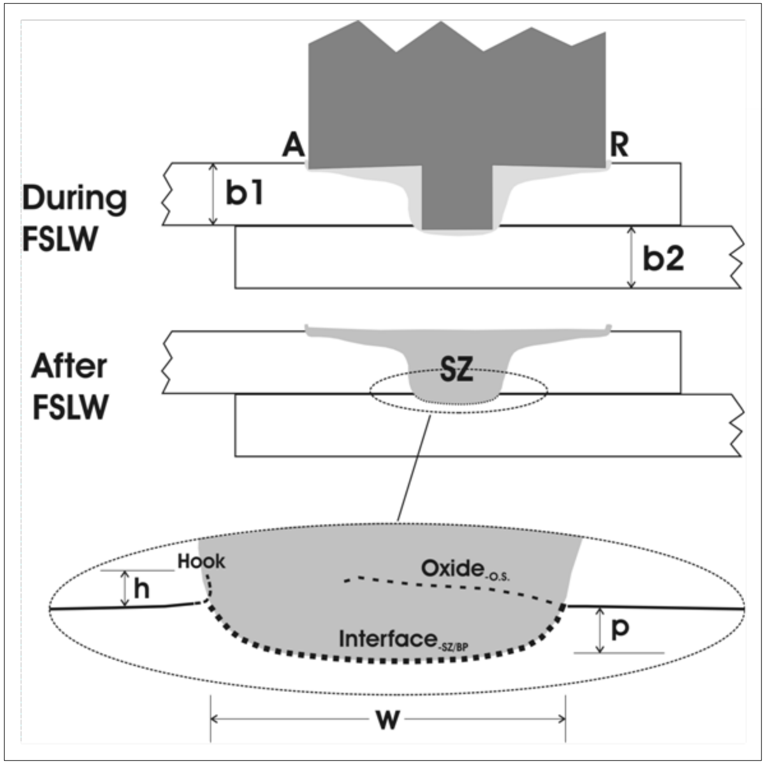
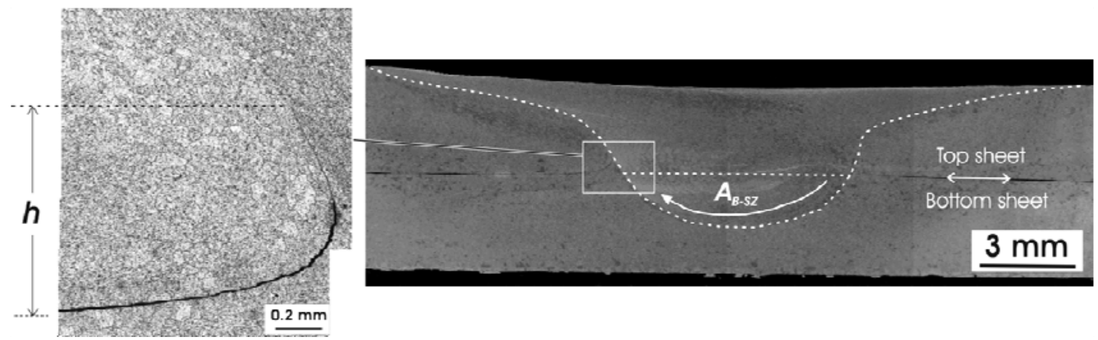


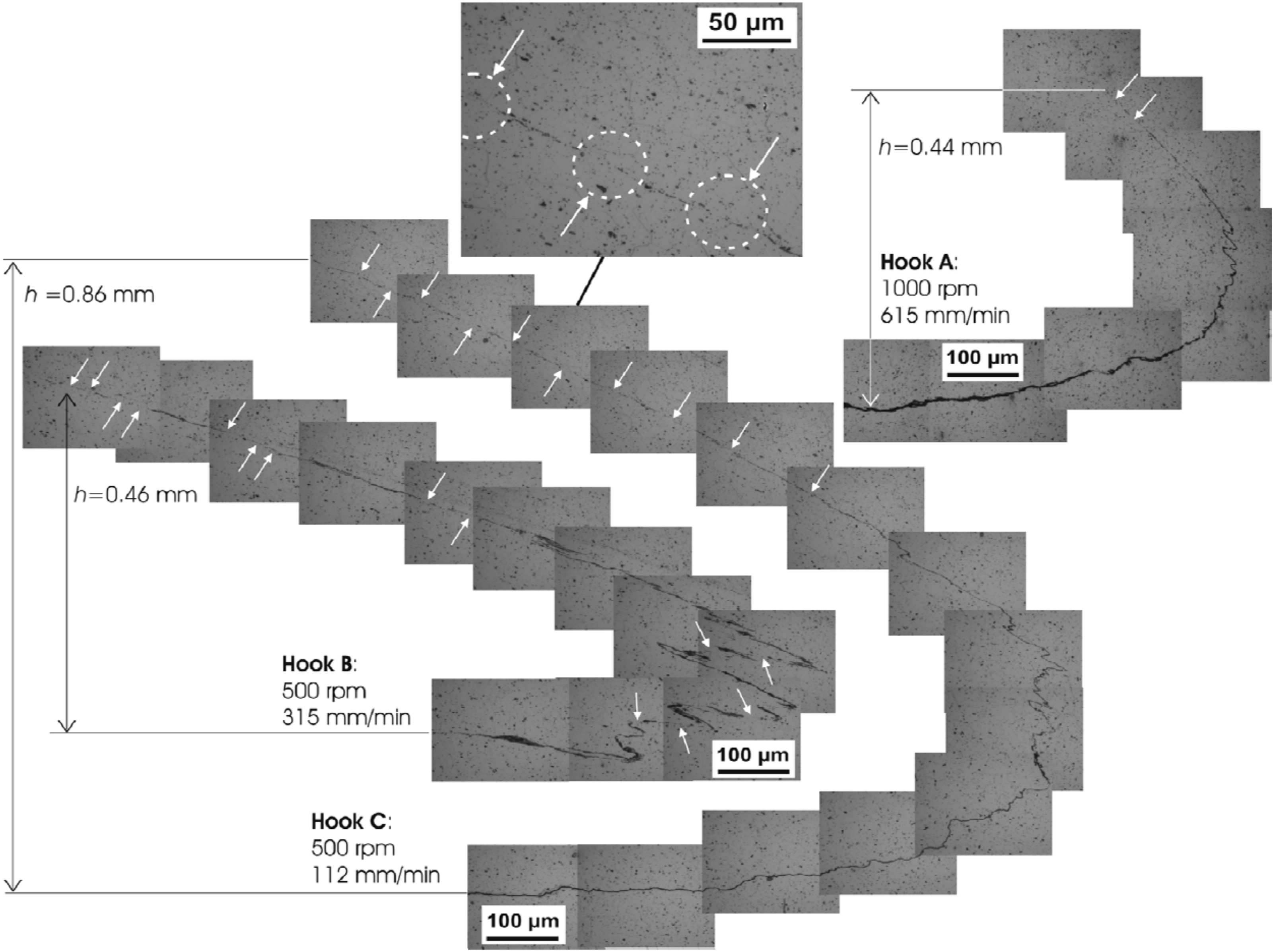
Illustration of the macro/micro-features affecting mechanical properties



Cross-sectional view of a Al6060T5 FSLap weld made using ω = 1,000 rpm and v = 224 mm/min showing hooking on the advancing side and next to the stir zone as outlined with the flow direction in the stir zone during FS indicated

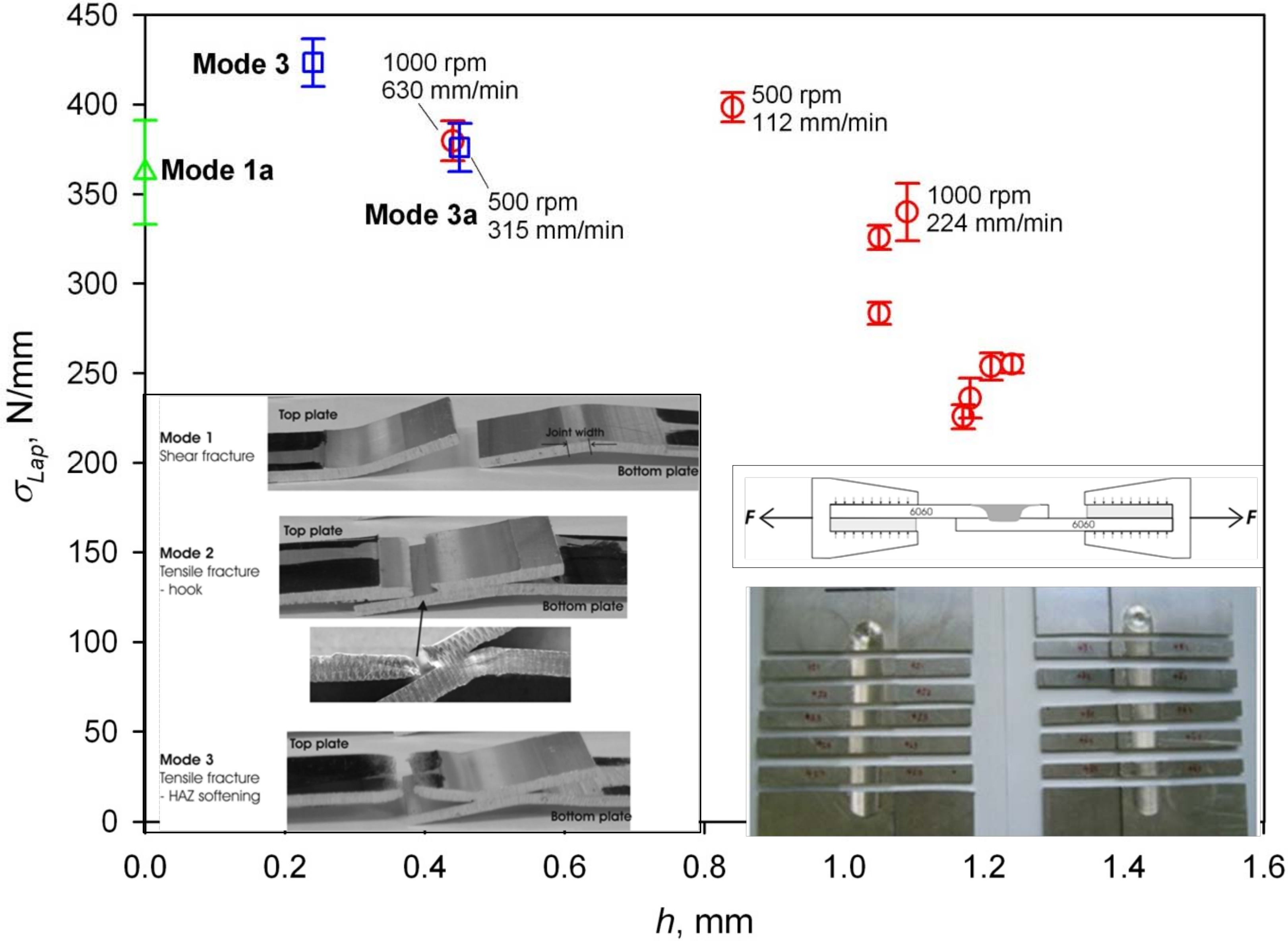
We are studying how *v*, ω & L_{pin} affect the temperature field, flow mode and volume, interfacial reaction ….. and the subsequent fracture strength

AUT UNIVERSITY ENGINEERING



Cross sectional views of FSLap welds (A6060-T5): three hooks of welds made with various ω and v values. The small arrows point to locations of hook discontinuity.

AUT UNIVERSITY ENGINEERING

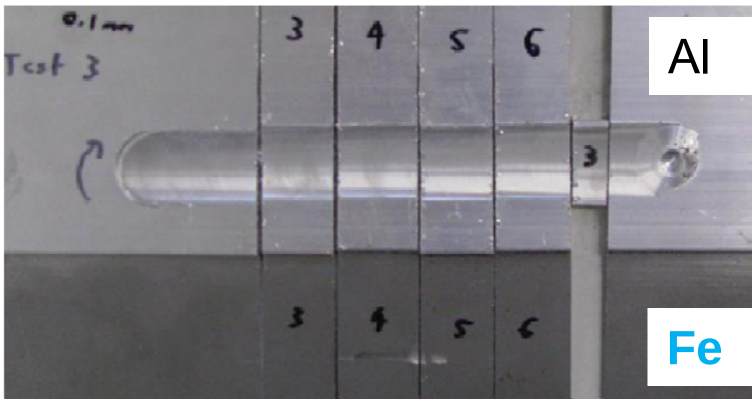


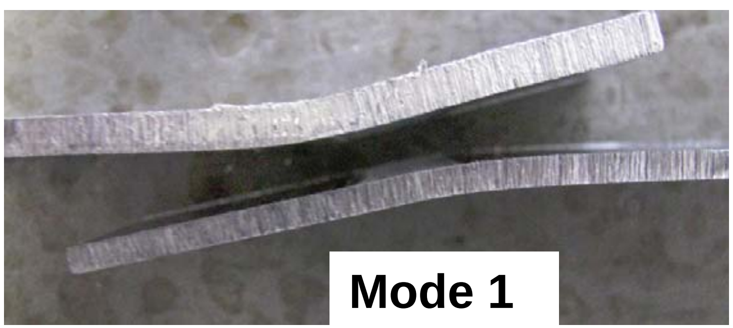
- (Not shown) The equivalent max σ_{BoP} for bead-on-plate ≈ 410 N/mm
- When $h < h_{Critial} \approx 0.9$ (~ 30% of plate thickness) other factors compete for location deformation & fracture to lower σ_{Lap}, but σ_{Lap} is close to σ_{BoP}

- Dissimilar alloys with a large difference in melting point ($\Delta T_{Melting}$) – difficult to fusion weld
- Al to steel lap joints – applied in automotive industry
- Al to Ti alloy lap joints, if weldable, large potential in aerospace industry
- FS (diffusion) lap welding of dissimilar alloys with large $\Delta T_{Melting}$, h = 0

Al6060T5 to Mild Steel FSLW

ω = 1,000 rpm, v = 50-85 mm/min



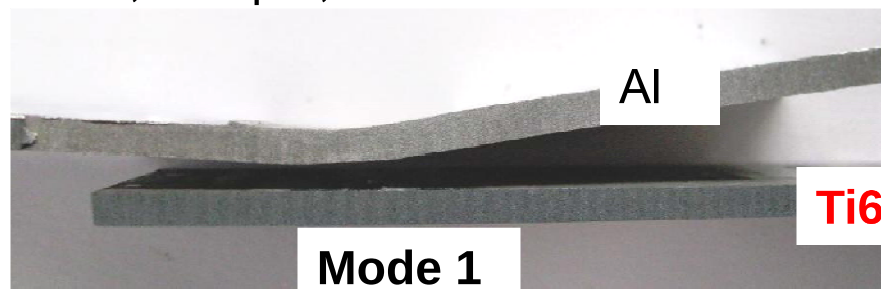


σ_{Lap}= **145-228** N/mm

Brittle interfacial intermetallics thus low σ_{Lap}

Al6060T5 to Ti-6Al-4V FSLW

ω = 1,000 rpm, v = 85 mm/min



σ_{Lap}= **398** N/mm, close to max σ_{Lap} (Al6060-Al6060)

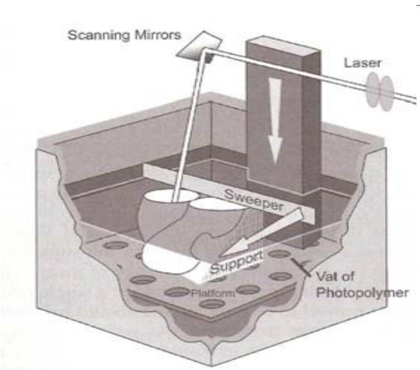
Strong interface, thus high σ_{Lap}

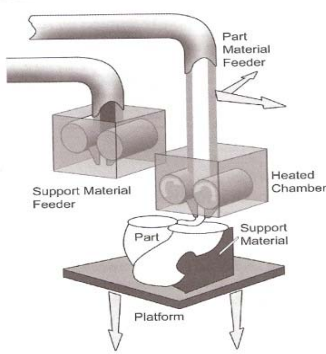
σ_{Lap}= **394** N/mm, close to max σ_{Lap} (Al6060-Al6060)

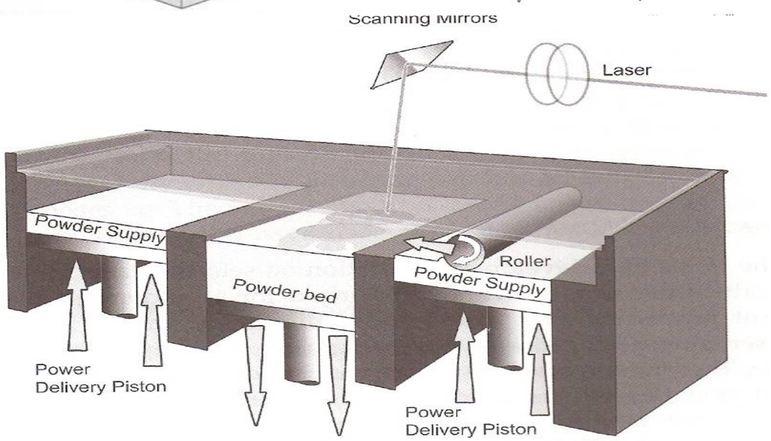
Strong interface thus mode 3 & high σ_{Lap}

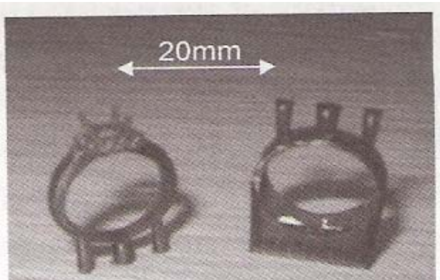
FS (diffusion) lap welding Al to Ti alloys – weldable!

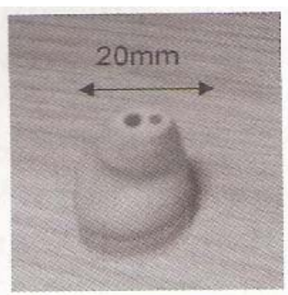
RAPID PROTOTYPING AND CASTING

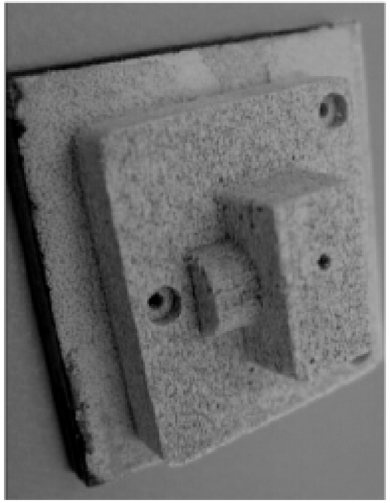


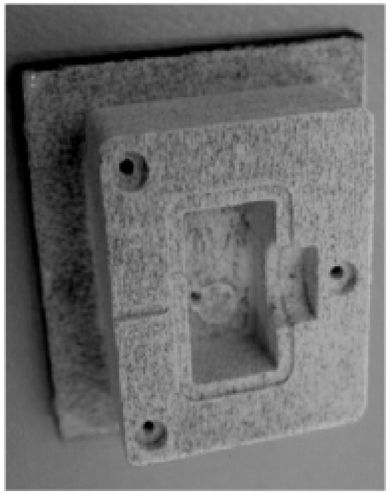






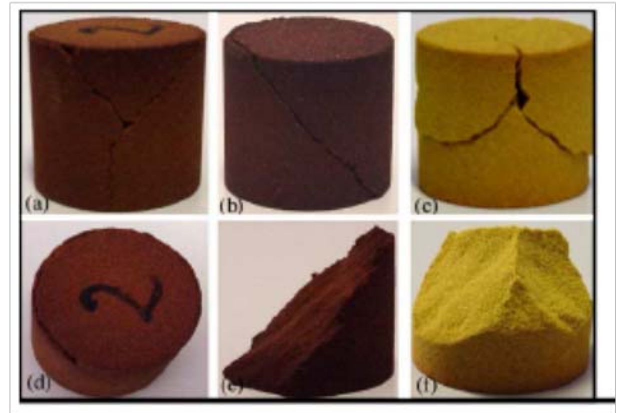


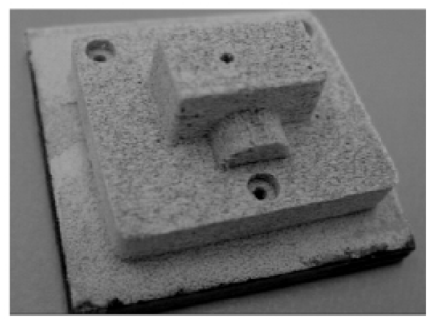


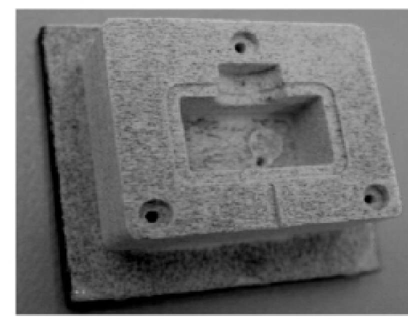


Rapid Casting

Direct Production of sand moulds using SLS

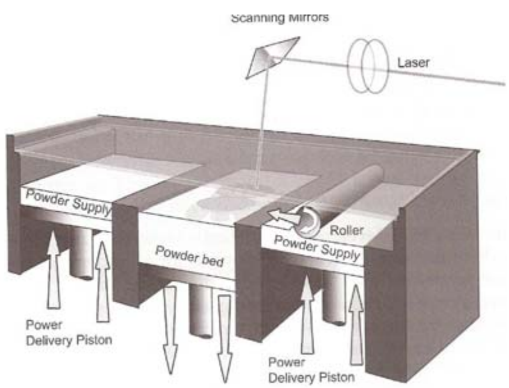


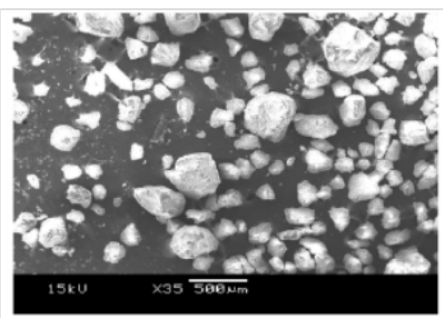


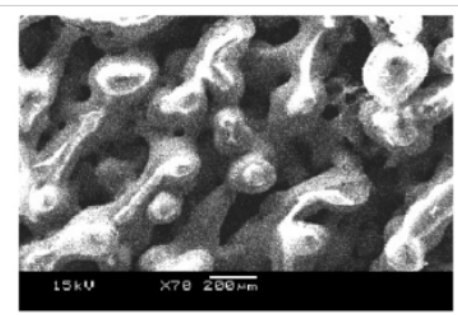


Two Approaches

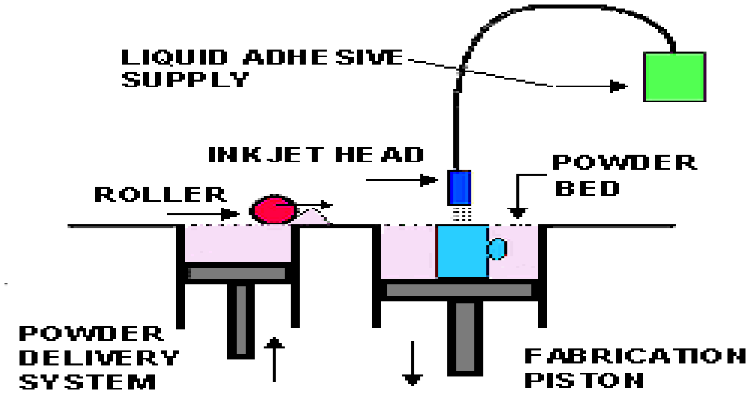
- Laser treating of polymer coated sand particles
- Direct melting and fusing of sand particles



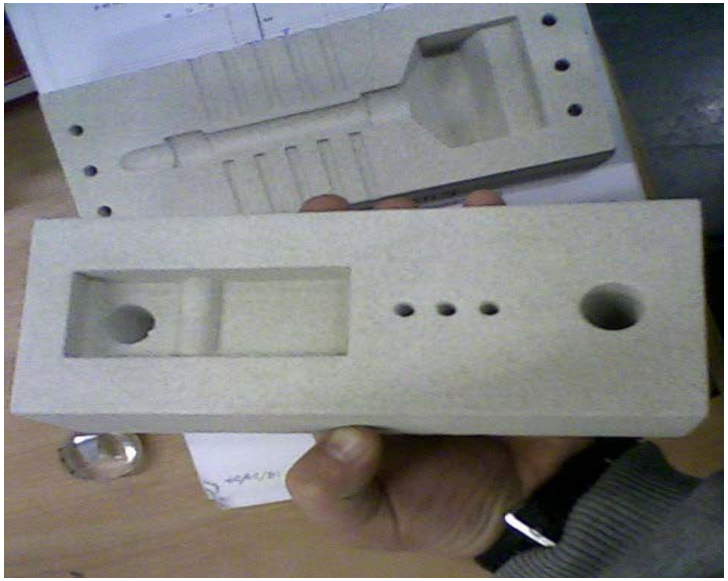




3D PRINTING FOR CASTING



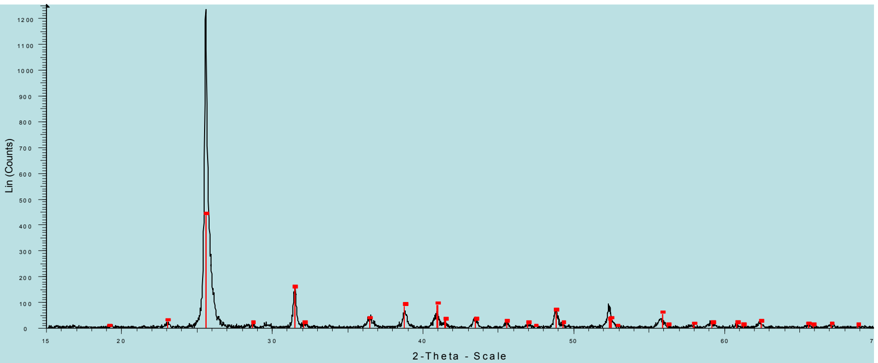
- Direct printing of sand moulds from CAD files
- Pattern-less moulding
- Unlimited freedom, short lead times



Rapid Prototyping and Manufacturing

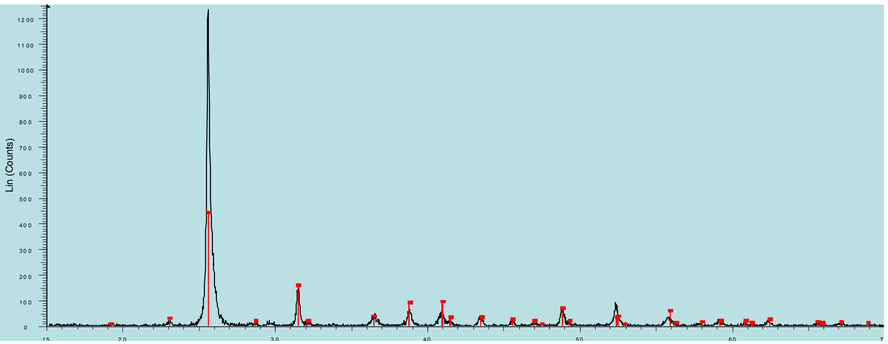
3D PRINTING FOR CASTING

ZP 131

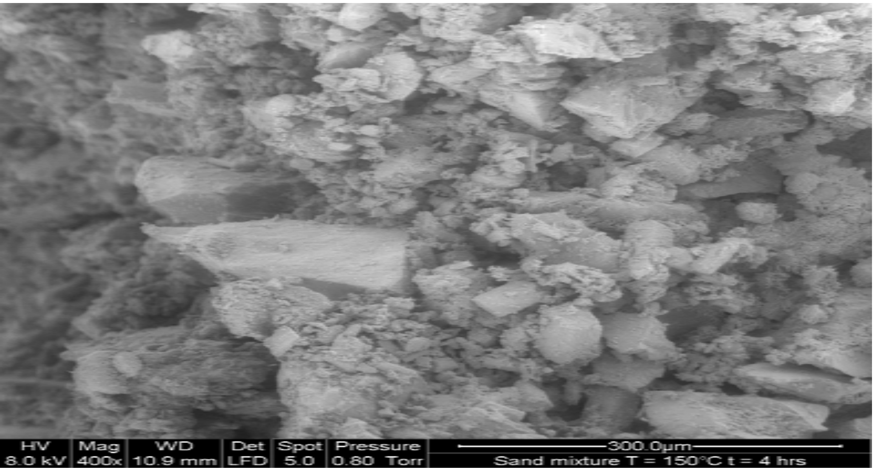


$CaSO_4 \cdot 0.67H_2O$
Calcium Sulphate Hemihydrate

ZCAST 501



$CaSO_4 \cdot 0.67H_2O$ (50 wt. %)
$MgSiO_4$ (50 wt. %)



Both materials yield similar compressive strength and permeability values

ZP131 gives better surface quality part definition

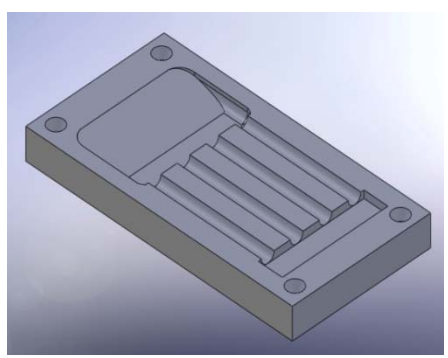
Rapid Prototyping and Manufacturing

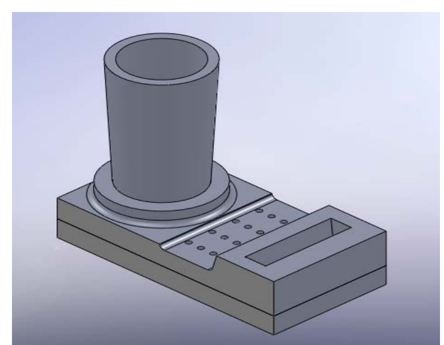
CASTING IN 3D PRINTED MOULDS

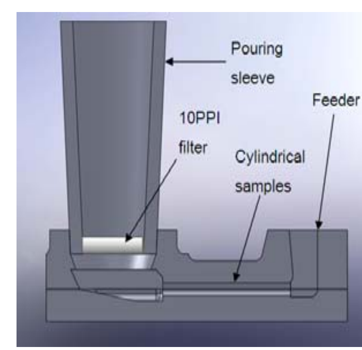
Experimental Factors

- Mould material
- Mould coating
- Alloy type
- Pouring temperature

	Factors			
	Mould material	Mould coating	Pouring temperature	Alloy
Level 1	ZP131	Isomol 200 (graphite based)	690°C	Mg : AZ91HP
Level 2	ZCast501	Zircoat W (Zirconium Silicate based)	730°C	Mg: AM-SC1
Level 3	Resin bonded Silica sand	Magcoat S (Magnesium Oxide based)	770°C	Al: A356







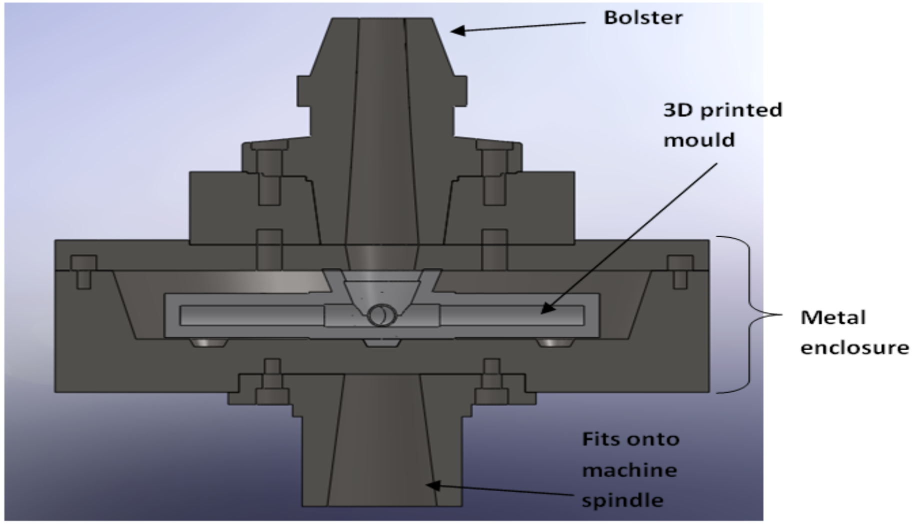
TAGUCHI L9 EXPERIMENTAL DESIGN

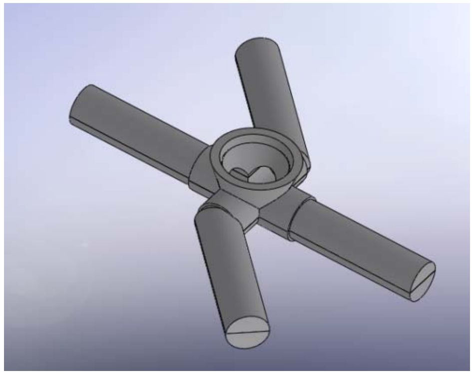
Trial	Mould	Coating	Alloy type	Temp (°C)
1	ZP131	ISOMOL	AZ91HP	690
2	ZP131	ZIRCOAT	SC1	730
3	ZP131	MAGCOAT	A356	770
4	ZCAST	ISOMOL	SC1	770
5	ZCAST	ZIRCOAT	A356	690
6	ZCAST	MAGCOAT	AZ91HP	730
7	SILICA	ISOMOL	A356	730
8	SILICA	ZIRCOAT	AZ91HP	770
9	SILICA	MAGCOAT	SC1	690

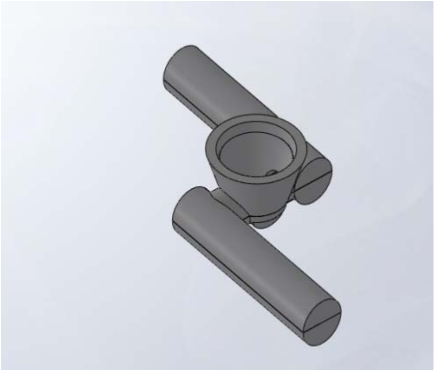
OVERALL RANKING OF RESULTS

	Factors			
Response	Mould material	Mould coating	Alloy type	Pouring temp.
UTS	(ZP131) :4th	(Magcoat):3rd	(AZ91HP):1st	(690°):2nd
Strain	(ZP131):3rd	(Magcoat) :4th	SC1: 99.99%:1st	690°C:90%:2nd
Ra	ZP131:95%: 1st	(Magcoat) :2nd	(A356):3rd	(690°C):4th
HB	(ZCast501):2nd	(Zircoat):3rd	A356: 90%:1st	(690°):4th

CENTRIFUGAL CASTING USING RP MOULDS







CENTRIFUGAL CASTING USING RP MOULDS

Complex Shapes

Experimental analysis of centrifugal casting

Acknowledgment

- Air New Zealand Gas and Turbine Division for performing Electron Beam Welding
- Loewy Family Foundation
- ATLSS @ Lehigh
- Andrew Thome
- Mr. Rodney Boyer from Boeing Company
- Prof. Guy Littlefair
- Dipl.-Ing. Thomas Heil
- Shamzin Yazdanian, MSc
- David Yan, ME
- Nick McKenna, ME

AUT UNIVERSITY ENGINEERING