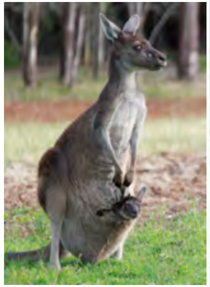

An Overview of Light Metals and Additive Manufacturing Research at Monash University

Andrey Molotnikov

Department of Materials Science and Engineering, Monash University

Contact: andrey.molotnikov@monash.edu

Monash University

- Established in 1958 ~347 students
- 2015 ~65,000 students
- 1970 Department of MSE

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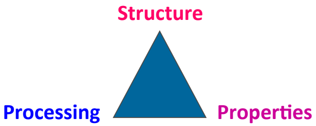
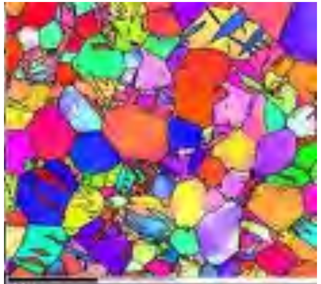
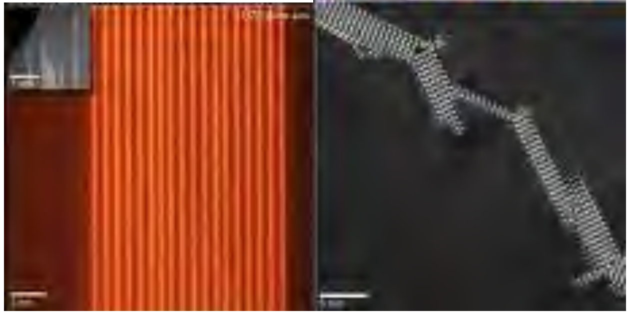
Department of Materials Science and Engineering

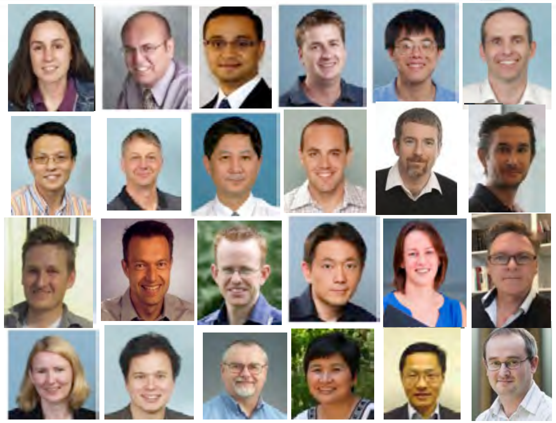
MONASH University

- Long history in light metal alloy research
- 24 academic staff, very global reach
- Strong track record of industrial delivery
    - Local
    - International
    - Defense
    - Spin offs









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SAFRAN Microturbo

TECHNOLOGY TO WIN

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woodside

BAOSTEEL-AUSTRALIA JOINT RESEARCH AND DEVELOPMENT CENTRE

SCIENCE AND INDUSTRY ENDOWMENT FUND

Department of Materials Science and Engineering, Monash University

MONASH University

- **FACILITIES**: Massive investment in world-class infrastructure unique to the region (including the Australian Synchrotron, and the Clayton Precinct…).
- **BREADTH**: Capabilities in many materials and advanced manufacturing areas (modelling, nanomaterials, alloys, biomaterials, automotive/aerospace Al, 3D printing…).
- **DEPTH**: Focused research with world-class expertise in key areas (e.g. light metals, additive manufacturing, aerospace materials, functional materials materials durability).
- **DELIVERY**: Strong track record of delivering useful results to industry (internationally).
- **COLLABORATION**: Collaborations around the world.

MC^{N} Melbourne Centre for Nanofabrication

CSIRO

Australian Synchrotron

Mg Al Ti ARC Centre of Excellence Design in Light Metals

SCIENCE AND INDUSTRY ENDOWMENT FUND

Australian Government Australian Research Council

Cooperative Research Centre for Polymers

Light metals areas of research

- Physical metallurgy
- Al, Ti, Mg
- Glasses and High entropy alloys
- Modelling
- Characterisation (structure and properties)
- Corrosion and coatings
- Fatigue
- Alloy design
- Processing

Light metals capabilities

- Induction melting, arc melting
- Extrusion, rolling, SPD (HPT, ECAP, etc)
- Spark plasma sintering
- Laser powder processing
- HIPing

Light metals alloys for dental application
Example of output

- Ti–15Zr alloy
- Institut Straumann AG, Basel, Switzerland

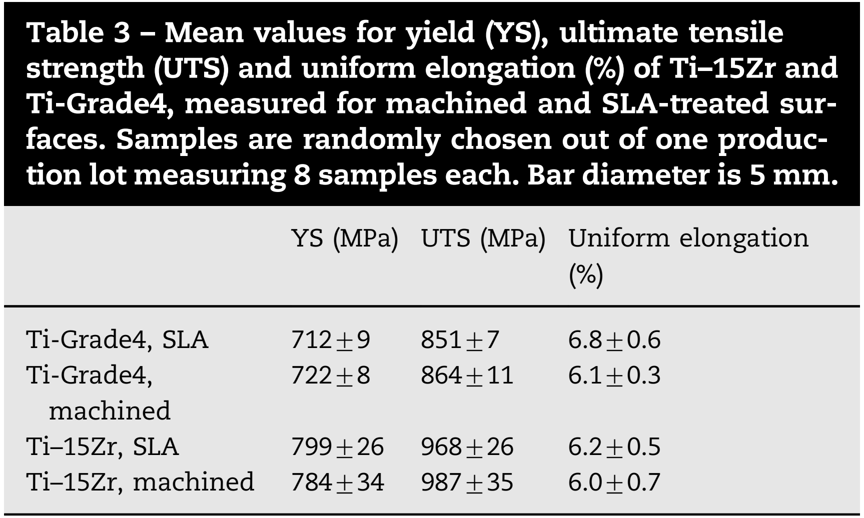
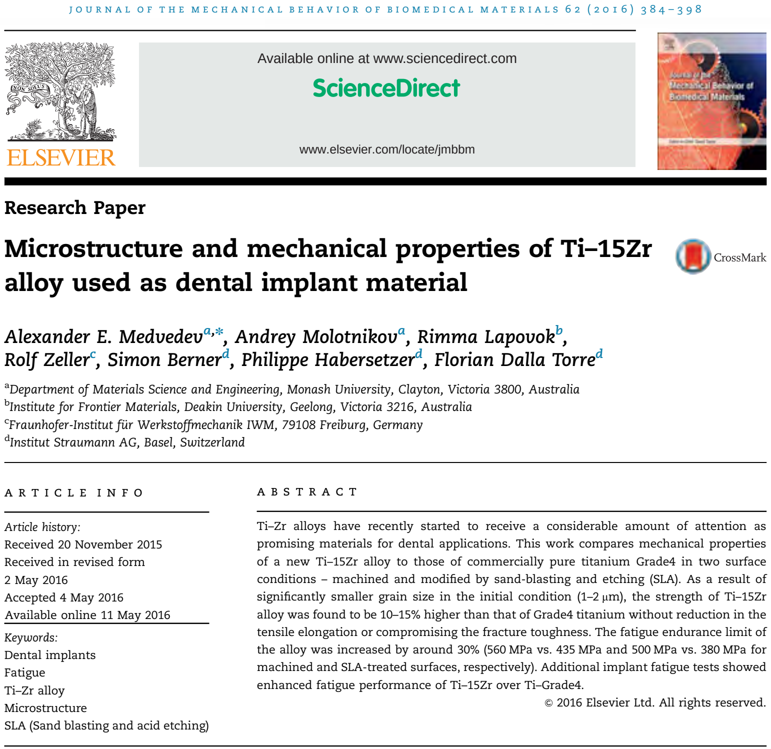


Table 3 – Mean values for yield (YS), ultimate tensile strength (UTS) and uniform elongation (%) of Ti–15Zr and Ti-Grade4, measured for machined and SLA-treated surfaces. Samples are randomly chosen out of one production lot measuring 8 samples each. Bar diameter is 5 mm.

	YS (MPa)	UTS (MPa)	Uniform elongation (%)
Ti-Grade4, SLA	712±9	851±7	6.8±0.6
Ti-Grade4, machined	722±8	864±11	6.1±0.3
Ti–15Zr, SLA	799±26	968±26	6.2±0.5
Ti–15Zr, machined	784±34	987±35	6.0±0.7



JOURNAL OF THE MECHANICAL BEHAVIOR OF BIOMEDICAL MATERIALS 62 (2016) 384–398

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Research Paper

Microstructure and mechanical properties of Ti–15Zr alloy used as dental implant material

Alexander E. Medvedev[a,*], *Andrey Molotnikov*[a], *Rimma Lapovok*[b], *Rolf Zeller*[c], *Simon Berner*[d], *Philippe Habersetzer*[d], *Florian Dalla Torre*[d]

[a]*Department of Materials Science and Engineering, Monash University, Clayton, Victoria 3800, Australia*
[b]*Institute for Frontier Materials, Deakin University, Geelong, Victoria 3216, Australia*
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ARTICLE INFO

Article history:
Received 20 November 2015
Received in revised form
2 May 2016
Accepted 4 May 2016
Available online 11 May 2016

Keywords:
Dental implants
Fatigue
Ti–Zr alloy
Microstructure
SLA (Sand blasting and acid etching)

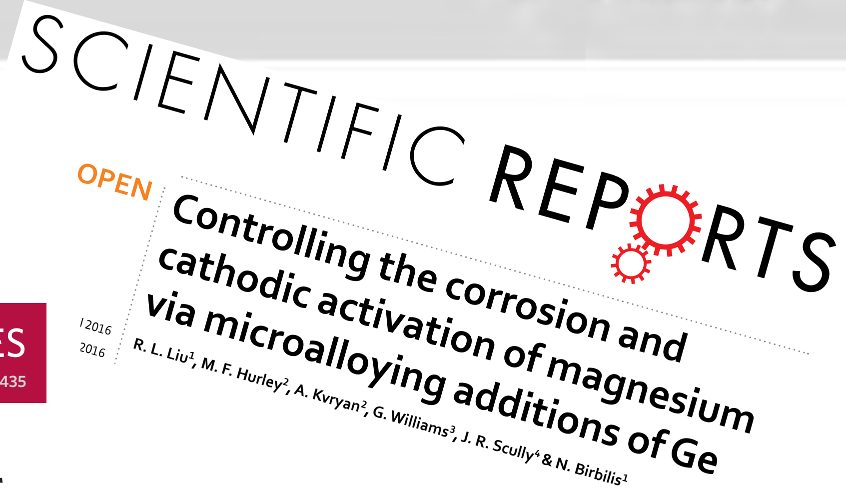
ABSTRACT

Ti–Zr alloys have recently started to receive a considerable amount of attention as promising materials for dental applications. This work compares mechanical properties of a new Ti–15Zr alloy to those of commercially pure titanium Grade4 in two surface conditions – machined and modified by sand-blasting and etching (SLA). As a result of significantly smaller grain size in the initial condition (1–2 μm), the strength of Ti–15Zr alloy was found to be 10–15% higher than that of Grade4 titanium without reduction in the tensile elongation or compromising the fracture toughness. The fatigue endurance limit of the alloy was increased by around 30% (560 MPa vs. 435 MPa and 500 MPa vs. 380 MPa for machined and SLA-treated surfaces, respectively). Additional implant fatigue tests showed enhanced fatigue performance of Ti–15Zr over Ti-Grade4.

Corrosion of light metals
Example of outputs

Key focus areas are ‘stainless light metals’

- Development of corrosion resistant Mg-alloys
- Development of corrosion resistant Al-alloys



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Controlling the corrosion and cathodic activation of magnesium via microalloying additions of Ge

R. L. Liu[1], M. F. Hurley[2], A. Kvryan[2], G. Williams[3], J. R. Scully[4] & N. Birbilis[1]

nature materials

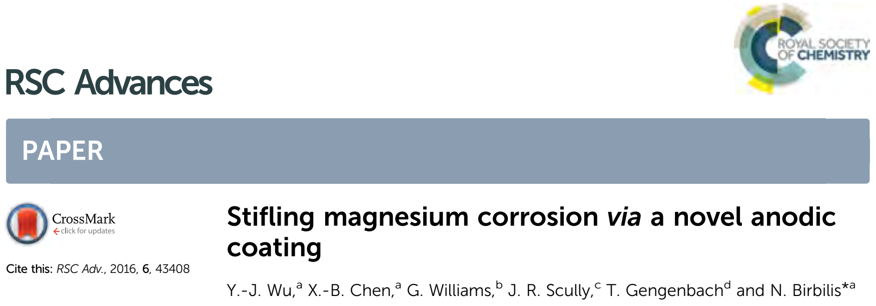
ARTICLES

PUBLISHED ONLINE: 19 OCTOBER 2015 | DOI: 10.1038/NMAT4435

A high-specific-strength and corrosion-resistant magnesium alloy

Wanqiang Xu[1,2], Nick Birbilis[2,3], Gang Sha[4], Yu Wang[5], John E. Daniels[1], Yang Xiao[6] and Michael Ferry[1,2]*

- A magnesium alloy containing (at.%/wt%) 30.30/10.95Li, 2.34/3.29Al, 0.039/0.19Zr and 0.128/0.59Y



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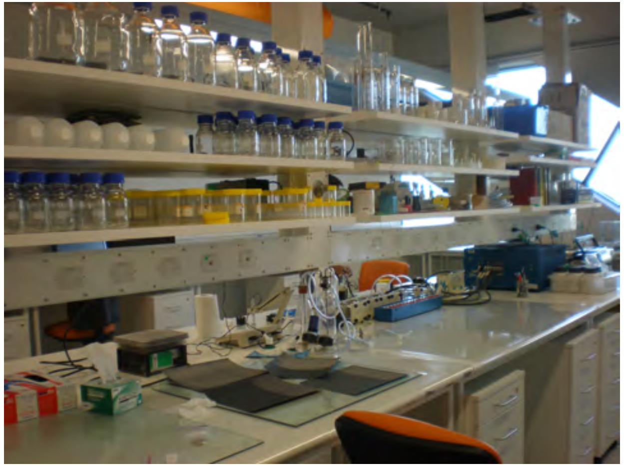
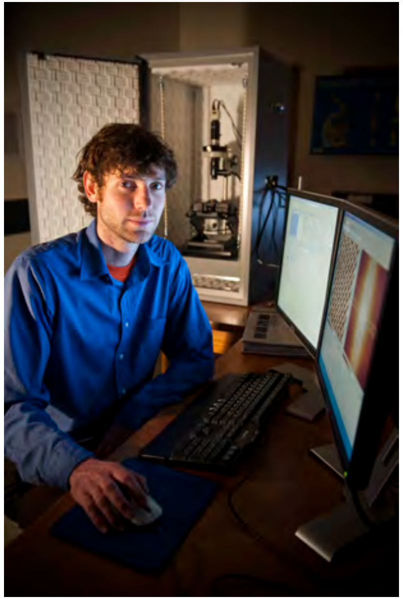
Cite this: *RSC Adv.*, 2016, **6**, 43408

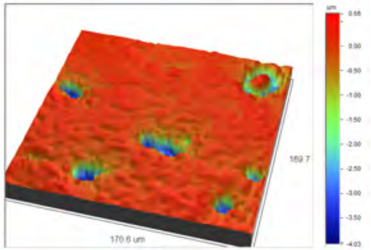
Stifling magnesium corrosion *via* a novel anodic coating

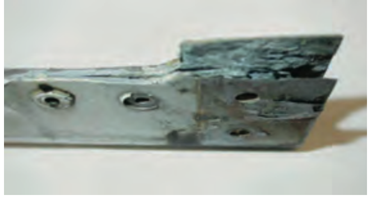
Y.-J. Wu,[a] X.-B. Chen,[a] G. Williams,[b] J. R. Scully,[c] T. Gengenbach[d] and N. Birbilis*[a]

Corrosion of light metals









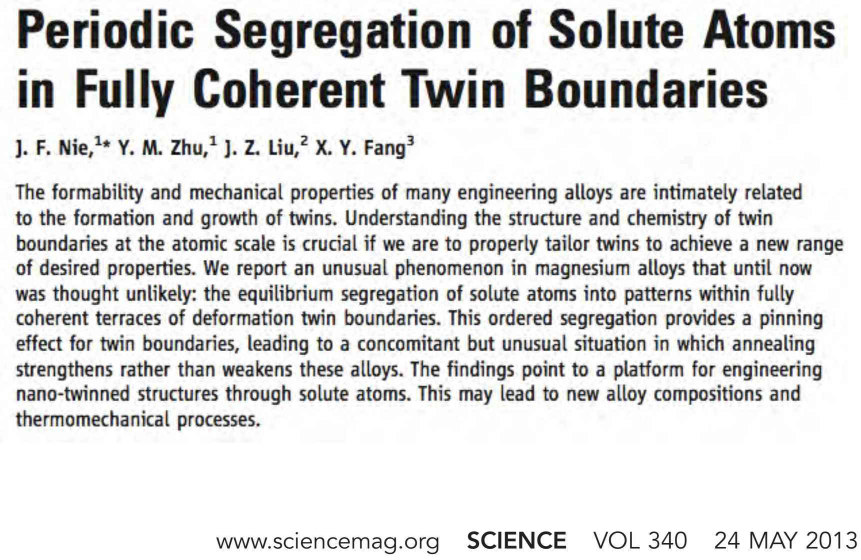
Credit: Prof Nick Birbilis

Monash Centre for Electron Microscopy

- Provides advanced instrumentation, expertise and training to conduct specialist research in advanced electron microscopy and atom probe microscopy;
- The suite of instrumentation can determine the composition, structure and bonding of materials down to the atomic scale;
- Building designed to provide exceptional mechanical, thermal and electro-magnetic stability to optimise instrument performance.

www.mcem.monash.edu

An example of outputs

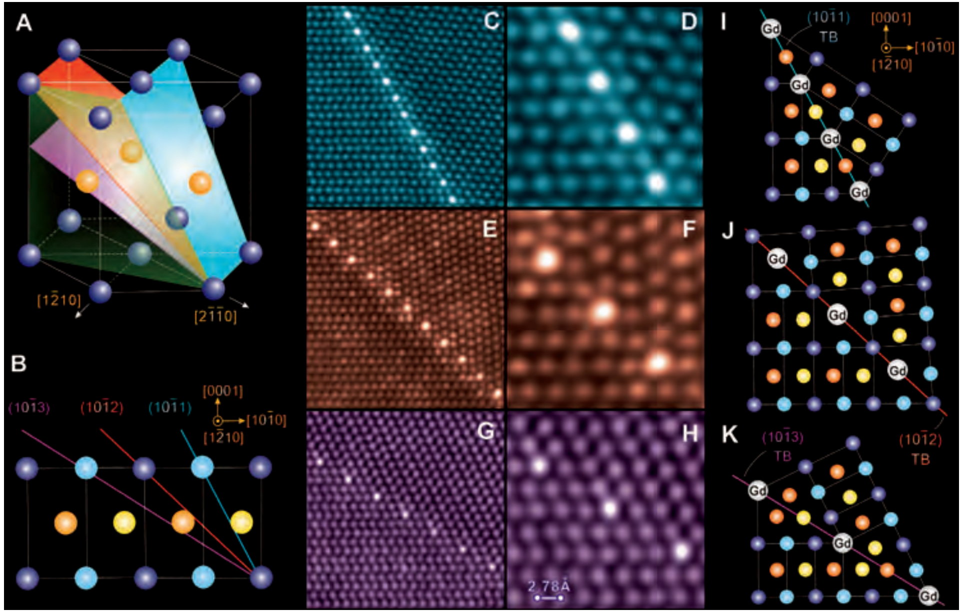


Periodic Segregation of Solute Atoms in Fully Coherent Twin Boundaries

J. F. Nie,[1]* Y. M. Zhu,[1] J. Z. Liu,[2] X. Y. Fang[3]

The formability and mechanical properties of many engineering alloys are intimately related to the formation and growth of twins. Understanding the structure and chemistry of twin boundaries at the atomic scale is crucial if we are to properly tailor twins to achieve a new range of desired properties. We report an unusual phenomenon in magnesium alloys that until now was thought unlikely: the equilibrium segregation of solute atoms into patterns within fully coherent terraces of deformation twin boundaries. This ordered segregation provides a pinning effect for twin boundaries, leading to a concomitant but unusual situation in which annealing strengthens rather than weakens these alloys. The findings point to a platform for engineering nano-twinned structures through solute atoms. This may lead to new alloy compositions and thermomechanical processes.

www.sciencemag.org SCIENCE VOL 340 24 MAY 2013

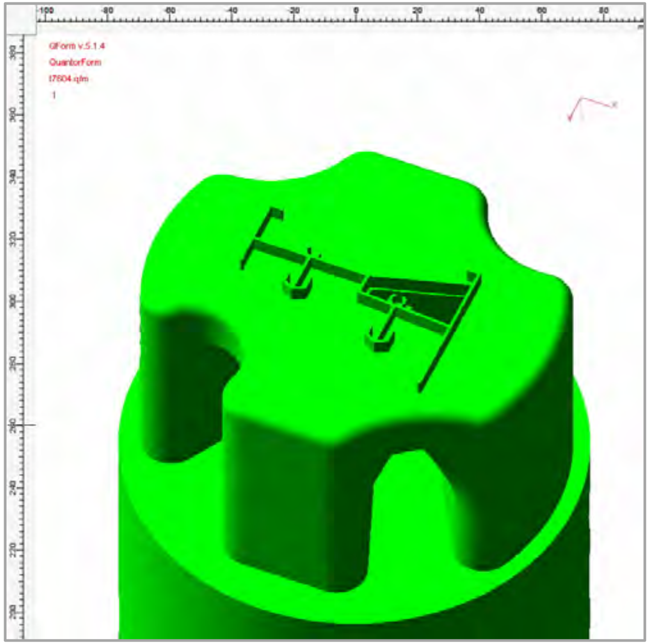


Materials Modelling
Development of physically based constitutive models

- Phenomenological Models
  - Large number of fit parameters
  - Limited predictive capability

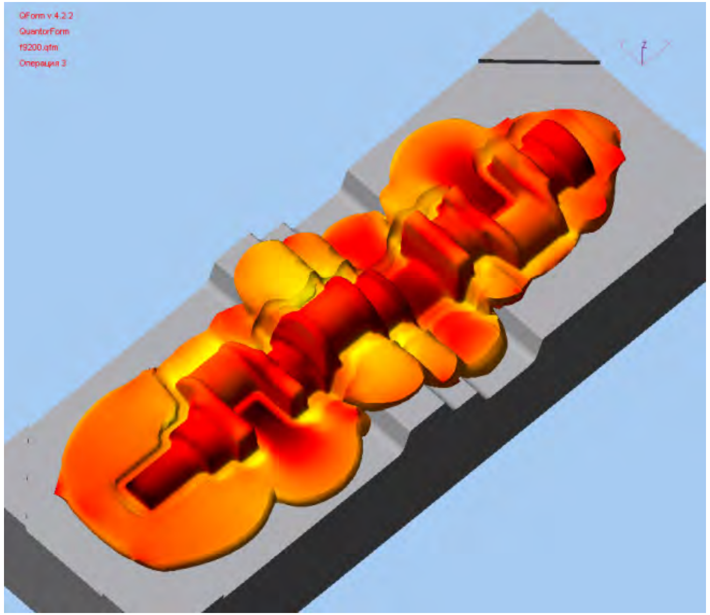
- Physically based Models
  - Small number of adjustable parameters
  - Excellent predictive capabilities

Materials Modelling
Process optimisation



Extrusion

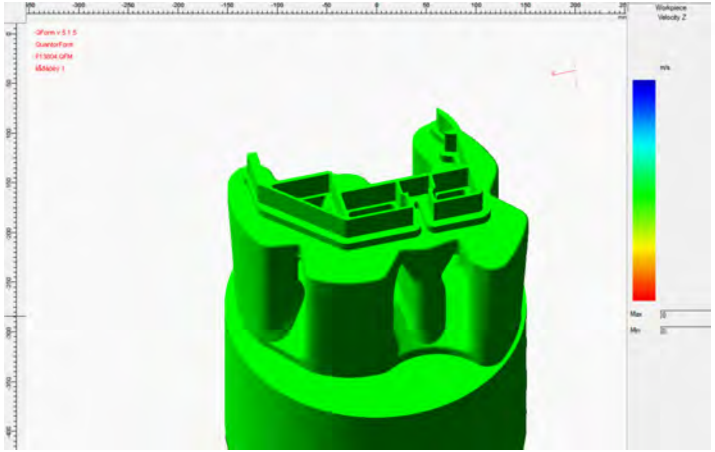
Qform 8 Extrusion,
www.qform3d.com

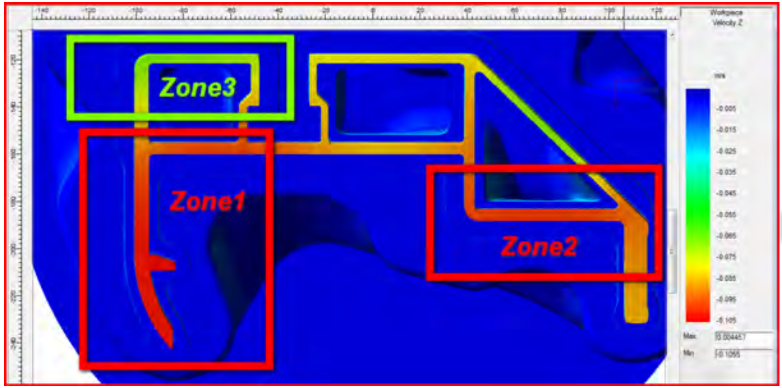


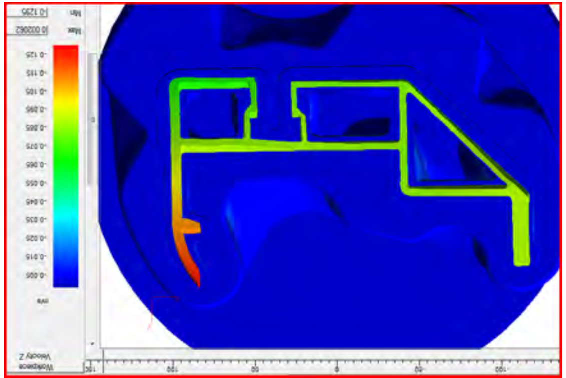
Forging

Materials modeling
Extrusion

- Optimisation of extrusion process
  - Increase productivity
  - Improve die life
  - Quality of the product surface
  - Different materials (Al, Mg)

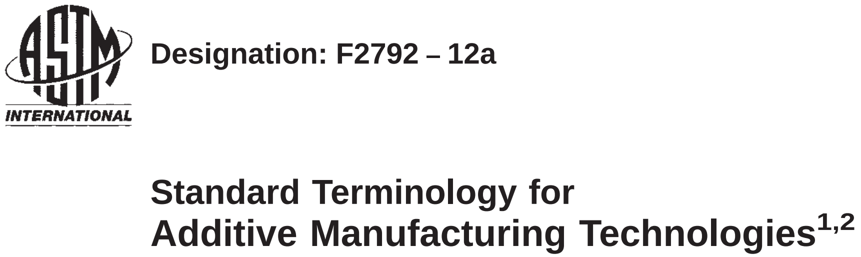






Definition of Additive Manufacturing

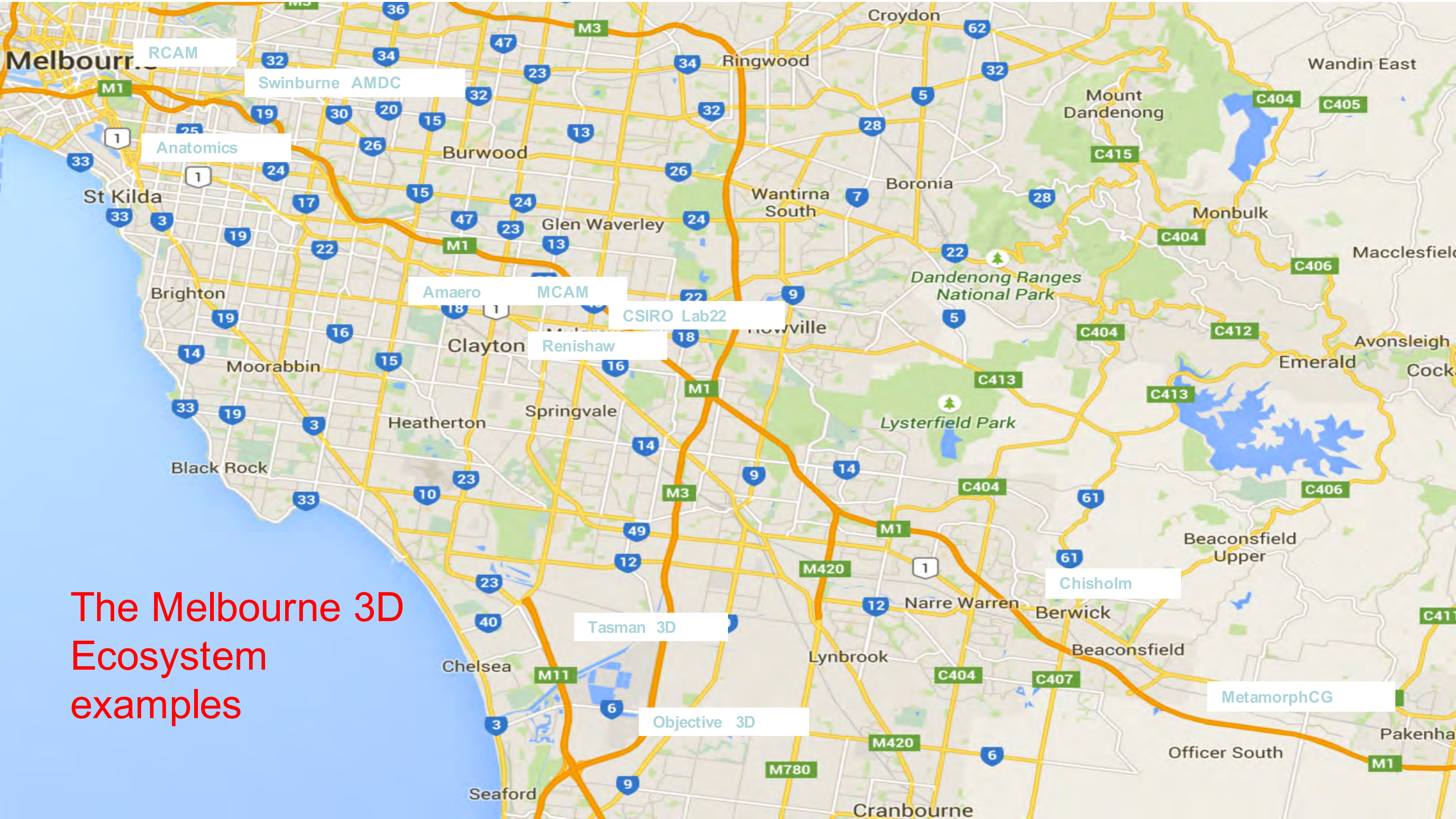
- A process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.
- Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication



Designation: F2792 – 12a

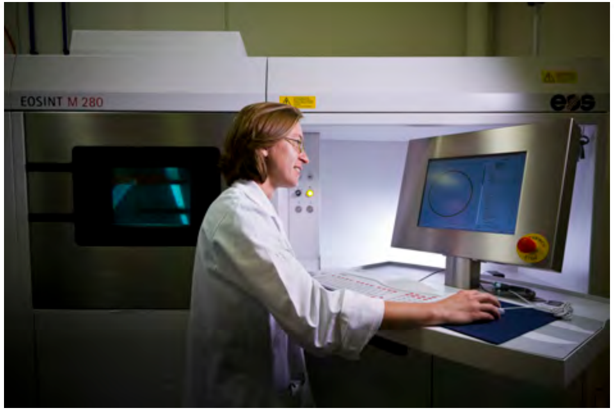
Standard Terminology for
Additive Manufacturing Technologies[1,2]

The Melbourne 3D Ecosystem examples



Monash Centre for Additive Manufacturing
Prof Xinhua Wu

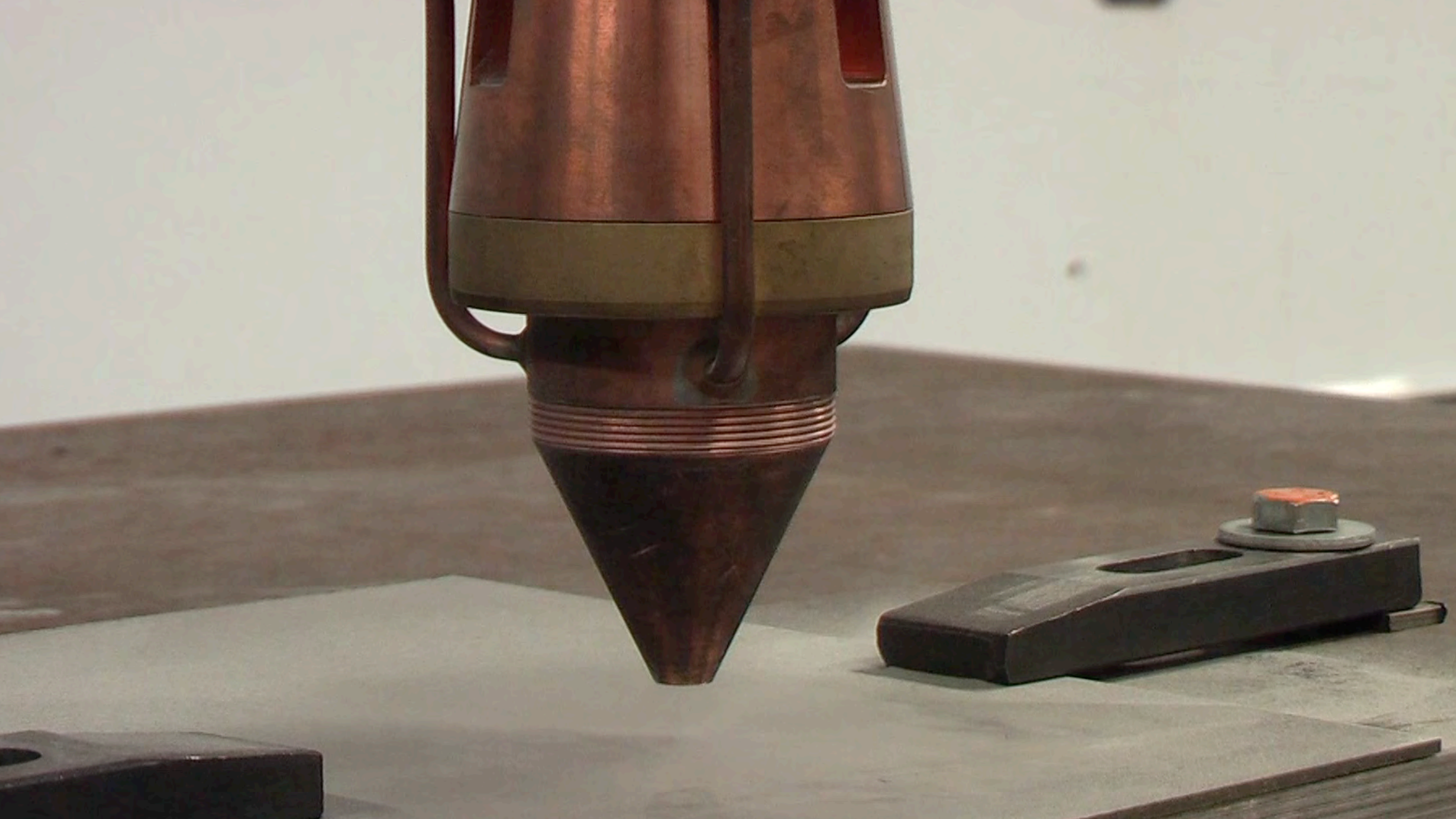
MONASH University

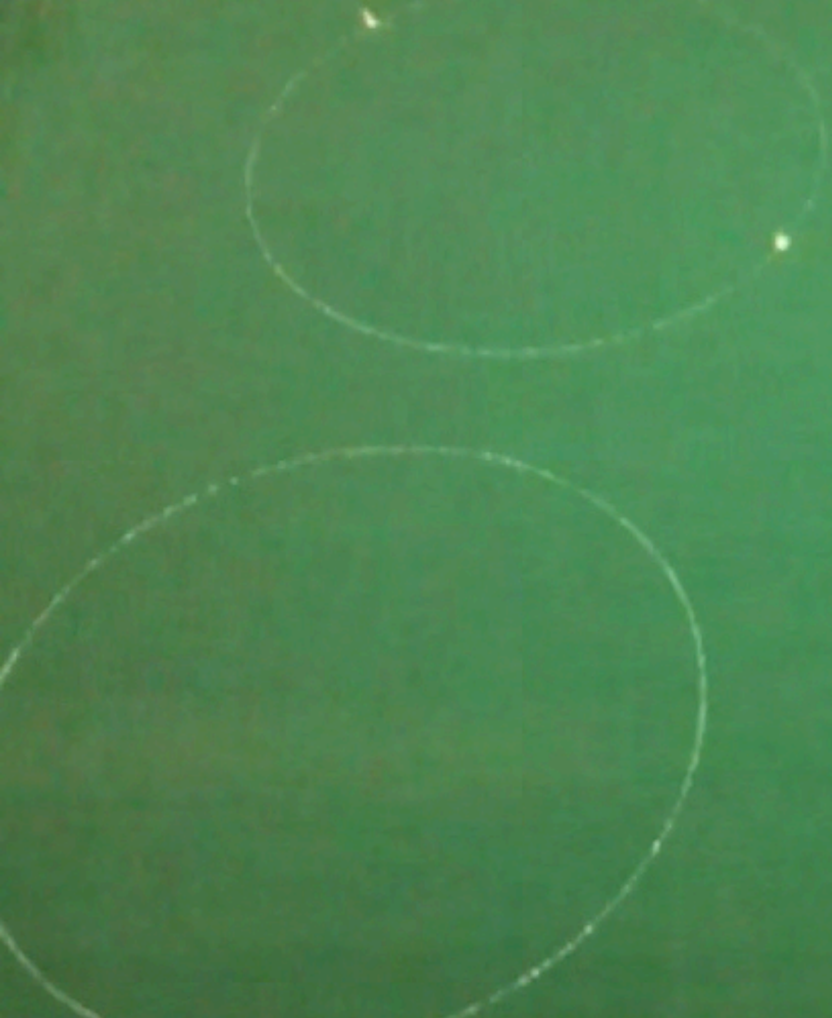


EOS M280 (x2)
- 400 W fibre laser
- Max build: ~ 250 x 250 x 300 mm^3
- Ni, Ti, Al alloy and steel powders

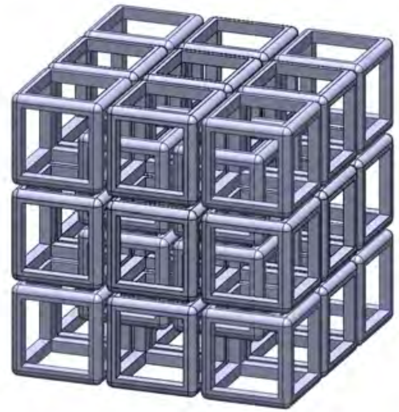
Concept Laser X1000R LaserCUSING®
- 1000 W fibre laser
- Largest in world: 400 x 600 x 500 mm^3
- Ni, Ti, Al alloy and steel powders

Trumpf TLC 7040 DLD
- 4 kW Disk Laser
- 5 axis + rotation
- 4000 mm x 1500 mm chamber
- Programmable spot size (0.2-6 mm)
- Blown powder mixing capabilities
- Local shielding to 10 ppm O_2

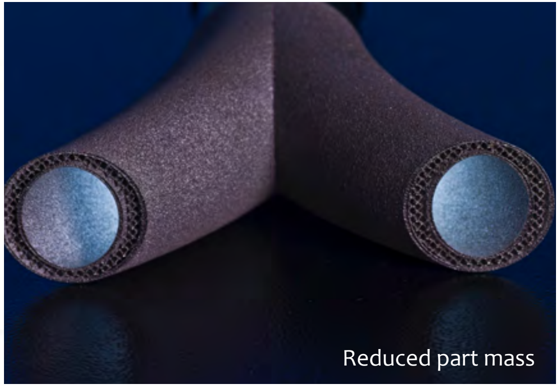




Design for Additive Manufacturing



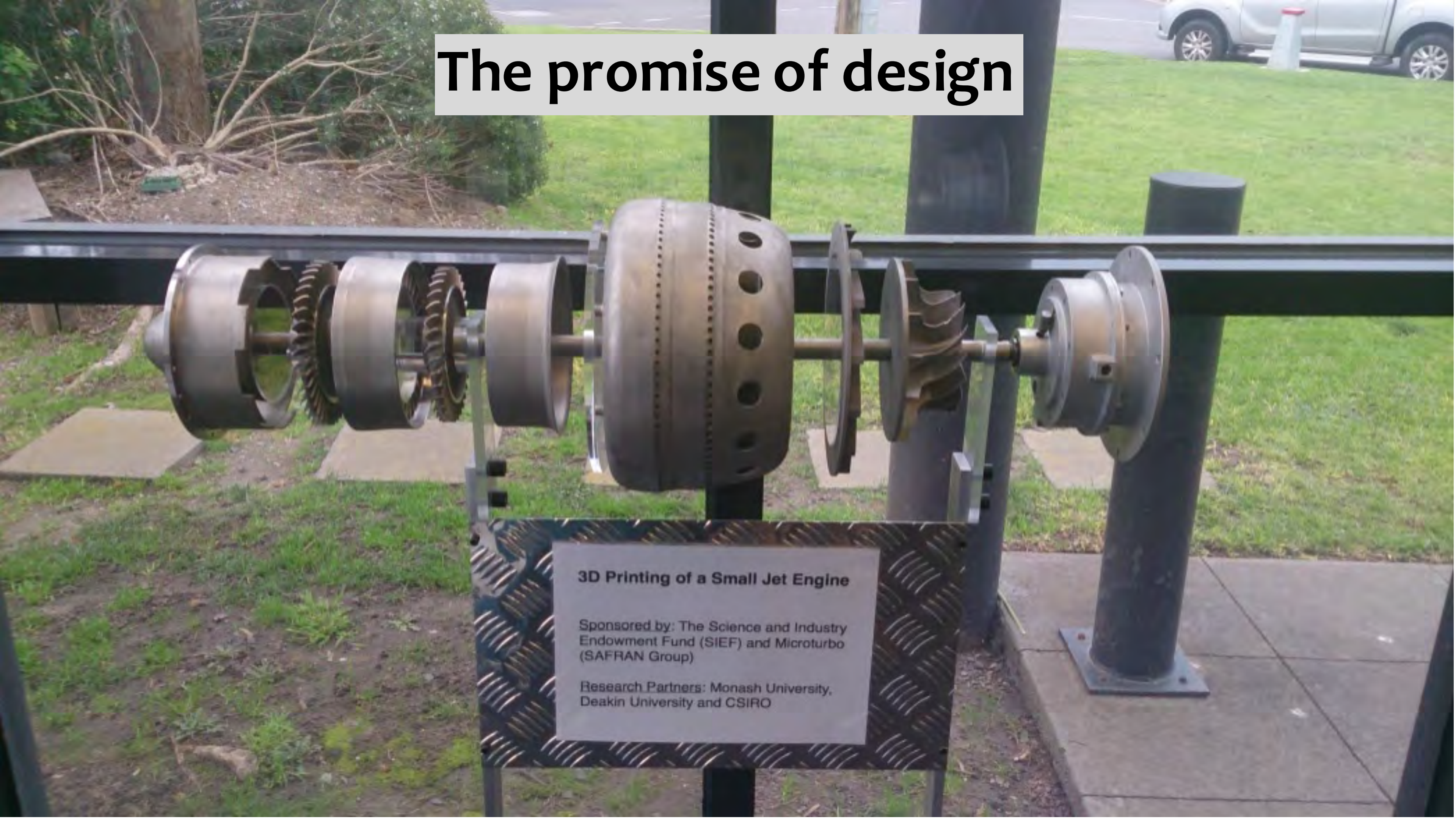
Increased part complexity



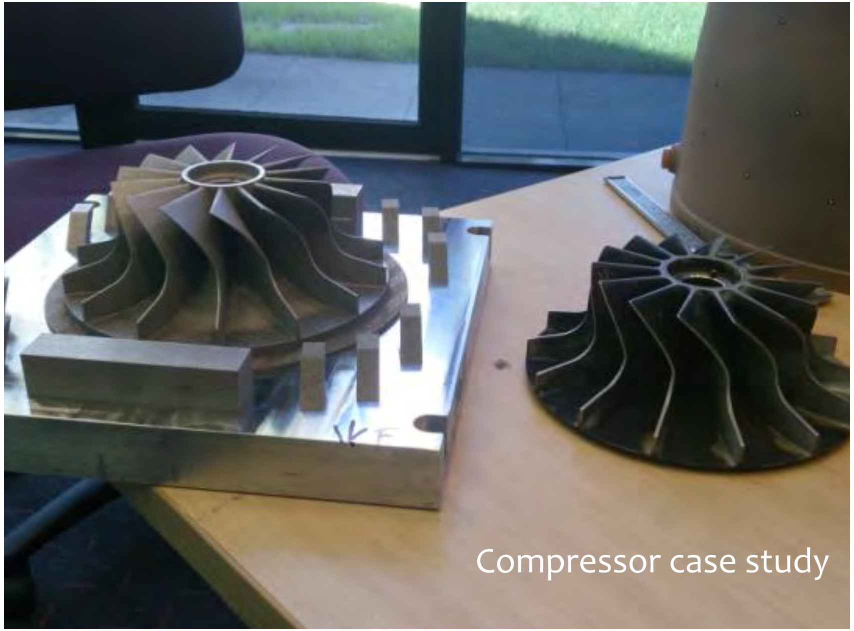
Reduced part mass

Credit: Chris Davies,Xinhua Wu, Lee Djumas and Marten Jurg

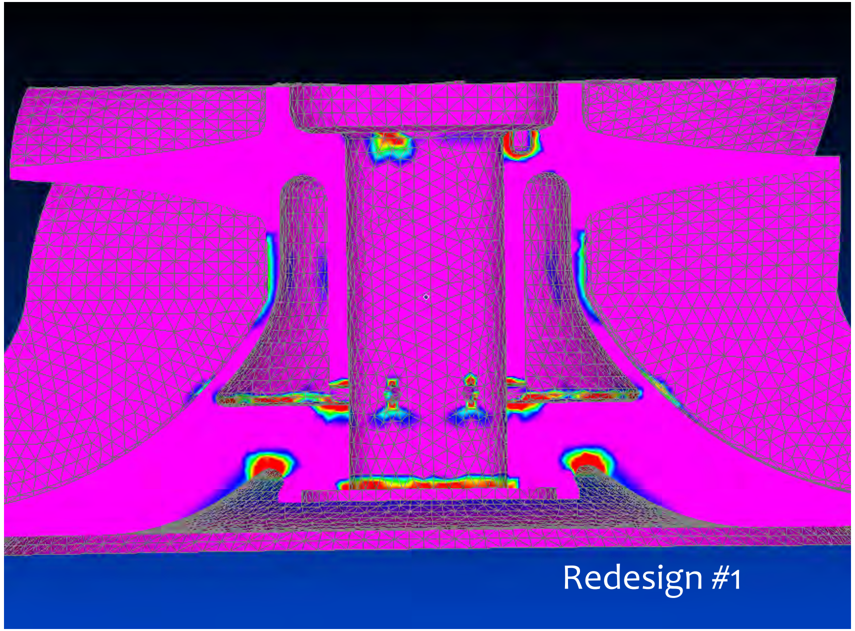
The promise of design



Design for Additive Manufacturing



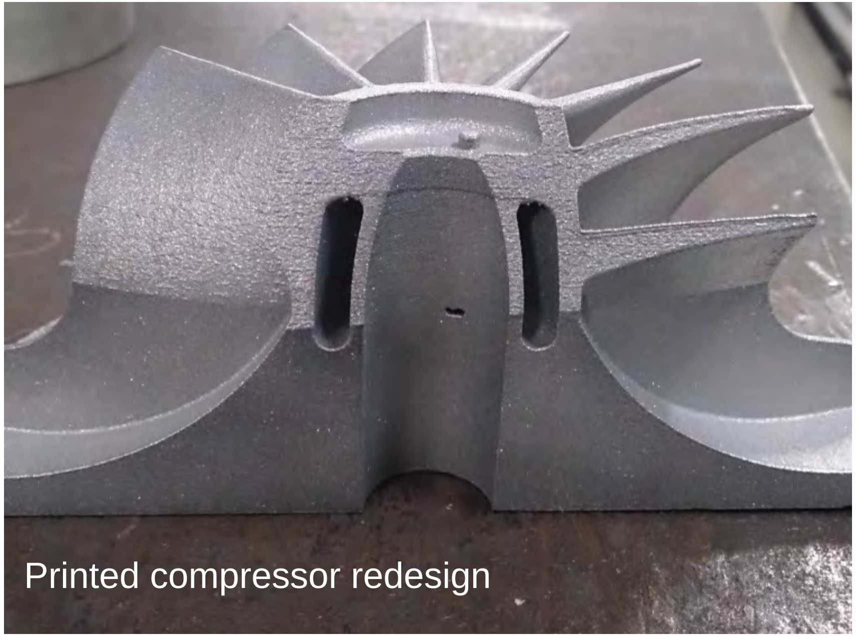
Compressor case study



Redesign #1

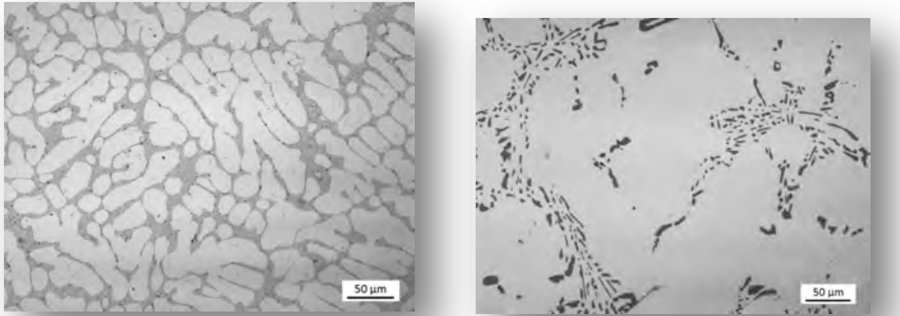
Credit: Chris Davies

Design for Additive Manufacturing



Printed compressor redesign

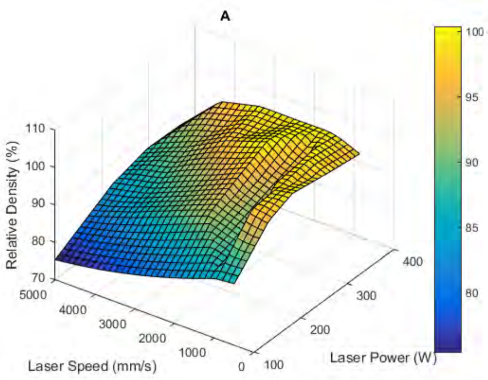
- A357 aluminium cast alloy
  - Al, Si (6.5% - 7.5%), Mg (0.4% - 0.7%)
- structural durability, corrosion resistance
- T6 heat treatment (Cast alloy)

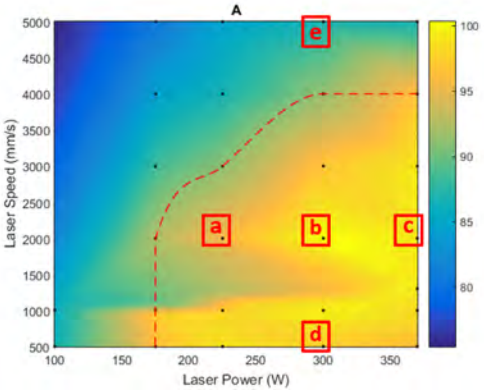


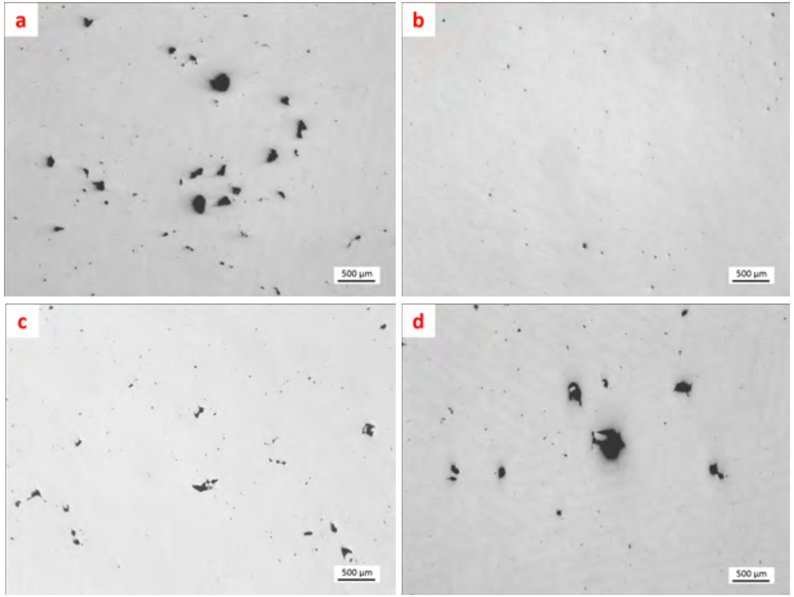
Credit: Chris Davies and Heng Rao

Selective Laser Melting of Aluminium Alloy A357
Density measurement

Sample scanning parameters	A	B
Substrate temperature (°C)	35	200
Powder layer thickness (µm)	30	30
Hatch distance (µm)	100	100
Spot size diameter (µm)	100	100
Laser power (W)	100, 175, 225, 300, 370	
Scan speed (mm/s)	500, 1000, 2000, 3000, 4000, 5000	
Specimen geometry (mm)	15 x 15 x 10	

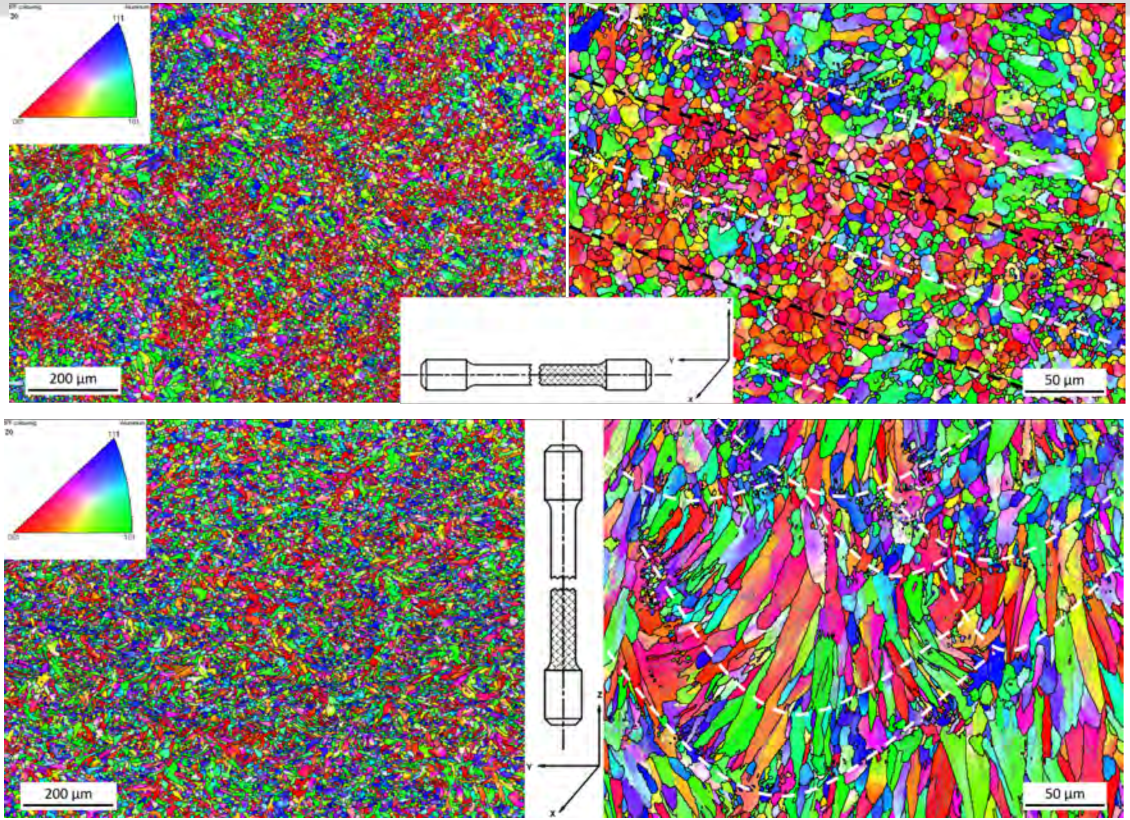






Rao, S Giet, K Yang, X Wu, CHJ Davies, Materials & Design 109, 334-346, (2016)

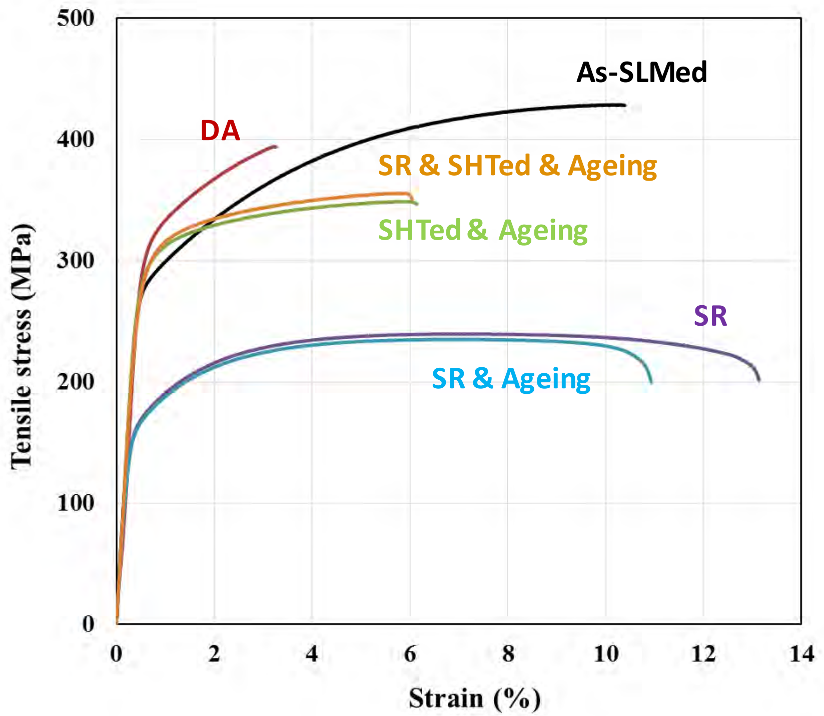
The microstructure & molten pool morphology of as-SLMed specimen built at 200°C



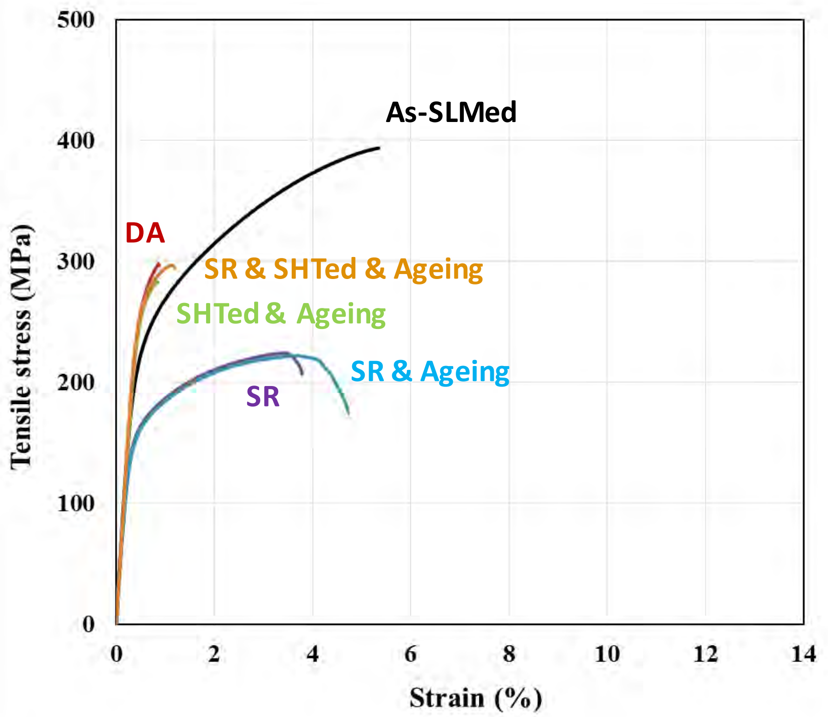
Rao, S Giet, K Yang, X Wu, CHJ Davies, Materials & Design 109, 334-346, (2016)

Tensile testing
Influence of SLM process and post heat treatment

Horizontal direction



Vertical direction



Rao, S Giet, K Yang, X Wu, CHJ Davies, Materials & Design 109, 334-346, (2016)

Selective Laser Melting of Aluminium Alloy A357

Summary

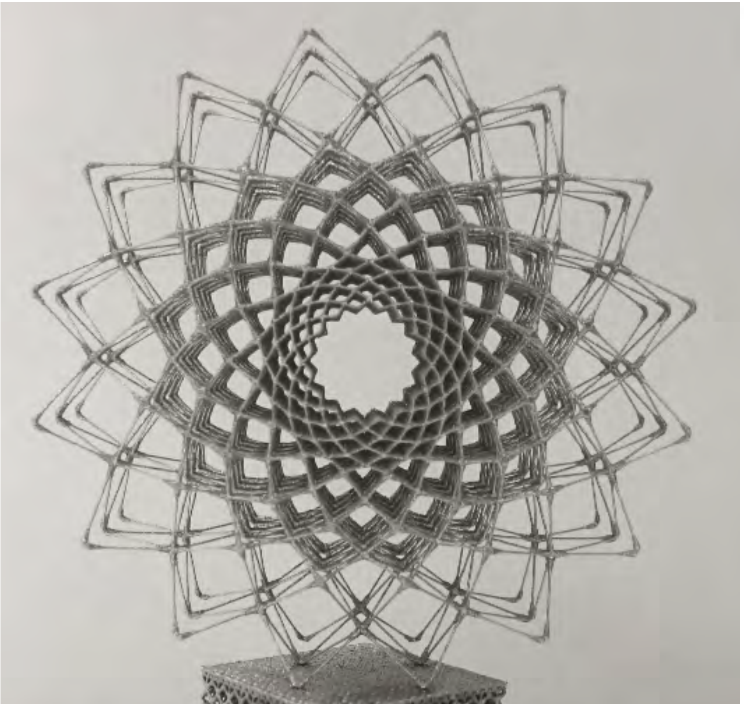
- Optimised SLM process parameters based on density measurement;
- Influence of SLM process and post heat treatment on the microstructure and mechanical properties;
- Mechanical property difference in relation to the directionality.

Rao, S Giet, K Yang, X Wu, CHJ Davies, Materials & Design 109, 334-346, (2016)

Selective Laser Melting

SLM Surface Finish

- Highly complex geometries possible
- Near fully dense components (>99.9%)
- High value proposition

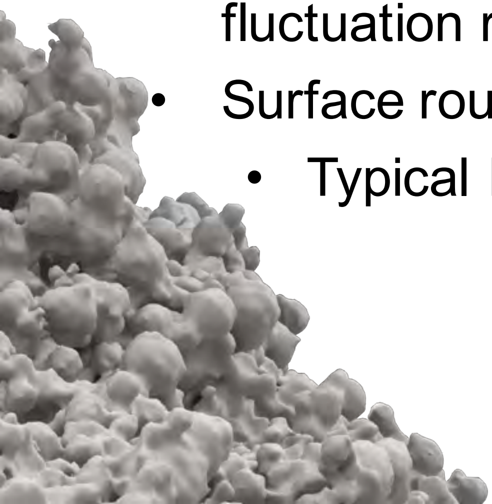


Credit: Marten Jurg

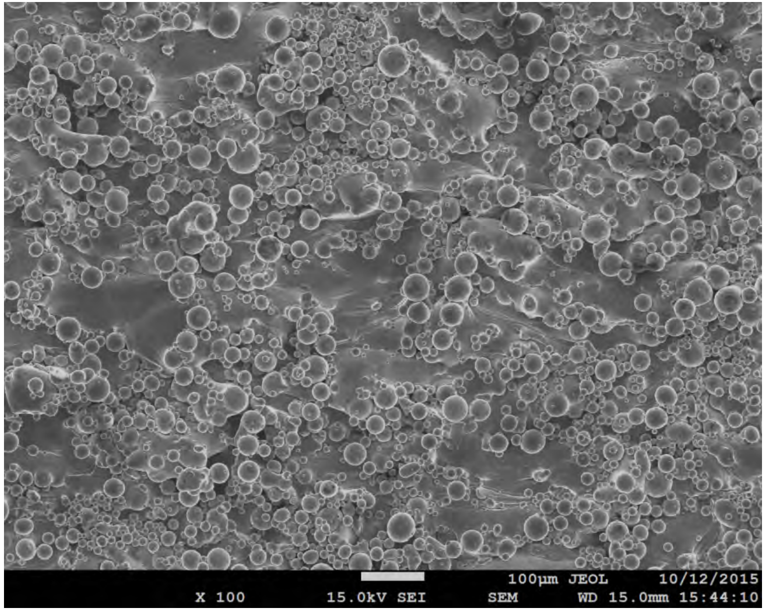
Selective Laser Melting

SLM Surface Finish

- SLM surface a limiting factor
- Some improvement possible through parameter development
- Adhered powder and melt pool fluctuation remain an issue
- Surface roughness $\propto$ angle
    - Typical R_a 10-60µm



As built surface (vertical)

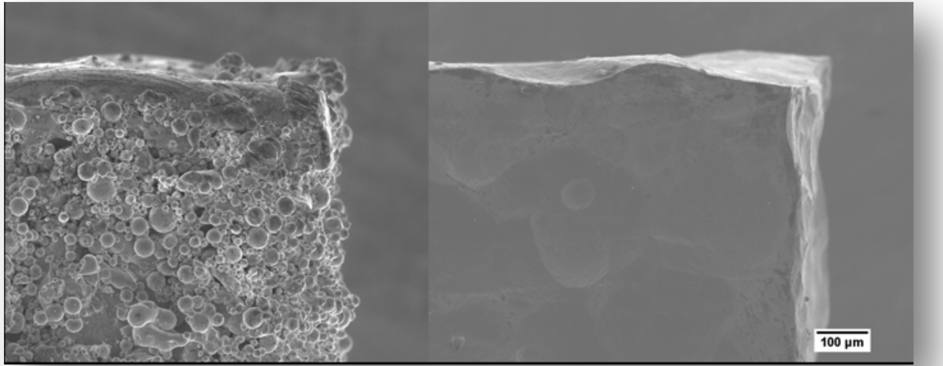


Credit: Marten Jurg

Non-Contact Polishing

Chemical Polishing

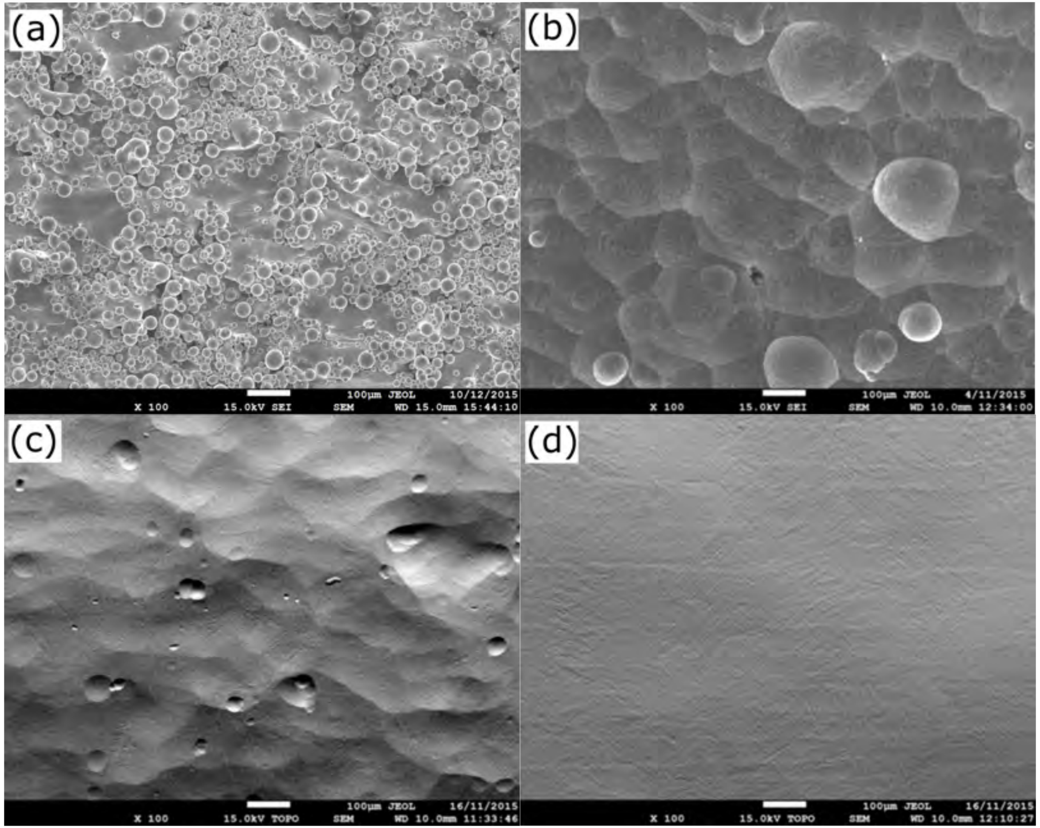
- Roughness results in poor fatigue performance & reduces effective specific strength
- Fatigue crack initiation result of surface roughness
- In simple cases machining applicable → Complex geometry prohibitive
- Only non-contact methods applicable
- Titanium alloys corrosion resistant – limited chemical treatment options
- Hydrofluoric acid solutions proven & effective



Marten Jurg, W. Yan, A. Molotnikov, unpublished

Non-Contact Polishing

HF-HNO_3 Polishing



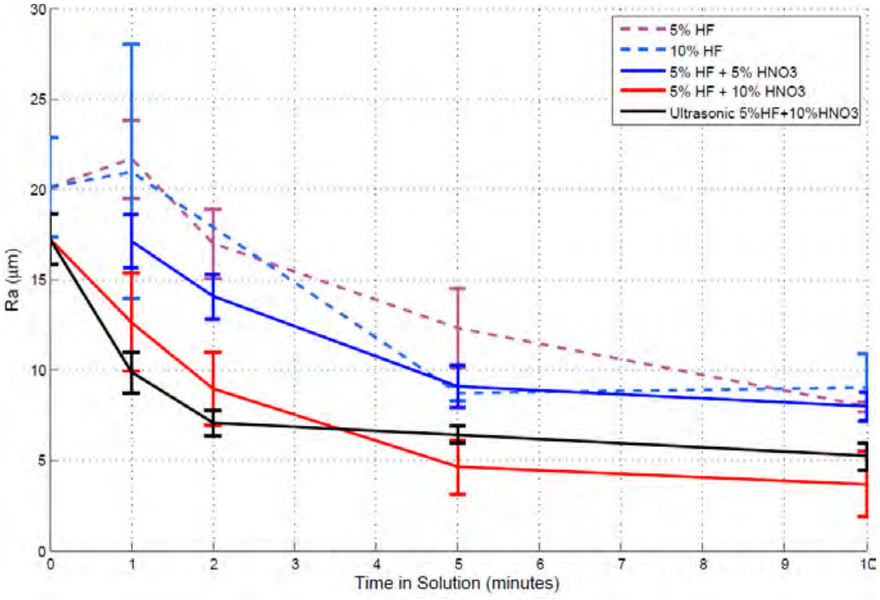
Solution Trials:
(a) As-built
(b) 10% HF
(c) 5% HF + 5% HNO_3
(d) 5% HF + 10% HNO_3

10 minute immersion

Marten Jurg, W. Yan, A. Molotnikov, unpublished

Non-Contact Polishing

Initial Roughness Reduction



- 5% HF and 10% near stoichiometric optimum – greatest roughness reduction
- Very aggressive, greatest material reduction

Marten Jurg, W. Yan, A. Molotnikov, unpublished

Non-Contact Polishing

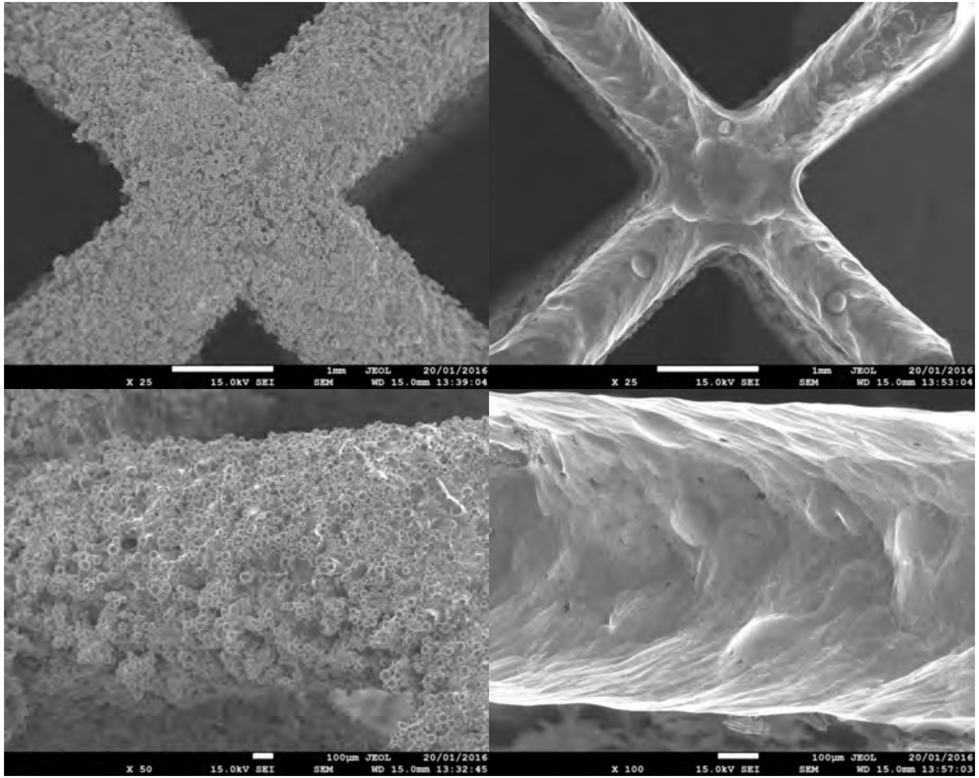
Design Methodology

1. Initial designed geometry
2. As-built geometry
3. Chemically polished result

Credit: Marten Jurg

Design for Surface Quality

Design Example



- Desired final R_a <6μm
- Desired thickness 1mm
- Solution: 5% HF & 10% HNO_3
- 3.5 minutes @ 63μm/min = 220μm
- Design thickness 1440μm

Marten Jurg, W. Yan, A. Molotnikov, unpublished

Biomedical applications

Custom Triflange Shell
HA Coating with Silver Ions

Signature ORTHOPAEDICS

10th July 2015

Acusure Ag® Technology Clinical Case

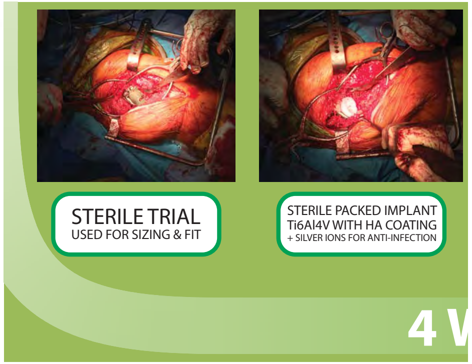
PLANNING

SURGEON FEEDBACK

CUSTOM DRILL GUIDE FOR ACCURATE DRILLING

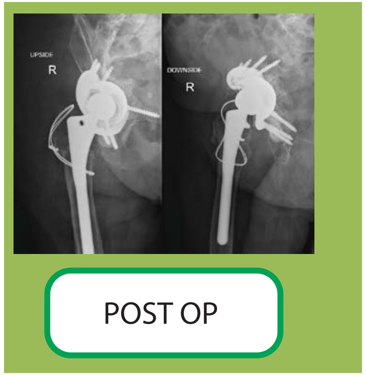
CEMENTED XLPE LINER

CUSTOMISED SCREW TRAJECTORY FOR OPTIMAL BONE PURCHASE



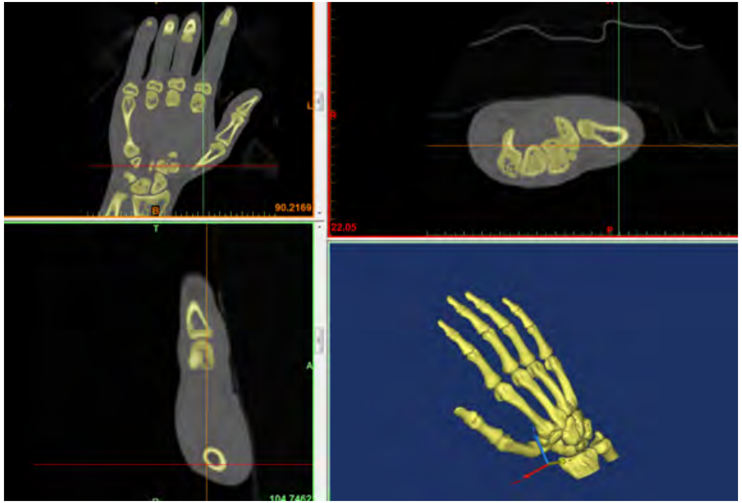
STERILE TRIAL
USED FOR SIZING & FIT

STERILE PACKED IMPLANT
Ti6Al4V WITH HA COATING
+ SILVER IONS FOR ANTI-INFECTION

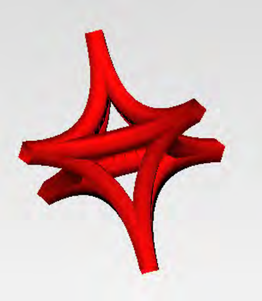


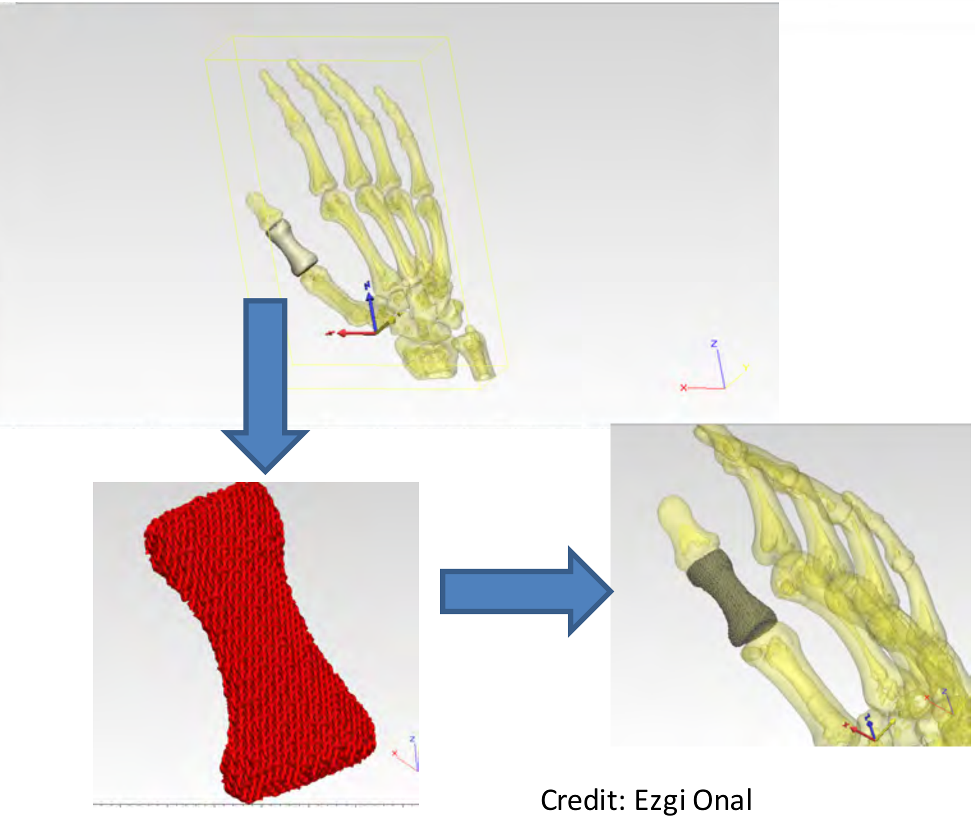
POST OP

Biomedical applications
EXAMPLE Case study: Thumb Phalange



octahedral

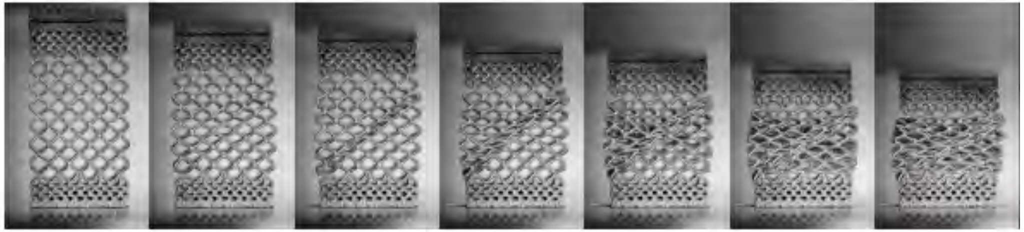


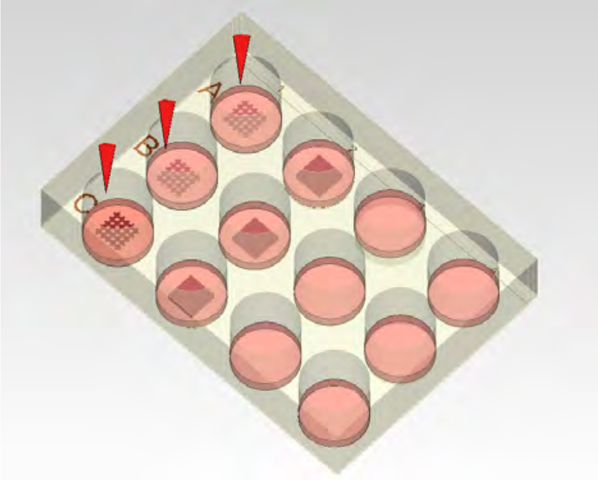


Credit: Ezgi Onal

Biomedical applications

- New generation of metallic orthopaedic implants with tailored mechanical and biological properties
- Design of functionally graded structures
- Cell behaviour with Cell line MG-63 cell line (human osteoblast cells)
- Mechanical Characterization,
- Simulation..





Credit: Ezgi Onal, Marten Jurg

17th Australian International Aerospace Congress

AIAC17

INNOVATION INTO AEROSPACE FUTURE

26 FEBRUARY – 02 MARCH 2017

In conjunction with the

AUSTRALIAN INTERNATIONAL AIRSHOW AND AEROSPACE & DEFENCE EXPOSITION
AVALON2017
28 FEBRUARY - 5 MARCH
AVALON AIRPORT GEELONG AUSTRALIA

INCORPORATED CONFERENCES:

17th Australian International Aeronautical Conference

10th Australian International Space Conference

10th DSTG International Conference on Health & Usage Monitoring Systems

1st AHS Composite and Additive Manufacturing Conference

- Five symposia focusing on Material Science and Engineering
  - Additive manufacturing
  - Corrosion
  - Light metals design
  - Composite materials
  - Fatigue and Fracture
- Abstract submission: open

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Thank you for your attention!

Questions?

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