Towards an Australian Titanium Industry

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Research Program Director | Metal Industries | CSIRO Manufacturing
Outline

• CSIRO
• CoMet™ for Titanium Powder
• Technologies to Accelerate (the Industry)
• Overview of the AM Landscape in Australia
CSIRO

Commonwealth Scientific and Industrial Research Organisation
‘Australia’s National Lab’
Team CSIRO

- 5486 talented staff
- $1 billion+ budget
- Working with over 2800+ industry partners
- 55 sites across Australia
- Top 1% of global research agencies
- Each year 6 CSIRO technologies contribute $5 billion to the economy

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Big ideas start here

- **3773** patents
  - Biggest patent holder in Australia
  - 47% involve collaboration

- **150+** spin-out companies
  - worth $1bn in market capitalisation

- **300** licenses
  - Most with Australian companies

**WiFi**
- Extended-wear contact lenses

**UltraBattery**
- Building IQ

**WASP**
- Zebedee

- **1,200+** schools benefit from our scientists in schools program
- **200,000+** people visit our public facilities and visitor centres

Globally our publications are **Top 1%** in 15 of 22 research fields

- **150+** licenses
  - Most with Australian companies

**Patents**
- 3773
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**Spin-out companies**
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**Licenses**
- 300
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We focus on four core industry areas:

- **Defence, Space, and Aerospace Metals** – an ongoing core focus for the Program, and for Australia as a nation. A key link to the Titanium value chain.
- **Mining and Rail Metals** – the Mining, Engineering, Technology, and Services sector, and in particular the Rail manufacturing and maintenance areas.
- **Energy and Resources Metals** – including energy storage, renewables, corrosion, and related applications, and the link with Lithium and other battery materials.
- **Medical Metals** – focusing on metal structures and their interactions; work in prosthetics, dental, and related technologies. Links to Titanium and alloys.
Supporting technologies

“Powder to Product”

Alloy and Powder Technologies

Innovative Additive Manufacturing

Surface and Functionality Technologies

Modelling Technologies

Future Metals

‘Adding Functionality’

• Additive Manufacturing incorporating functional devices and surfaces; and
• Better techniques and processes for additive manufacturing

We work with Australian SMEs through to multinationals to add value to metal industries
A metal halide precursor is reduced to produce a pure metal. This process applies for single metals and alloys.

- *low CAPEX*
- *low energy*
- *clean tech*
Metal value chain

CoMet™ drastically reduces the steps to final product, cutting down waste and saving on costs.

The CoMet™ value chain

A traditional value chain
Research on CP Ti (Commercially Pure Titanium) powder production resulted in technology now licensed as Coogee Titanium. The process uses a fluidised bed reactor and magnesium reductant, followed by continuous vacuum distillation.

Use of Aluminium as the reductant allows for the production of Titanium-aluminium powders of various compositions. This technology is subject to an existing co-development agreement.

Similar benefits can be realised for a suite of metals beyond titanium, including production of Aluminium-Scandium powder (AlSc, AlSc₃). Patented; currently pursuing scale-up partners.
Further research continues into high-value low-volume metals, where the value of powder is particularly high. A number of examples are under development.
Platform opportunities and current status

CoMet™

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Titanium
 Titanium Alloy
 Scandium
 Zeconium
 Tantalm
 Molybdenum
 Zirconium
 Scandium
 Titanuim
Technologies to Accelerate

PMT™ - Powder Manipulation Technology
Ti Sheet
Ti Wire
Cold Spray Titanium
Modelling and Simulation
Industrial X-Ray CT
Reducing the Cost of Metal Feedstock

PMT™ Manipulation of Ti takes place in a safe environment

Ti Sponge/Cake
$15/kg

Gas atomised Powder
$300 - $700/kg

PMT™
~$20/kg

Final Product

~$35/kg

>$300/kg
Continuous Strip Production

The CSIRO DPR/HRD Process Schematic

Direct Powder Rolling (DPR)

Hot Rolling Densification (HRD)
Analysis of microstructure using EBSD

HRD (1 pass) + annealed (750°C 2 hrs)

HRD, cold rolled + annealed (750°C 2 hrs)

Commercial CP Ti grade 2

Grain size distributions

HRD CP Ti
ave. 40.3 μm

HRD/CR CP Ti
ave. 34.5 μm

Commercial CP Ti
ave. 25 μm
Continuous extrusion of Ti alloys wire/rod from flowing powders, pelletised powders and cold isostatically pressed (CIPed) powders and gauge reduction from wrought feed

- Patent filed 2012
- Wire from CIP BE (blended elemental) feed has been the focus
- BE approach: product is composite and requires homogenisation anneal. For re-melting purposes, this may not be required
- Powder is 65-80% of input costs to process
- Other significant cost is tooling and how often it must be replaced
- Traditional, niche & novel Ti alloys are possible, e.g. Ti-7Al-4V AM (Additive manufacturing) wire. Typical diameters 5-12mm. Can be drawn/swaged down.
- TRL 4-5. Additional development needed to scale up continuous feeding, achieve tooling with durability for commercial quantities & produce diameters outside of 5-12mm range.
- Possibility to process recycled materials,
- Applications: conversion of CP powder, BE powder, potentially granules and potentially machining waste to: alloy weld wire, AM alloy wire, fastener stock, atomisation alloy wire, etc.

Figure 1. The process schematic; machine; product
Challenges of Cold Spray Additive for Titanium Manufacturing

1. Multiple parameters (15+) for the cold spray optimisation and elimination of porosity
2. Requirement of post treatment to improve ductility of the additive structure for some applications
3. Difficult to manufacture highly complicated net shape designs
4. Visualisation of complicated events that occur during rapid (ultra high speed) transformation of powder to product
Residual stress: Blown-powder deposition

Temperature (K) – during build

von Mises stress (MPa) – during build

von Mises stress (MPa) – cooling to below 90°C

Displacement (mm) – released from clamps

TiAl6V4 (50 layers, 100 mm/min), 2.5 mm wide layers
Powder bed raking animation (side view)

Our approach can treat spherical and non-spherical particles with any size distribution
Data Constrained Modelling (DCM characterised porosity distributions in 3D)

Fine porosity distribution in the Ti64 AM component (red – high, blue-low).

High porosity regions in the Ti64 AM component.
Metal Printers in Australia

The 1\textsuperscript{st} powder-bed-fusion metal printer (an EOS machine) in Australia

Installed in 2004 by Betta-Machine Tools (BMT) in Sydney (Australia’s only distributor of EOS printers today)

32 metal printers by end of 2017 in Australia (21 in Melbourne)

13 metal printers will be acquired in 2018
Innovative Manufacturing Cooperative Research Centre (IM-CRC)
(headquartered at RMIT University, Melbourne CBD)

A$40M funding from the Federal Government for industry-led Innovative Manufacturing Research in Australia, leveraging 1:1 cash matching from Industry; 2017 - 2024

Four programs of the IM-CRC
1: Additive Manufacturing Processes (A$10M)
2: Automated & Assistive Technologies
3: High Value Product Development
4: Industry Transformation
IMCRC research participants
Additive Manufacturing Capability Map

- Equipment (type Materials etc.)
- Research Interests (Materials, Equipment development, Design, Processing Etc.)
- Industry Sector Engagement
- Collaboration between Universities
- Future Investment and Growth
Targeted industries in Australia:
- Aerospace: 14%
- Energy: 6%
- Medical: 19%
- Defence: 12%
- Biomaterials: 12%
- Consumer goods: 9%
- Marine: 9%
- Oil and gas: 9%
- Other: 10%
AM Growth Sectors in Australia

- Medical Technology 33%
- Manufacturing 48%
- Titanium alloys
- Stainless steels
- Aluminium alloys
- Oil & Gas 9%
- Mining Equipment 4%
- Food Agribusiness 0%
- Building Construction 6%
32 metal printers by the end of 2017 in Australia (21 in Melbourne)
RMIT Centre for Additive Manufacturing (6)
Powder bed: SLM 500HL (4 Lasers), SLM 250HL (2 Lasers), SLM 250HL, SLM 125HL, TRUMPF 1000
LMD: TRUMPF TruLaser 7020 (powder & wire, 1500mm²)

Monash Centre for Additive Manufacturing (6)
Concept 2000, Concept 1000, EOS M290, 2×EOS M280
LMD: Trumpf TruLaser

CSIRO Lab 22 (5.5)
Powder bed: Arcam A1, Concept laser M2, Aurora Labs Titanium S Pro
Blown powder: LENS MR-7, LaserTec 65, Cold Spray Voxel Jet 1000X (0.5)
RMIT AMP Additive manufacturing capability 2018

Polymer

**FDM** – Fortus 900mc, Uprint, 10 Makerbot, 10 Zortrax, Markforge

**SLA** – 3D Systems Projet 7000, DLP systems

**MJ** – Polyjet J750, Connex 350

Metal

**SLM** – SLM Solutions 500HL, 2x250HL, 125 HL, TRUMPF 1000

**LMD** – TRUMPF TruLaser 7020

Supporting

**CNC** – 3 & 5 Axis machining centres

**Metrology** – 3D scanning, CMM, CT

**Simulation** – Virtual design, Optimisation

**Mechanical Testing** – Extensive capabilities
Powder Bed Additive Manufacturing

Aurora Labs
Titanium S Pro

Arcam A1

Concept laser M2

Voxel Jet 1000X
Blown and Spray Powder Systems

Optomec LENS MR-7  LaserTech 65  Cold Spray
Metal Printers Planned to be Acquired in 2018

Planned (2018/2019) 29%

Current Metal Machine Capacity 71%
Current researchers on metal AM (275) and planned (27% growth for 2018/2019)
Monash University is looking for at least 2 academics in the diverse realm of additive manufacturing, at any academic level.

Please email: Nick.Birbilis@monash.edu (Head of Department; Nick is also at TMS!)
$AU59M identified in Public Funded Research Activities in metal AM in 2017
Startup companies

Titomic has raised some $6.5M via an IPO to finish the commissioning of its large format Cold Spray AM platform and its bike frame production cell.

Aurora raised some $7M through public offering to commercialize its large powder bed machine.

Spee3D is a privately held company that raised $1.5M to expand its sales channel in Europe and North America.

Conflux (Geelong) is developing patented AM heat exchange technology for the automotive industry.
New Government initiatives

South Australia has launched a new state-of-the-art metal additive manufacturing facility, *Australian Advanced Materials Manufacturing Pty. Ltd.* (AAMM). It aims to help local companies accelerate product development and validation testing in the broad field of additive manufacturing.
New Recent Major Metal AM Projects

“Just in time implants”

A$12.1 million for 5 years from Oct 2017

Led by RMIT University (Prof Milan Brandt) with IM-CRC, the University of Technology Sydney (UTS), St Vincent’s Hospital Melbourne and global medical technology firm Stryker
AIM: To investigate and develop a method to automatically generate conformal implant structure suitable to the bone’s biomechanical function, enhance bone in-growth rate and be manufacturable using AM

• Partner – Prof. Peter Choong

Vision: Manufacture and implant during surgery

Patent application on methodology
Application: Vertebra lattice implants

Successful implanted into patient 2015

Australia’s first 3d printed spine implant
Woodside Innovation Centre at Monash University (Prof Nick Birbilis)

Woodside is an Australian oil and gas company with a global presence

A$ $10 million over 5 years by Woodside from June 2016; mainly on AM of stainless steels
Local AM product development

SPEE3D released their LightSPEE3D machine for sale at the end of 2017 and have now sold systems in Australia, Germany and Singapore.
Aurora continues to develop and sell their low cost SLM based machines globally and will be releasing their large format machine in 2018.

We manufacture the world's most affordable multi mode 3D metal printer in its class at $49,999USD.
Thank you

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