Cold Spray Additive Manufacturing: from the Laboratory to the Market

North American Cold Spray Conference 2016 Edmonton Canada
December 1, 2016

Stefan Gulizia - Research Team Leader
Outline

• CSIRO – a snap shot

• CSIRO Cold spray Titanium Additive Manufacturing Technologies :-

1. CSIRO Cold spray facilities
2. Modelling Capabilities
3. Low cost Titanium powder production
4. Billet and preform Technology
5. Continuous pipe manufacture
6. Print Roller Technology
7. Low cost Invar 36 tooling for carbon fibre part manufacture
8. Aero engine casing
9. Spark Plasma Sintering of Cold Sprayed Ti-6Al-4V

• Summary Q&A
CSIRO today: a snapshot

Australia’s national science agency

One of the largest & most diverse in the world

5400+ staff over 55 locations

Ranked in top 1% in 14 research fields

150+ spin-offs based on our IP & expertise

170+ active licences of CSIRO innovation

Building national prosperity and wellbeing
CSIRO Delivers via Business Units

AGRICULTURE  BIOSECURITY  DIGITAL PRODUCTIVITY AND SERVICES  ENERGY

FOOD AND NUTRITION  LAND AND WATER  MINERAL RESOURCES  OCEANS AND ATMOSPHERE  MANUFACTURING

North American Cold Spray Conference 2016 Edmonton Canada, December 1, 2016 - stefan.gulizia@csiro.au
We pull resources from the overall pool of 5,000 dedicated employees of CSIRO.
The Program taps into the skills of 100 CSIRO scientists and engineers.
We strive to assist industry to be more efficient and affordable.
Cold Spray Additive Manufacturing

Research Capabilities
CSIRO Cold Spray Capabilities

CSIRO has state of the art Cold Spray research facilities in Melbourne established 2002

- Cold Spray equipment CGT Kinetiks 3000 & 4000 Series
- Plasma Giken PCS 1000 with high deposition rate
- Low powered portable Cold spray – Cu, Al, Zn
- Australia’s Centre Cold spray Additive Manufacturing $10M Govt. funding
- AM & Deposition Team: 14 research staff, 4 PhDs, 1 Post doc, 2 visiting scientists
Capabilities

1. State-of-the-art fully Automated Cold spray systems

2. PIV – Tecna particle velocity, Flir IR Camera

3. Full Materials Characterisation; SEM, EDX, FIB,TEM, XRD, LOM, Mastersizer

4. Australian Synchrotron & Centre of Nano-fabrication

5. LAB 22 Centre of Excellence in Additive Manufacturing
   ARCAM, Concept laser, Optimet, Voxlejet
Modelling & Simulation

• To understand complicated deposition events in the rapid, solid state 3D additive manufacturing process

• A cost effective approach to optimise process parameters

• To develop future cold spray systems tailored for a particular industry
Validation of 3D Multicomponent Model

According to:

• Substrate temperature
• Particle velocity using Particle Image Velocimetry (PIV)
• Particle location on surface of substrate (current)
Comparison of the PIV measurements (Zahiri et al., 2009 and Wong et al., 2011) with 3D model results at 550°C, 1.4 MPa for helium and nitrogen.
Example 1: Visualisation of the Cold Spray Whole Flow Field for 3D Additive Manufacturing

CP Titanium cold spray whole flow field at 800C and 3Mpa for a commercially available cold spray nozzle (a) Temperate and (b) velocity.
Cold Spray Additive Manufacturing

Creating a New Titanium Industry in Australia
Development of New Titanium Manufacturing Industry in Australia

- Our research is concerned with manufacturing parts directly from low cost powder using Cold Spray technology.

- From ore to product

![Titanium Minerals Mine Production Graph](Image)
There ARE “other” Titanium Powders

- Armstrong Process – Cristal
- FFC Process – Metalysis
- Alloys
- CSIR
- Hydride DeHydride
- ADMA
- China

They all require shaping and sizing for Cold spray application
CSIRO Powder Manipulation Technology (PMT®)
Cold Spray Additive Manufacturing

Titanium Billet/Preform Manufacture
Low Cost Titanium Billet/Preform Processing Route

- Gas atomised Powder $$$
- HDH Powder $$
- CSIRO PMT sponge-derived Powder $

Cold Spray AM Billet & Preform

- Forging
- Extrusion
- Rolling
- HIP
CSIRO has the capability to produce >30 kg/hr of product via cold spray
Cold Spray Manufacture of Round CP-Titanium Billet

• Advantages:
  • Direct production of titanium billet from powder bypasses the traditional route of ingot manufacture
  • Product has excellent microstructural uniformity
Ti-6Al-4V Round Billet - Density uniformity

- Billet produced using Plasma Giken cold spray system; 900°C, 5MPa.
- Porosity variation to within 3.5 %
- Red line indicates porosity determined by bulk density measurement (Archimedes method)
Deposition Efficiency

- Deposition efficiency = mass of deposit / mass of powder sprayed
- Generally ~ 97% for CP titanium
- For Ti-6Al-4V, slightly lower
Tensile Testing of Hot Rolled & Annealed Samples

- After rolling the samples were heat treated at 950°C for 2 hours under argon
- At least 12% elongation in all hot rolled samples
- UTS = 994 – 1001 MPa
Microstructure After Hot Isostatic Pressing (HIP’ing)

- Commercial purity (grade 2), Ti powder
- Cold sprayed using a CGT Kinetiks 4000 system (800°C, 3.5MPa)
- HIP’d at 920°C, 100MPa for 2 hours
Mechanical Properties after Hot Isostatic Press (HIP)

- Commercial purity Ti powder
IP Landscape

- CSIRO has successfully used Cold spray technology as an Additive Manufacturing technology.

- We have protected our IP via National phase PCT:
  - “Cold spray billets and pre-forms”

- Our powder manipulation technology IP is also protected under a National Phase PCT:
  - “Powder Manipulation”
Cold Spray Additive Manufacturing

Continuous Titanium Pipe Manufacture
Titanium Pipe Production Technology – Cold Spray

- Utilizing either fixed length mandrel or using FTT’s continuous process.
- For larger scale production the continuous method is the most suitable process.
Cold spray Additive Manufacture of Continuous Titanium Pipe

- Continuous Additive Manufacture of Titanium pipe via Cold
- Large variation in pipe size and schedule can be manufacturing
- Seamless design
- Robust jig design
- Small equipment footprint
Titanium Printing Roller
Anilox Printing Rollers

- Anilox Rollers are a fluid (e.g. ink) transfer roller used in the flexographic printing process.

- Wear resistance is achieved by coating metal rolls with chromium oxide ($\text{Cr}_2\text{O}_3$) using plasma spray.

- A cell pattern is then engraved into the $\text{Cr}_2\text{O}_3$ surface by laser.


Plasma Spray Gun used for $\text{Cr}_2\text{O}_3$ coating.
2.5 year project between Melbourne-based company Kinetic Elements and CSIRO, and ongoing collaboration since

Kinetic Elements are commercialising the titanium anilox roller under the name ‘Tiaurum’ – made from titanium (Ti), looks like gold (aurum)

Titanium deposited by cold spray, followed by

Laser treatment of the titanium surface

Laser treatment of anilox roller
The Titanium Roller

- The laser treated titanium surface has proven wear resistance from printing press trials

- Deposition efficiency of cold spray of titanium 96-97%
  - Great improvement over plasma spray of Cr$_2$O$_3$ (<45%)

- Damaged roller surface can be repaired by cold spray
  - Plasma sprayed Cr$_2$O$_3$ coatings need to be completely stripped & re-sprayed
Acknowledgements:
Anselm Oh, Peter King, Andrew Urban, Saden Zahiri, Mark Styles & Darren Fraser, Christian Doblin – CSIRO
Muhammad Faizan-Ur-Rab PhD student – Swinburne University
JingJing Sun PhD student – RMIT University

Thank you

Stefan Gulizia - Research Team Leader
CSIRO Manufacturing

t +61 3 9545 2069
e Stefan.gulizia@csiro.au
w www.csiro.au/titaniumtechnologies