Economics of AM Today

**Production Requirements**
- 5,000 parts to be manufactured per annum
- 10 parts per build
- 500 builds per annum
- 0.9kg per final part

**Zero Reuse of Powder**
- 53kg powder wasted per build
- 26.5T of powder wasted per year (53kg x 500 builds)

**Arbitrary 10x Powder Reuse**
- 50 campaigns per year (500 builds ÷ 10 recycles)
- 53kg powder saved per subsequent recycle after 1st build
- 3.0T of powder wasted per year (59kg x 50 campaigns)

**23.5T Ti saved per annum**

As an industry do we have the confidence in our processes to continually re-qualify our powder?
The AM Barriers

- Integration?
- Consistency?
- Contamination?
- Quality?
- Data?
- Process optimisation?
- Environmental controls?
- Reuse?
- Powder handling?
- Health and safety?
- Material development?
- Traceability?

Economics?
Safety?
Risk?

Mechanical Testing
How do LPW Carpenter Additive provide solutions?

Take the handling of bulk powder today...

#ReducePlasticWaste
Risk – Environmental Control Solution

AM cell
Temp = ~28°C
Humidity = 60%

Logistics area
Temp = ~8°C
Humidity = 40%

PT123abc
Temp = ~8°C
Humidity = 20%

PT123abc
Temp = ~25°C
Humidity = 20%

X Hours later…
Move powder to AM cell
ready to perform build

Load powder into
AM machine

AM Machine

Question: Am I safe to open?
Answer: No, dew point too high. Please wait X hours

Question: Am I safe to open?
Answer: Yes, go ahead

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Risk – Traceability Control Solution

Key:
Gen = Generation

Batch A → Powder Cert

Group 100kg

Group 50kg

Group 25kg

Build

Sample Part

Input Group 10kg

Output Group 10kg

Gen A

Gen A

Gen A

Gen B

Gen A

Gen B

Gen C

Gen A

Gen A

Gen A

Gen D

Gen A

Blend

Combine

Group 55kg

Powder Sample

Sample Part

Input Group 10kg

Output Group 10kg

Input Group 10kg

Output Group 10kg

Input Group 10kg

Output Group 10kg

* Test For Elements - Certification Refers To Latest Test

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Risk – Traceability Control Solution
Quality – Contamination Control Solution

It’s not just grey dust…

Grey

Shades of Grey

Shades of Grey + Devil Particles

Virgin …as expected

What you get with reuse…

Powder that has previously been used in the AM process. Will contain an amount of oxidised particles but the individual O2 wt% of these particles will not cause localised failure of an AM part. But will contribute to the reduction of mechanical properties in a repeatable way.

Increased risks of re-use

Powder that contains powder particles or collections of powder particles that have super high O2 wt%. These increase the risk of localised failure due to inclusion type failure modes, previously presented by LPW.
Safety – Contamination Control Solution

The results of contamination can be catastrophic...

...but can originate from anywhere
Economics – Is ‘Arbitrary’ Acceptable?

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**Input powder** •63kg  
**Waste** •c.-1kg  
**Part** •.9kg  
**Powder for reuse** •53kg

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**Recycled Powder 53kg**

**Fresh Input 10kg**

**Next stage build 63kg**

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23.5T Ti saved per annum

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As an industry do we look to make these savings?
Economics – What Factors Affect Powder Degradation?

Mechanisms for O and N Pickup

- **Spatter reacts with O and N, forming O+N rich particles**
- **O+N rich particle falls into powder bed**
- **Greater scan area = more spatter**
- **More spatter = increased O and N**
- **Laser**
- **Ar flow**
- **Ti (>>450 °C)**

- **O and N in atmosphere react with melt pool surface**
- **Ar atmosphere**
- **O < 1000 ppm**
- **N < 4000 ppm**
- **O+N rich / TiOₓ + TiNₓ**
- **Ti powder**
Economics – What Factors Affect Powder Degradation?

Direct imaging of line scan at 100 W, 0.5 m/s - side view.

www.sciencedirect.com
Economics – What Factors Affect Powder Degradation?

- **Low part:** Powder ratio
  - Powder bordering part lies in ‘Heat Affected Zone’ (HAZ)
  - ‘Heat affected’ powder can pick up O and N

- **Higher part:** Powder ratio = larger area of HAZ

- **High part surface area = larger area of HAZ**
Examples from recycled powder

O+N rich particles which have fallen into powder bed

‘Heat affected’ powder which has picked up O and N

Ni (+ °C)
Economics – The Effect of O2 Pickup – Titanium Alloys

- Oxygen content of powder increases with increasing reuse
- Oxygen pick up in powder is reflected in built parts
- Increase of oxygen in parts results in evolution of mechanical properties
Economics – Material Cost vs. The Total Cost of Ownership

- **Powder cost per kg**
  - $/kg

- **Builds per batch kg**
  - /kg

- **Parts per build**
  - /parts

- **Cost per part**
  - $/

- **Volume**
  - Application and partner dependent

- **Powder specification**
  - In AM primarily supplier driven
  - Shift to partner driven as industry matures

- **Required kg of powder**
  - Application dependent

- **Exceed specification limits**

- **Size of parts**
  - Application dependent

- **Size of build volume**
  - Partner (machine) dependent

- **Initial properties**
  - Powder/supplier dependent

- **Rate of powder evolution**
  - Primarily influenced by processing but also powder dependent

- **Application Dependent**
  - Powder/supplier dependent

- **Partner dependent**
Economics – Cheaper Powder = Cheaper Parts?

Case Study - a **12.5 % increase** in cost of powder results in **25% reduction** in the powder contribution costs of the finished part.

- **$/kg**
  - **O=1150ppm**
  - **20x reuse**
  - **100 builds**
  - **1000 parts**
  - **Powder out of spec**
  - **Parts out of spec**
  - **$-$

**VS**

- **+12.5$/kg**
  - **O=1000ppm**
  - **30x reuse**
  - **150 builds**
  - **1500 parts**
  - **Powder out of spec**
  - **Parts out of spec**
  - **$-25%$**

**25.0% ↓**
Measuring O wt% in Ti AM Powder Today

How many particles are in 1kg of powder?

2,000,000,000

We typically take 0.1g (approximately 200,000 particles) and use a destructive test to give us an indicative result for the bulk O wt%.

On an average 100kg build and testing 0.1g equates to one in a million particles.
Exposure 1
Exposure 4
Would you be confident in reusing this powder...?

Comparison of exposure 6 (left) and exposure 1 (right):
Principles of Powder Image Analysis

- A powder image has lots of potential data
  - Colour
  - Size
  - Shape
  - Packing density
  - Non-powder artefacts
  - Powder anomaly detection
  - Texture

- Data from an image can be harvested using image processing algorithms and neural networks

Ti64 virgin powder doped with ~10% ‘blue’ oxidised powder
Powder Image Analysis – TEMPO & ILIAD

TEMPO – Technology for Evaluating Metal Powder Oxidation
ILIAD – In Line Image Analysis Device

• Method of capturing images of powder has been developed that can be used in the lab or within a ‘powder system’

• Beta test software can associate an oxygen wt% with each powder particle (AI developed from manufactured coloured powder)

The potential predictive power of powder image analysis could include the ability to:
• Understand properties that effect process parameters & mechanical properties
• Provide data to make closed-loop decisions to optimise AM & look at long term trends
• Develop new techniques to specify powder