Recent Advances in Wire-Based Additive Manufacturing

Presented by:

OSA Lasers in Manufacturing Technical Group

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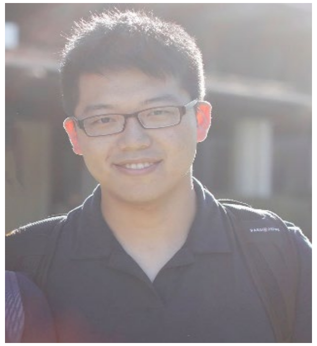

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Our Technical Group at a Glance

Our Focus

- A highly interdisciplinary group featuring members from both academia and industries covering range of topics related to lasers.
- To discuss the technologies used in manufacturing applications that uses lasers for cutting, drilling and welding processes.

Our Mission

- To benefit *YOU*
- To provide platform to optical community for connecting, Engaging and Exciting with others.
- To Organize webinars, social media, publications, technical events, business events, outreach
- Interested in presenting your research? Have ideas for TG events? Contact us at TGNonlinearOptics@osa.org.

Where To Find Us

- Website: www.osa.org/FL
- LinkedIn: https://www.linkedin.com/groups/8127636/9

Past/Upcoming Events:

1. Networking Event during OSA Laser Congress at Munich :

Recent Trends in Laser Technology and Its Applications in Manufacturing

Date: Monday, 30 Sep 2019 12:30-14:00

Location: Austria Centre Vienna, Austria

2. **Webinar 1:**

Recent Advances in Wire-based Additive Manufacturing

Date: 09th January 2020, at 12:30 PM - 1:30 PM (Eastern Time (US and Canada)

Dr. Yashwanth Kumar Bandari, Edison Welding Institute , Buffalo Manufacturing Works, USA

3. Panel Discussion during OSA High Brightness and Light-Driven Interaction Congress at Prague :

Date: TBD

Location: :Prague Congress centre, Prague, Czech Republic

How to join this Group:

If you are OSA member: Log-in to your OSA Account and chose FL group in Technical Groups Category.

You can also join in our dedicated linkedIn page : https://www.linkedin.com/groups/8127636/9

If you have any interesting activities/ideas or interested in giving a Webinar/Talk/Panel Discussion, do let me know by email nithi.physics@gmail.com

Today's Webinar

Recent Advances in Wire-Based Additive Manufacturing

Dr. Yashwanth Kumar Bandari

Edison Welding Institute, Buffalo Manufacturing Works, USA

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Speaker's Short Bio:

Ph.D. degree from Cranfield University, UK
Postdoc at the Oak Ridge National Lab (ORNL) USA

Large Scale Metal Additive Manufacturing – Processes, Configuration, and Challenges

by

Dr. Yash Bandari

Additive Manufacturing Applications Engineer
Edison Welding Institute (EWI)
OSA Technical Seminar
9th January 2020

Agenda

- ✓ Overview of Metal Additive Manufacturing (AM)
- ✓ Processes for building large scale metal parts – wire-based AM
- ✓ Types of wire AM processes – which is the best?
- ✓ Case studies
- ✓ Technicalities and challenges for wide adaption
- ✓ Futuristic goals and conclusions

What is Additive Manufacturing (AM)/3D-Printing ?

- AM is a technology that enables the fabrication of **complex**, near **net shape** components by deposition of many consecutive **layers** of one or more materials
- Metaphor of *Sculptor* vs *House builder*

The Traditional Approach: Subtractive Manufacturing

Additive Manufacturing (AM)

Plastic

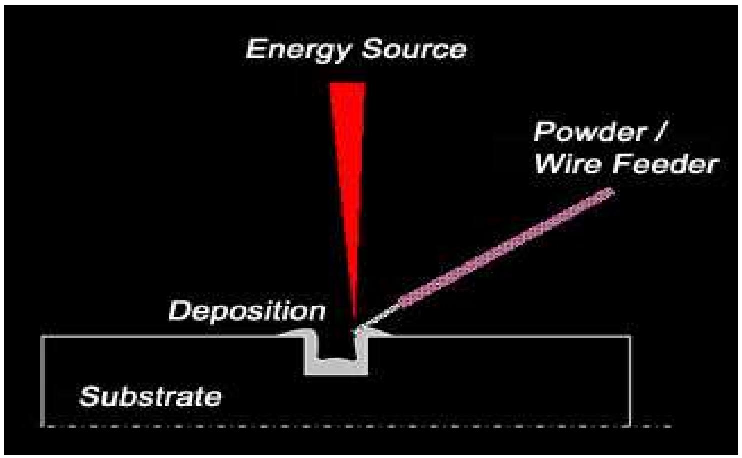
or

Metal

- Stereolithography
- Fusion deposition modelling
- ....

Metal AM // What is it?

Very Simply



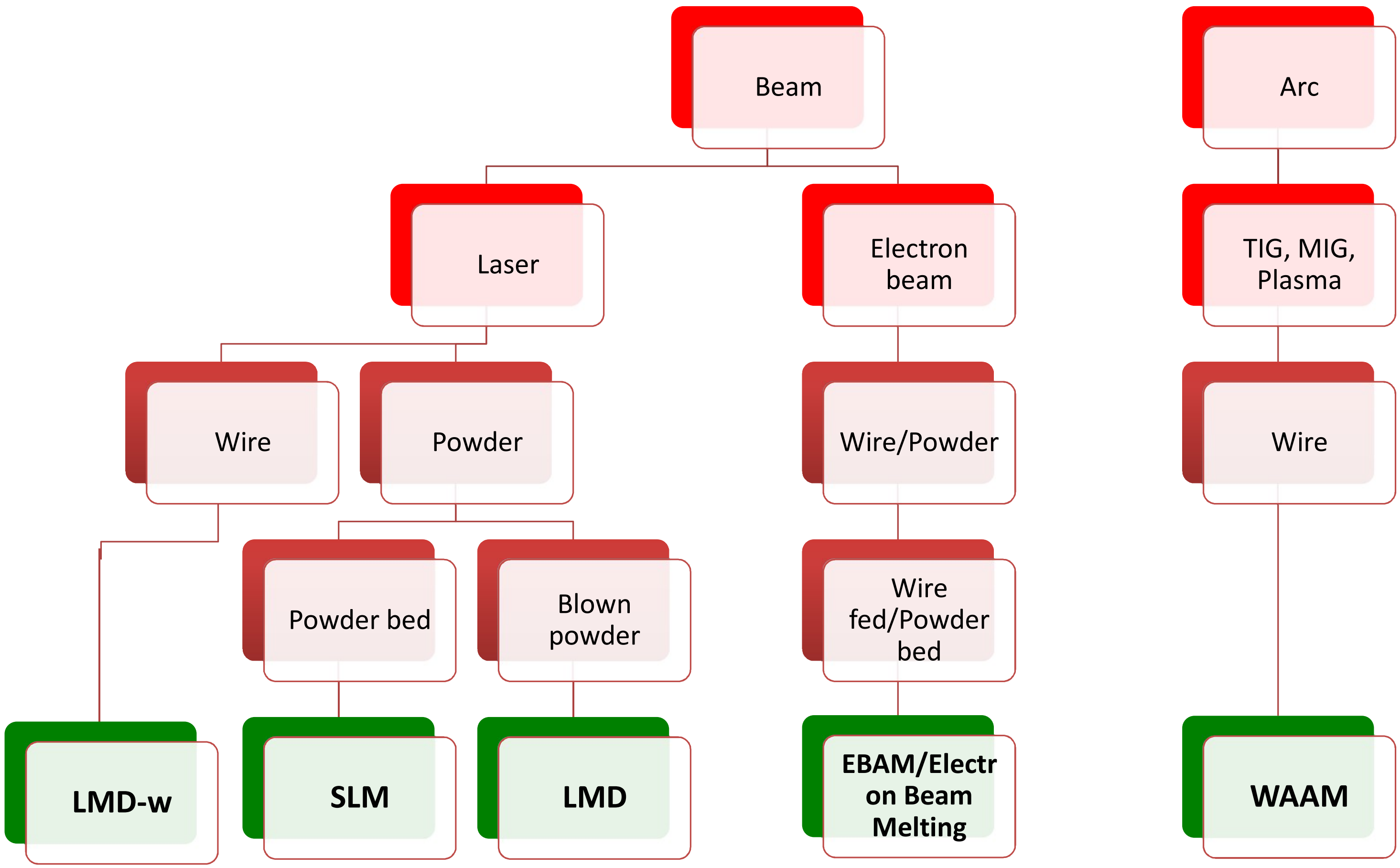
- Also known as
  - Additive (Layer) Manufacture (A(L)M)
  - (Laser) Cladding
  - Buttering
  - Digital manufacture
  - Direct Light Fabrication
  - Direct Metal Casting (DMC)
  - Direct Metal (Laser) Deposition (DM(L)D)
  - Laser Direct Casting or Deposition
  - Laser casting
  - Laser clad casting
  - Laser consolidation
  - Laser curing
  - Laser Engineered Net Shaping (LENS)
  - Lasform
  - Laser melting
  - (Metal) Rapid Prototyping
  - Net shape manufacture
  - Net shape engineering
  - Shaped deposition manufacturing
  - Shaped melting
  - Selective Laser Sintering (SLS)
  - Selective Laser Melting (SLM)
  - Shaped Metal Deposition (SMD)
  - Shape Melting Technology (SMT)
  - Shape welding
  - Solid freeform fabrication (SFF)

Metal Additive Manufacturing hardware

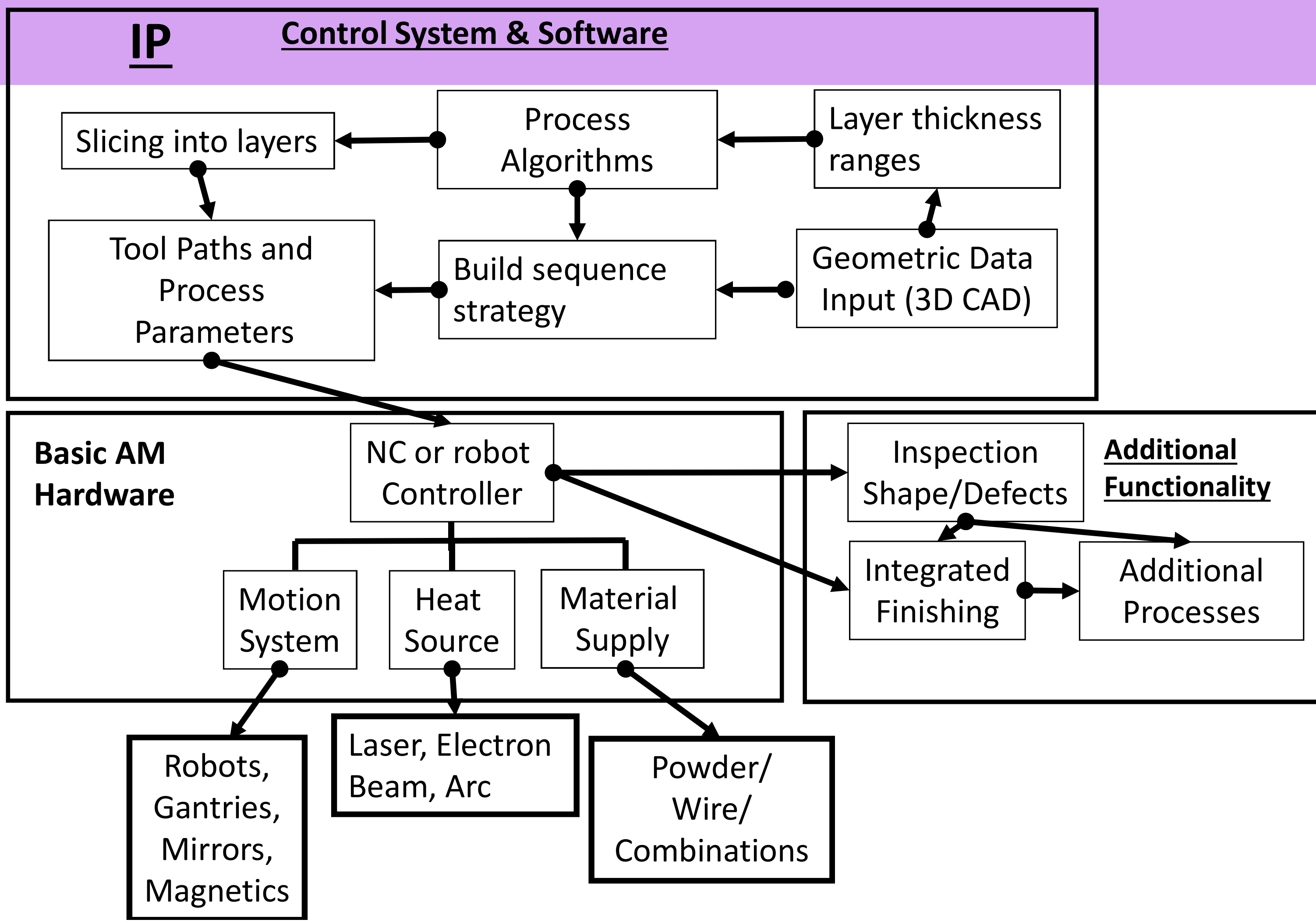
- **Three main constituents** are needed:
    1. Heat source – Electric Arc, Laser, Electron Beam
    2. Feedstock;
    3. Manipulator.

- The **combinations** of different types of each constituent creates a **wide range of metal AM processes**.

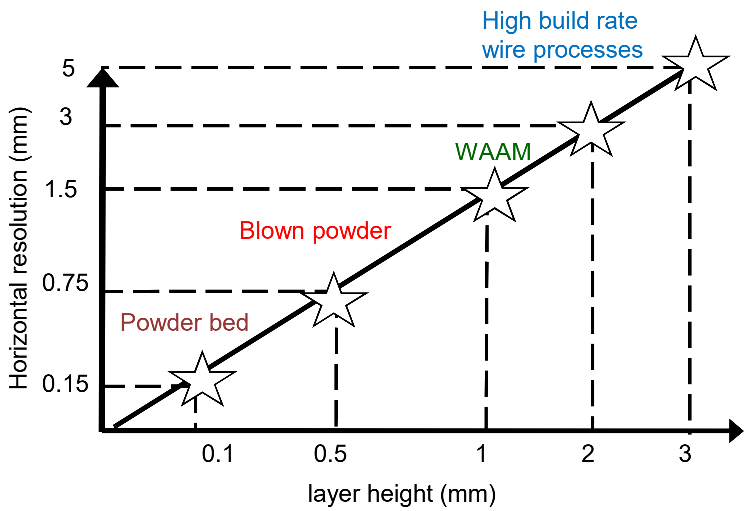
Metal Additive manufacturing processes



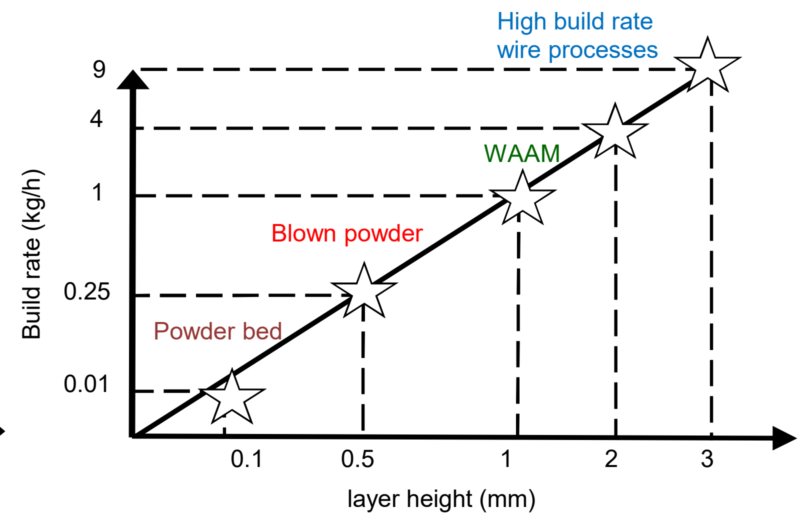
Basic metal AM system configuration



Metal AM // Which system to use?



Resolution depends on the exact width-to-height ratio and depends on several factors but is usually at best 1.5 times the layer height



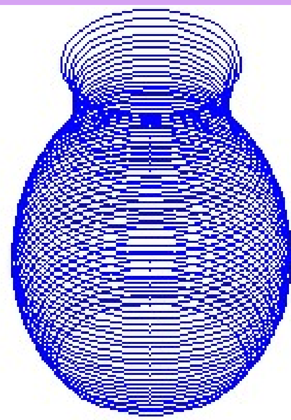
For a single axisymmetric energy source at maximum melting efficiency:
The build rate depends on the square of the layer height

Direct feed - powder or wire?

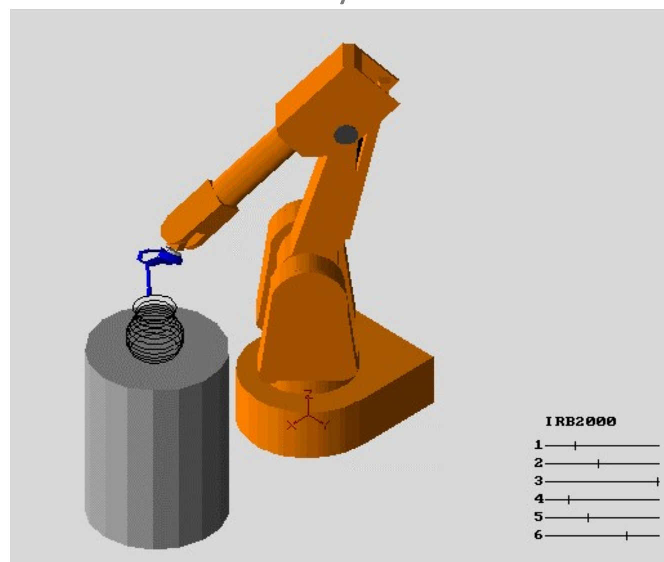
	Powder	Wire
Cost	High	Medium
Quality	Variable	High (Ti, Fe, Ni), variable Al
Feeding	Complicated unless using side feed	Easy well established industrial process
Material efficiency	Typical 40 - 60%	100%
Safety issues	Yes – especially Ti/Al	No
Recycling	Possible with processing	Not required
Out of position deposition	No	Yes
Rotation problem	Coaxial – no, side feed yes	CMT – no, plasma - yes

Wire-fed Metal AM

Slice an object into layers



Programme a robot or machine tool to trace out the layers



Using a deposition tool to **build up** your part

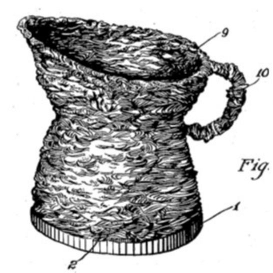
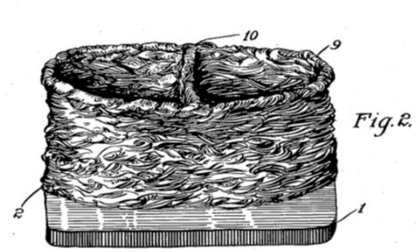
Wire fed Additive Manufacture – History

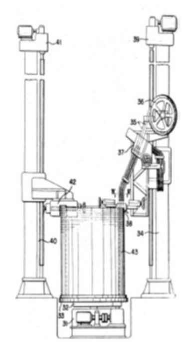
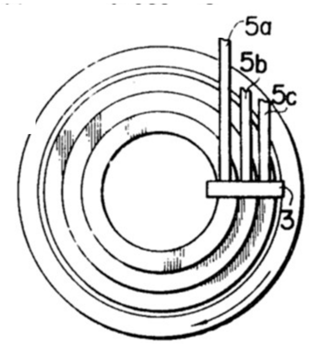
- **1926** Baker patented "The use of an electric arc as a heat source to generate 3D objects depositing molten metal in superimposed layers"

- **1971** Ujiie (Mitsubishi) Pressure vessel fabrication using SAW, electroslag and TIG, also multiwire with different wires to give functionally graded walls

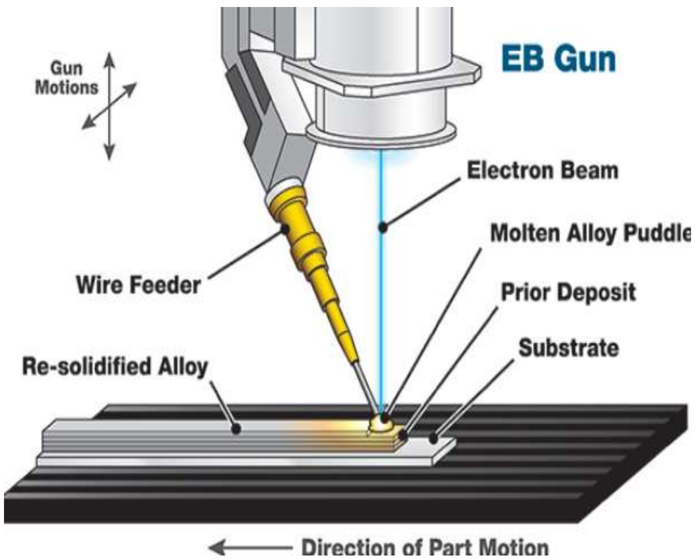
- **1993** Prinz and Weiss patent combined weld material build up with CNC milling – called Shape Deposition Manufacturing (SDM)

- **1994-99** Cranfield University develop Shaped Metal Deposition (SMD) for Rolls Royce for engine casings, various processes and materials were assessed – still in production

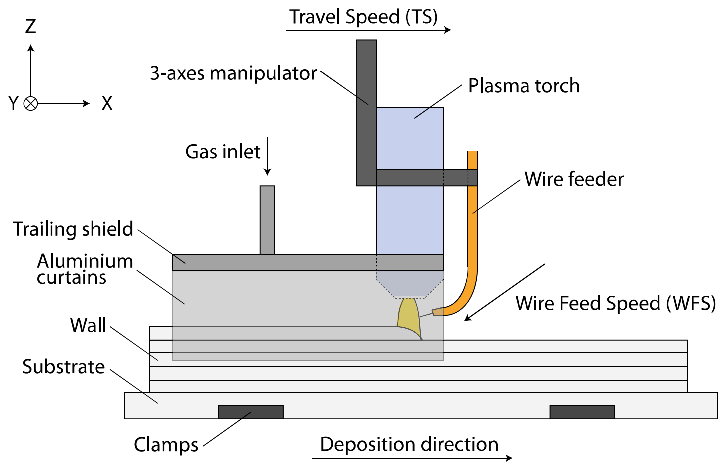



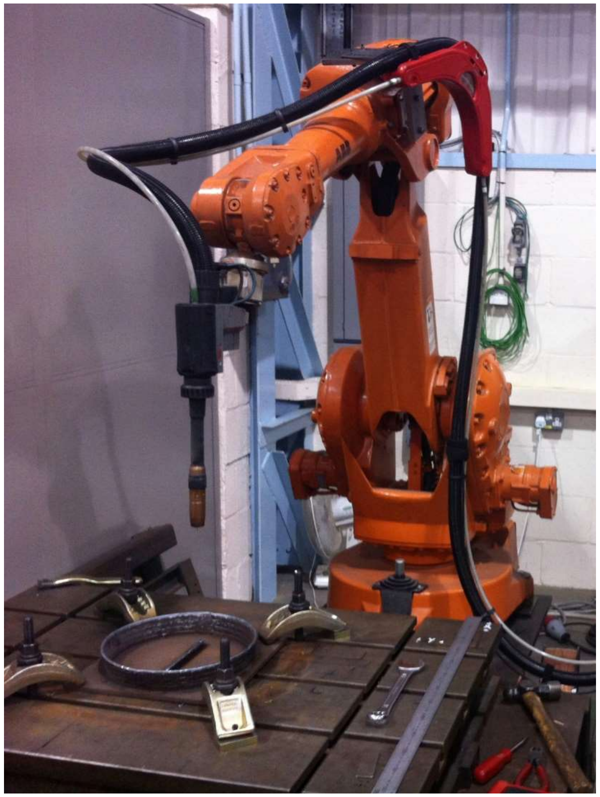
Electron Beam Additive Manufacturing (EBAM)



Wire + Arc AM (WAAM)

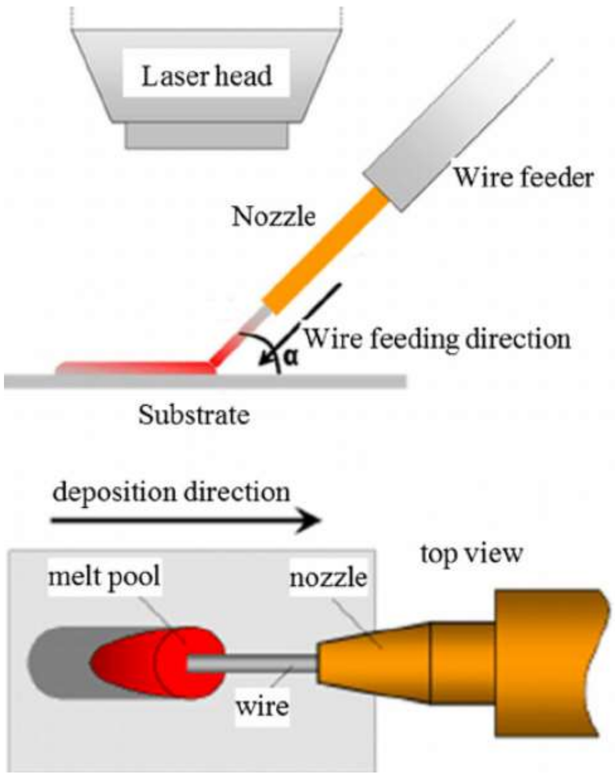


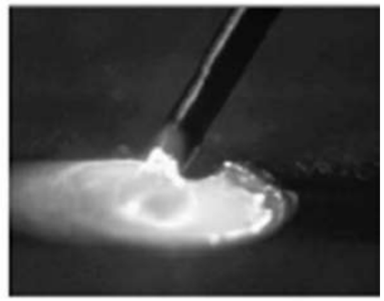
Plasma or TIG based deposition

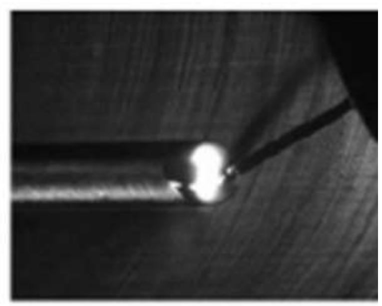


MIG based deposition

Laser Metal Deposition with wire (LMD-w)







Direct feed: E-Beam or Laser or Arc?

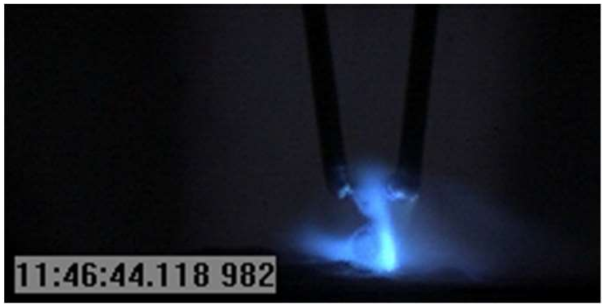
Criteria		E-Beam	Laser	Arc
Cost	*Capital*	Very high ($2M – 40kW)	High ($400k – 4kW)	Low-Medium ($100k – 4kW)
	Running	Medium	Medium	Low
Power efficiency		>80%	10% (CO_2 lasers)	>80% (MIG)
Heat and Mass transfer control		Yes	Yes	No (MIG)
Surface finish		Good	Very Good	Poor (MIG)
Feature size		0.5mm (upwards)	0.2mm (upwards)	1mm (upwards)
Residual stress		Less	Less	High
Safety issues		Very high	Very high	Medium
Build rate		High – very high	Medium - high	Medium - high

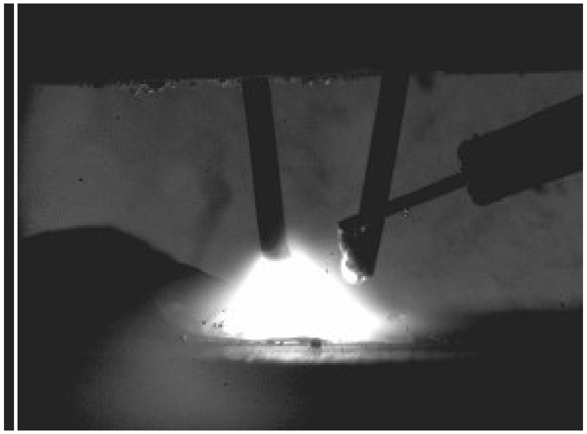
Organizations applying wire-based AM

Process	Organization/Company
EBAM	Edison welding institute (EWI), Sciaky, FAMAero, Lockheed Martin, University of waterloo etc.
LMD-w	Edison welding institute (EWI), Oak ridge national lab, GKN Aerospace, Additec, Fraunhofer, RWTH Achen, SMU Texas, Miller electric, MWES etc.
WAAM	Edison welding institute (EWI), Oak ridge national lab, Lincoln electric, Cranfield University, IIT Bombay, Gefertec, TWI, University of Nottingham, Wollongong University, Norsk Titanium, Glen Almond Technologies, LM UK etc.

Wire-feed Process features – deposit composition control using multiple feeds

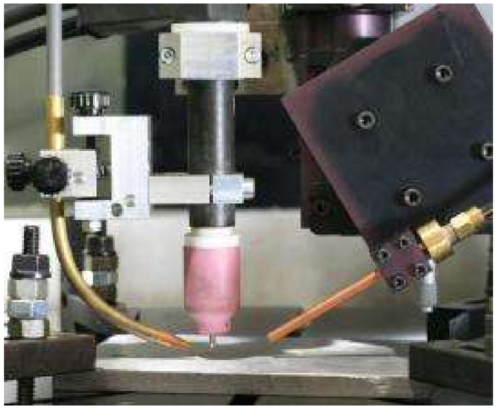
Multi wire approach





3 wire (Al8%Cu1.5%Mg – 140HV)

Wire + Powder



Part features

Straight near net shape Ti thin wall

Machined intersections

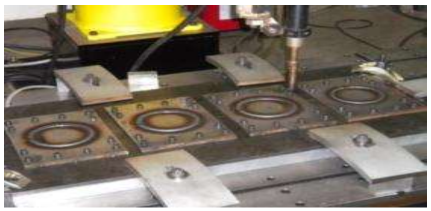
Angled and horizontal walls

Medium complexity 2D part

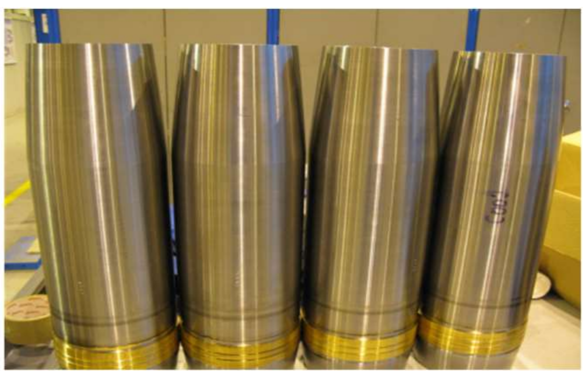
Weight efficient structure

With mixed materials

Example parts - 12 x projectiles



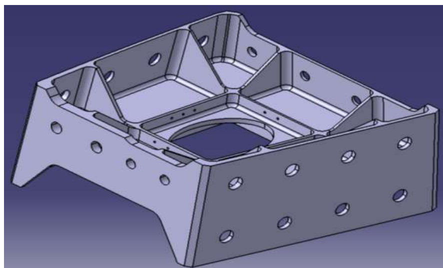
Mass 32 kg each // Deposition rate 4 kg/hr

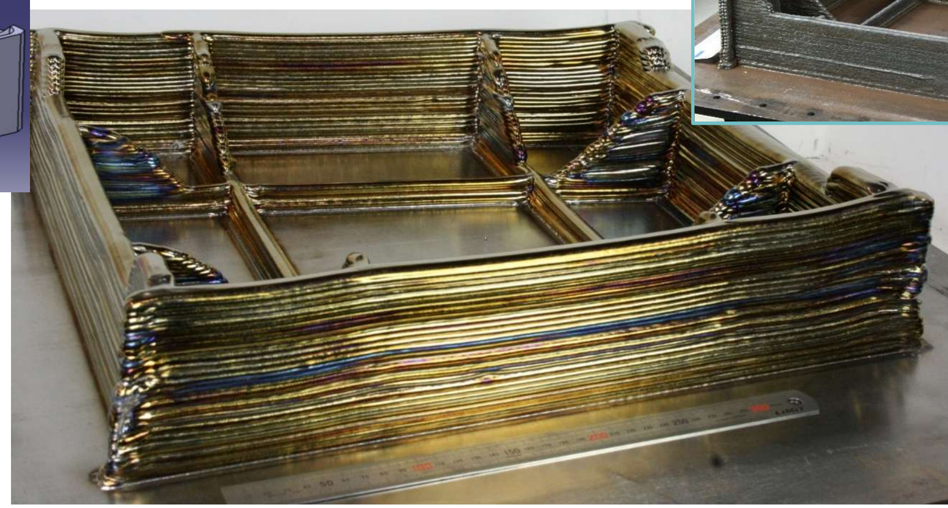


After machining

After assembly and just before firing

Case studies

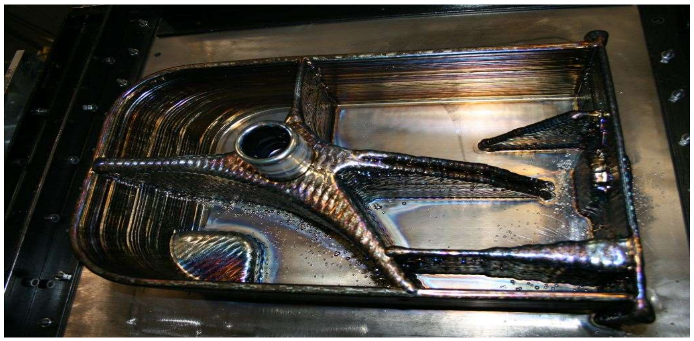




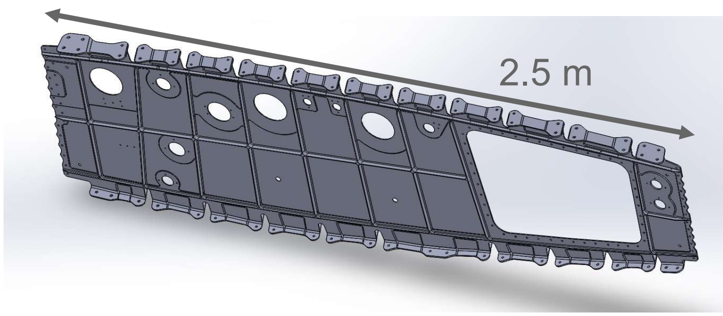
Landing gear component

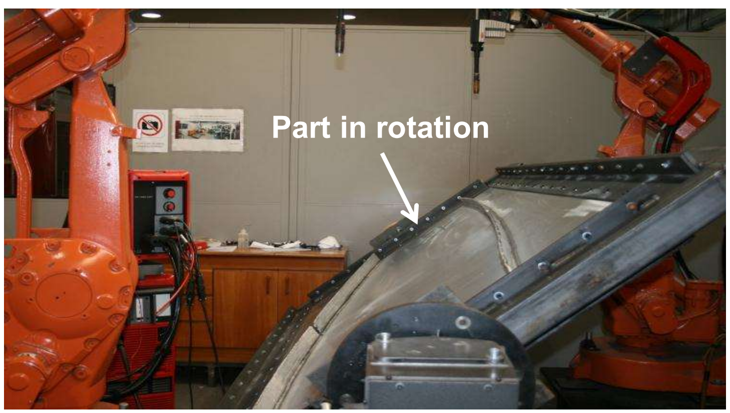
	Before Machining	After Machining	Buy-to-fly	Waste
Traditional	240 kg	21 kg	11.6	91%
AM	24 kg	21 kg	1.15	13%

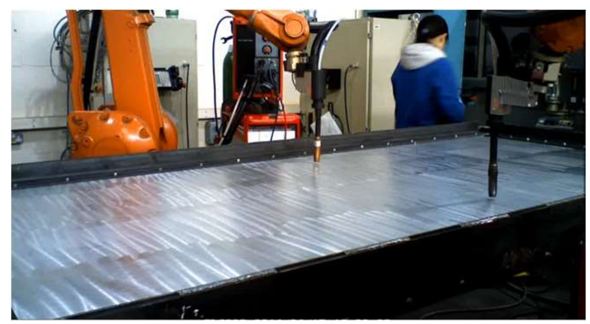
Other titanium parts



Tandem robots - Aluminium wing rib – case study

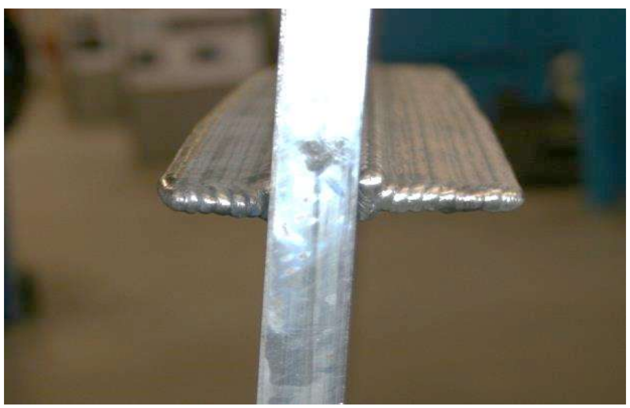






Contd.

This manufacturing method saved 500kg of material

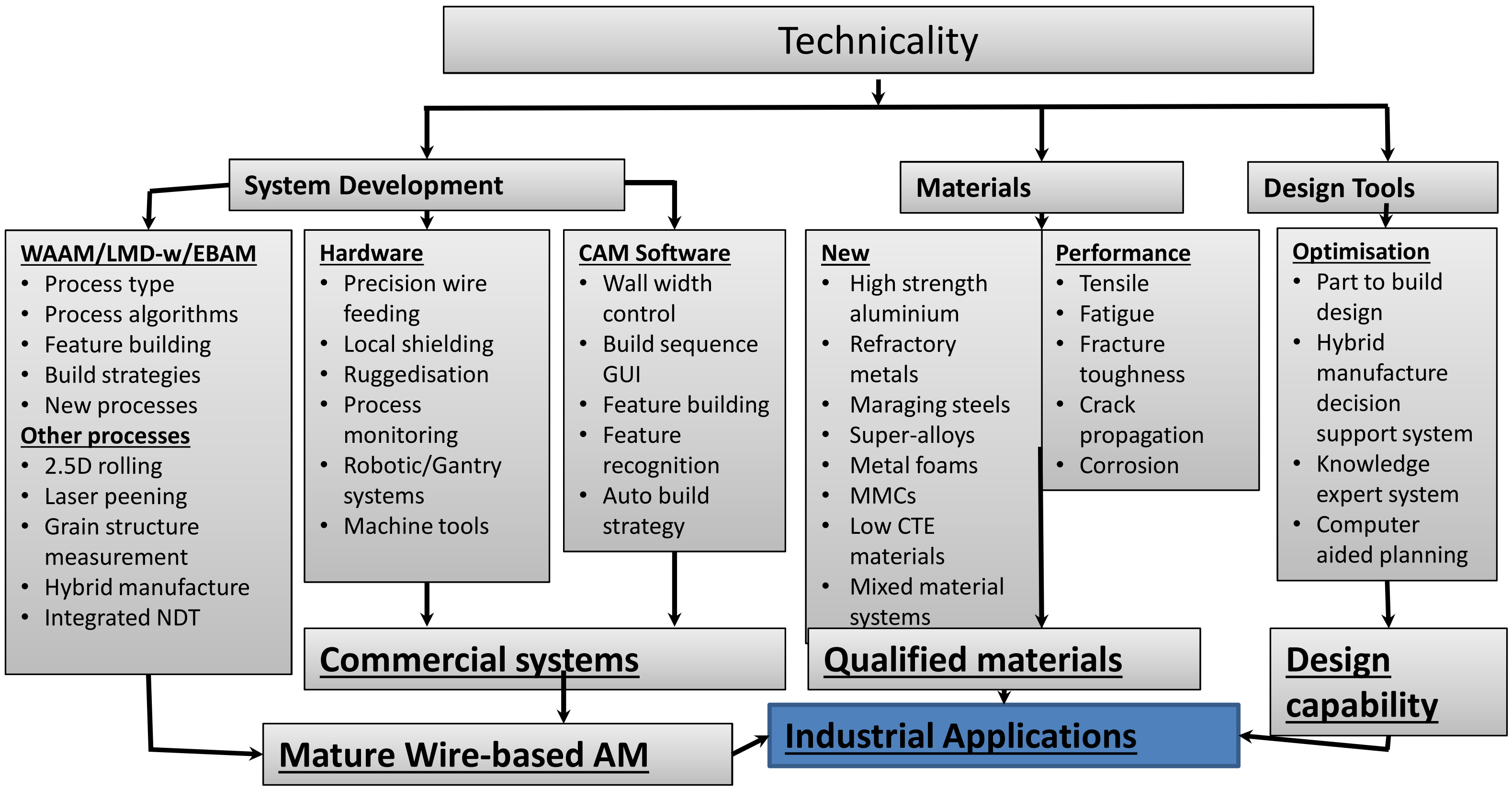


Design option (MRR = 65 kg/h)	BTF	Cost (£k)	Cost red.
Machined from solid	45	4.9	-
WAAM	12.3	2	58%

Example mechanical properties

Material	Titanium				Aluminium			Steel		
	6Al4V				2319		5087	HS	Maraging	
	Horizontal	Vertical	Horizontal rolled	Vertical rolled	As deposited	With ST and ageing	Rolled	As deposited	As deposited	With ST and ageing
2% Yield (MPa)	870	810	1020	995	120	310	239	660	1000	1765
UTS (MPa)	920	890	1075	1075	260	460	343	950	1350	1950
Elong. (%)	12.2	20.3	13	13	14	12	17	12	14	10

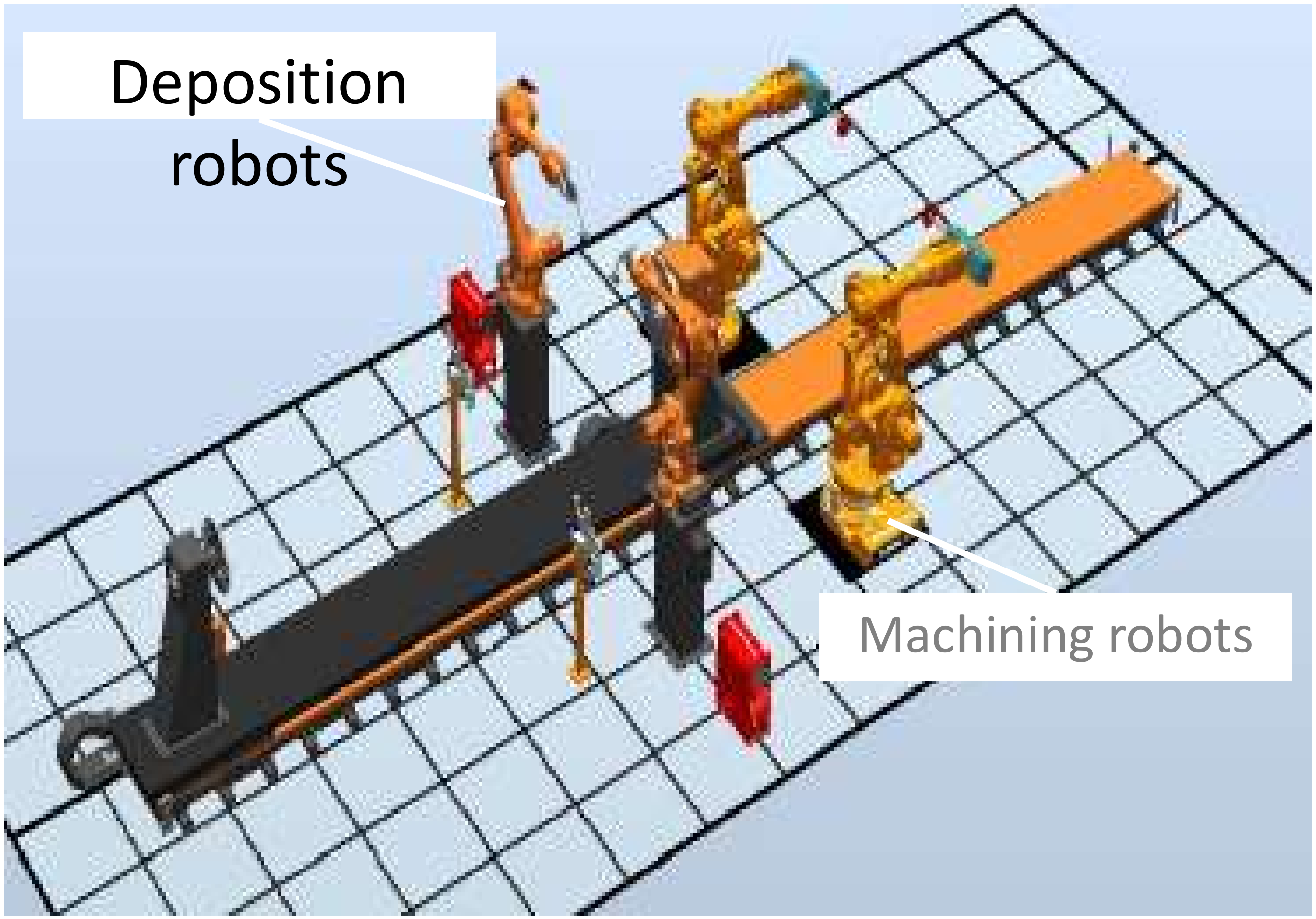
Wire-fed Technicality/Challenges



Implementing smart manufacturing (Ideas)

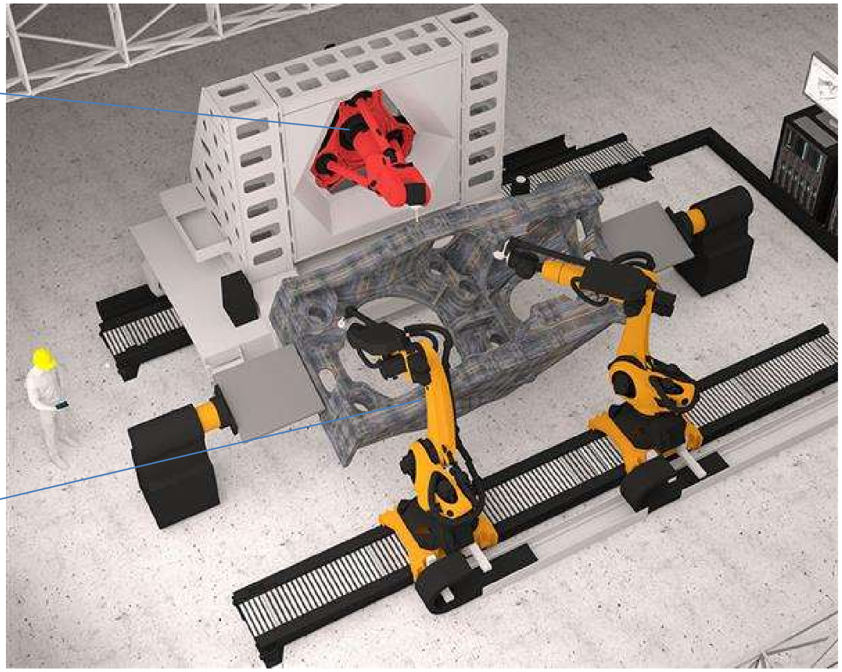
- Cobots – personal assistant like siri, alexa etc.
- Remote operator access – operator less part building
- Data logging – save all the process data
- Cloud computing – save the data in cloud for anyone to access
- Machine learning – predict when to change consumables, safety concerns
- Data analytics – perform in-situ monitoring and analyse
- Process simulation (not only visualization) – predict distortion, residual stresses etc
- Sharing economy – anyone can use the machine

Future - Tandem operations (Hybrid)



AM cell of the future (Hybrid)

Machining



Deposition robots

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Conclusions

- **Wire-fed Additive Manufacturing** is a feasible solution for low to medium complexity, **medium to large scale metal parts**
- **Any material** available in the form of wire can be applied
- **High deposition rates**, unlimited build volume, low capital and material costs
- WAAM, LMD-w, EBAM – each of them has pros/cons
- Qualification and certification still a bottle neck
- **Smart manufacturing** can be applied like cobots, cloud computing, remote access, machine learning, data analytic etc.

Thanks for your attention!

Dr. Yash Bandari

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