GE9X EBM TiAl Blade industrialization

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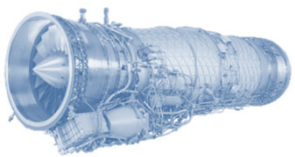
AvioAero History

In 1904 first flight Wright brothers

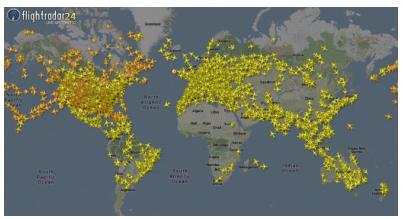
fighter-bomber G91 has been selected as option for NATO fleet



EJ200 is the engine for new aircraft
Eurofighter Typhoon

Start the production of **GEnx** engine,
Huge step forward in aviation propulsion tefchnology

In **2013** the society has been acquired by **General Electric** and start the design of new future's engine: **GE9X**



80% of aeroengines in the world are flighting with our components

1904 ----- **1908** ----- 1956 ----- **1969** ----- 2001 ----- **2003** ----- 2004 ----- **2013** ----- 2014 ----- **2019** ----- **TODAY**

FIAT AVIAZIONE

FiatAvio

Avio

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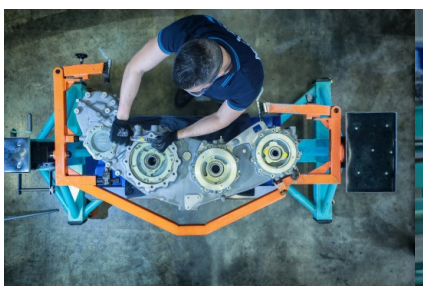
AvioAero Products

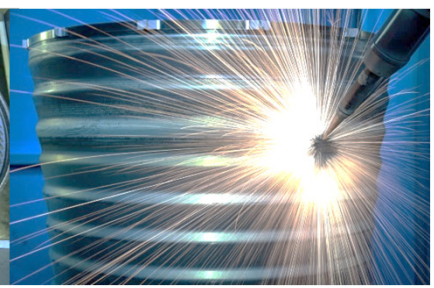
ACCESSORY GEARBOXES



POWER GEARBOXES

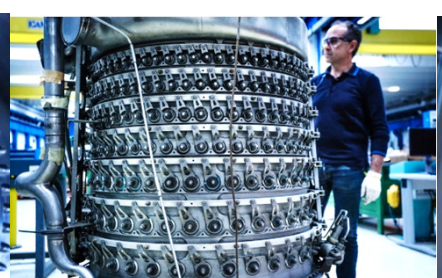
TURBINES

COMBUSTORS



STRUCTURES

MAINTENANCE



SAND CASTING FOUNDRY

ADDITIVE MANUFATURING

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GE Aviation – Global IPT Additive Footprint

2013 opening

EN9100 in 2015

1,800+ Sqm

35+ employee

50+ EBM machines (A2X / Spectra H)

AvioAero has 10 years of experience in ADDITIVE MANUFACTURING – EBM and DMLM

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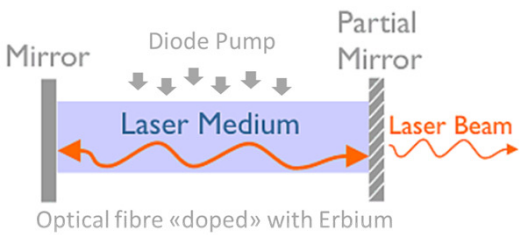
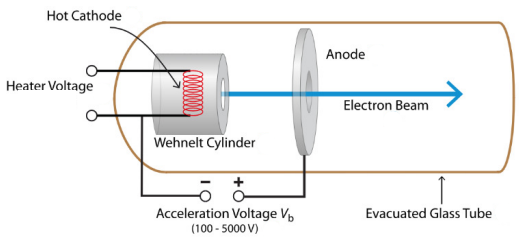
Powder bed: Laser & Electron Beam

Fibre Laser



Electron Beam Gun



Photons are "packets of energy"

- "Slow" scanning speed (deflected by mirrors)
- Do not interact with Gas
- Easy to focus (with optical lens)

- "Easy" powder evacuation
- Better feature resolution
- Needs many supports
- High residual stress and distortions

Electrons have mass and electric charge…

- High speed scanning (electromagnets)
- Needs vacuum and sintered powder
- More difficult to focus but better powder penetration

- All powder is sintered, difficult to clean internal passages
- Lower feature resolution and higher roughness
- Requires few supports allows 3D stacking
- Control of the thermal gradient very low residual stress

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Why TiAl? Why EBM?

Same material capability of Nickel Alloys but less than half the weight !

GEnx first engine with **Ti Aluminide** rotor blades: a **~400 lbs saving** per engine

- Ti Aluminide difficult to cast and prone to cracking during cooling
- Only few casting suppliers are able to produce blades

With Electron Beam Melting is possible to control the thermal gradient avoiding shrinkage and cracks defects during production

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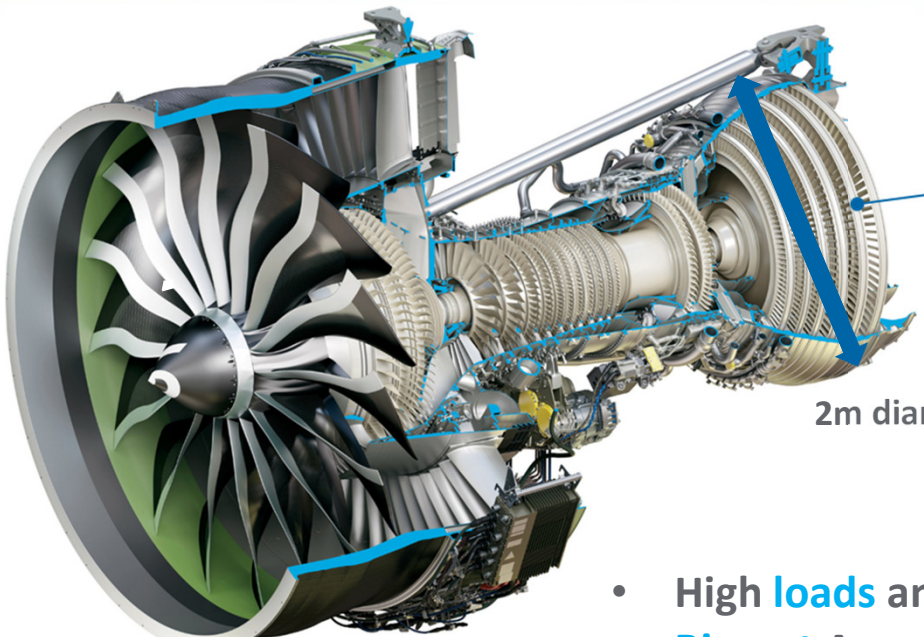
GE9X Low Pressure Turbine Rotor Blades



2m diameter

As built Blades

Finished Blade

40 cm

- High **loads** and **temperature**
- **Biggest** Aero engine LPT blades ever build
- Very **difficult material** to melt
- High production volumes: **50000+** blades per year in 2025

Big challenge for Additive manufacturing !

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TiAl Blades main milestones

2007-2013: early machine (A2X) and Material development

Mar 2014: TRL plan start

Jun 2015:

Endurance test completed on GEnx for TRL maturation

Dec 2015:

delivered **9X stg 5 and stg 6** FETT blades

Apr 2016:

Cameri site and EBM process qualified for **production quality**

Jan 2017:

second engine set delivered to assembly

Oct 2019:

~9000 blades produced, **Flight test bed** and **85% certification tests completed**

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EBM TiAl blade process

3D CAD model
Final part design

Build file

Machine prep

Additive Process

Machine unload

Powder recovery

Support removal

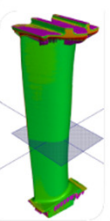
Hipping

Final HT

As built blade inspections

Machining and coatings

Final Inspections



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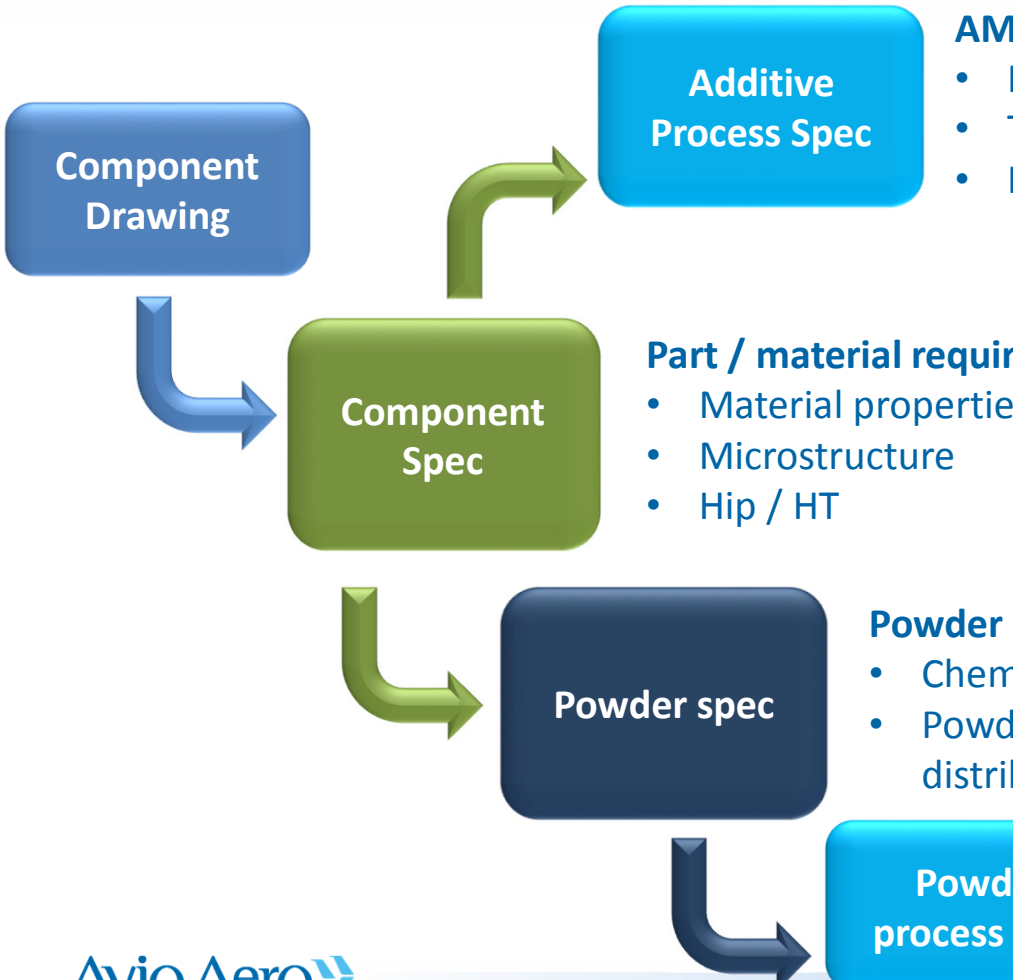
Qualification: Specification Approach



AM Process
- Machine maintenance
- Tech Plan
- Machine qualification

Part / material requirements
- Material properties
- Microstructure
- Hip / HT

Powder Spec
- Chemistry
- Powder size distribution

Powder process
- Process and quality controls

- Specifications established to provide limits for quality critical manufacturing variables.
- Processes locked by Significant Process Substantiation (SPS)

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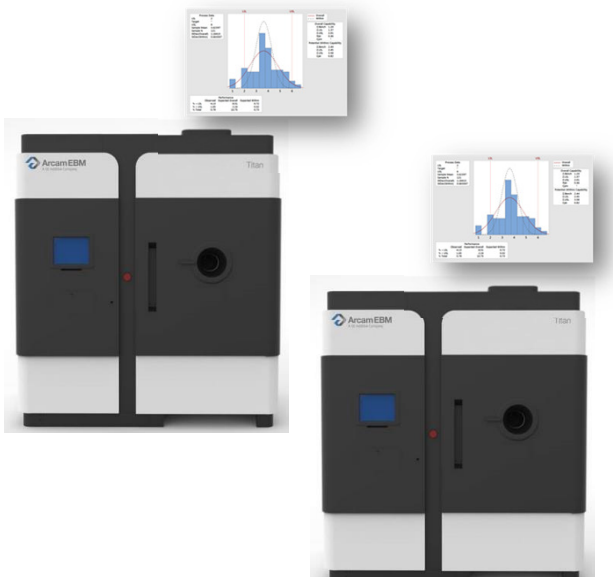
Qualification steps … *"Every Machine a Micro-Foundry"*

Powder…must meet specs for manufacturing and raw material reqs

Additive Process…has to demonstrate to have all the procedures and in instructions in place to guarantee quality and traceability, including powder management and recycle

Machine qualification… each single machine has to demonstrate material buy in and uniformity of results

Part qualification (SPS)… each machine must demonstrate to be in control and capable to produce the component for all the relevant characteristics: dimensional, microstructure, chemistry…



Qualification…and then fixed process control

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Lesson learned: measure the process…

Overall Equipment Efficiency = Availability x Performance x Quality

How much is your equipment is Available for production

- Build crashes
- Maintenance

How much you are good to use the available time

- N. Of Operators
- N. of Shift

What is the variation in the parts you are producing

- Microstructure
- Internal defects
- Chemistry
- Dimensional
- Tensile

Accurate measure of the process allows to react to issues and introduce improvements…

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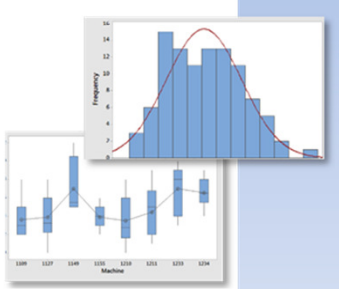
Lesson Learned: process variation

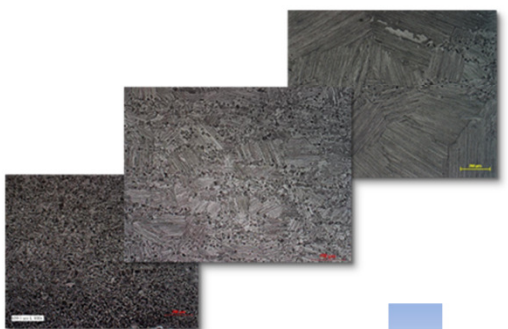
Powder characteristics
Chemistry
PSD / Flowability

Heat treatments
Parameter tolerances
Uniformity



Machine to Machine / build to Build
H/W Config /replacement
H/W Tolerances
Machine Setup

Microstructure variation



Impact on OEE

OEE= Availability x Performance x Quality

TiAl *microstructure* is sensitive to process variation at fixed parameters

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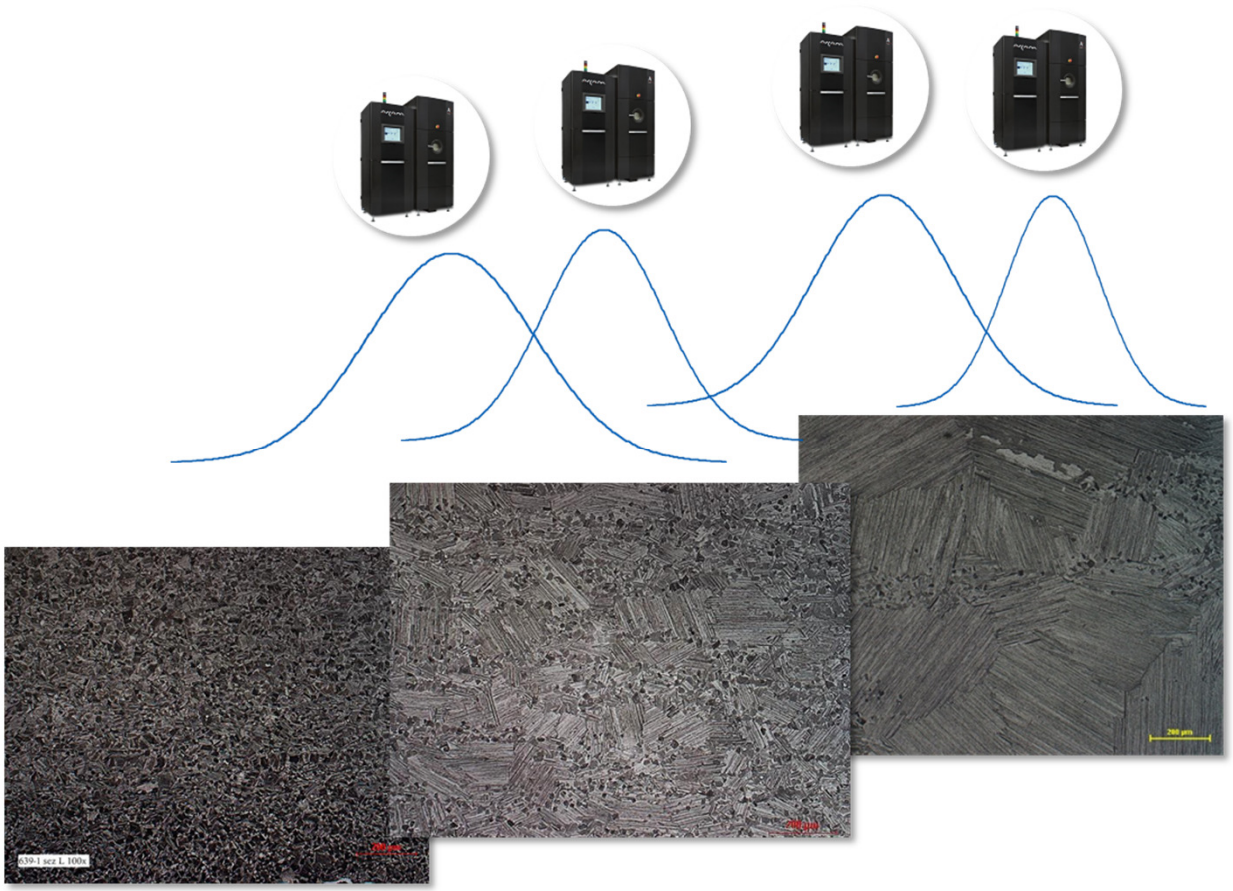
Process variation: Microstructure



At the initial phase of development microstructure variation was impacting yield

- Good portion of variation was coming from different machine behavior
- Initial characterization was using casting material as reference and not including all possible microstructures

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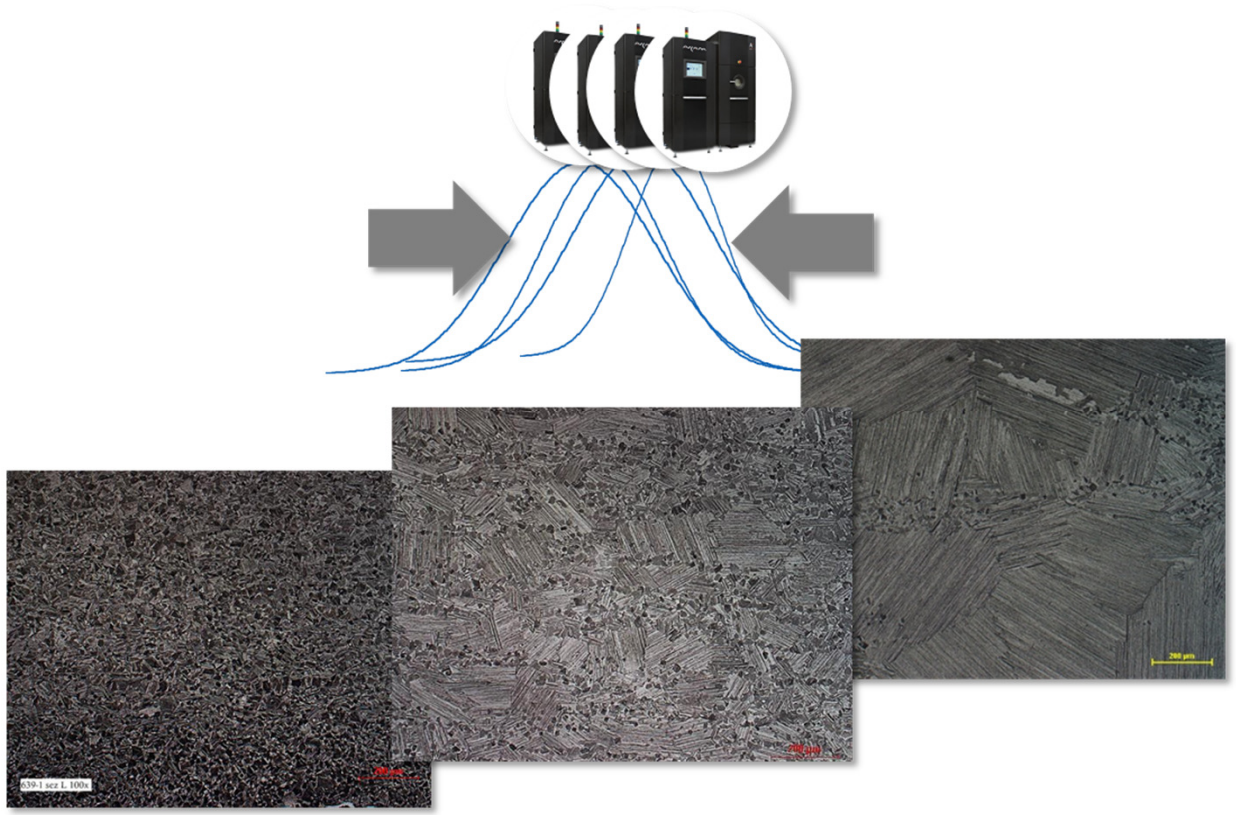
Process variation: Microstructure



To increase microstructure yield, activity were focused on:

- Move the overall process with improved EBM and postprocess parameters
- Improve machine uniformity trough machine qualification and calibration
- Extend material characterization to all microstructure range

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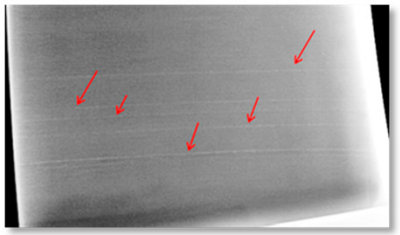
Lesson learned: NDTs



Layers with microstructure changes

Production of TiAl blades by EBM has typical indications that can be different from traditional technology and must be understood.

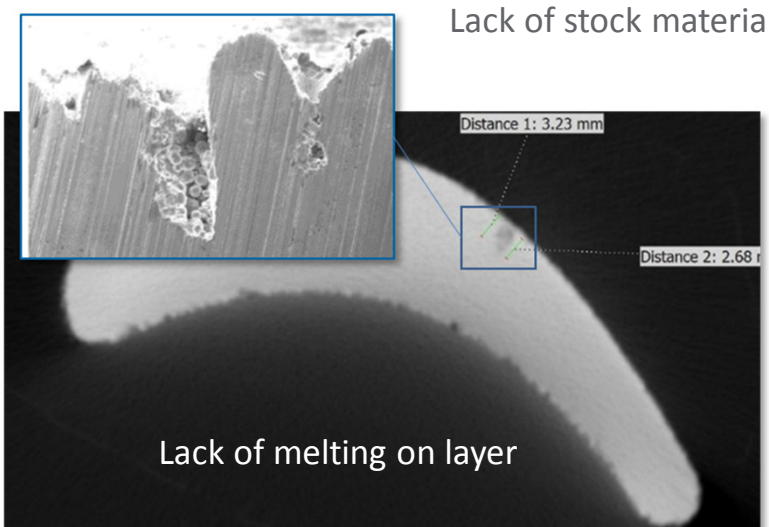
A catalog has been defined including:

- Description
- Root Cause
- Inspection methods to detect
- Validated acceptance limits

Operators have been trained to recognize these indications with X-Ray, FPI; CT scan and visual inspections

Some of these can also be detected analyzing the machine logfiles

Lack of stock material



Lack of melting on layer

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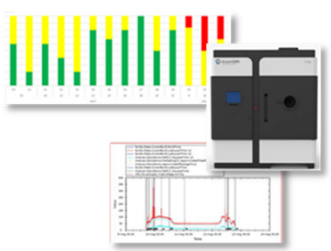
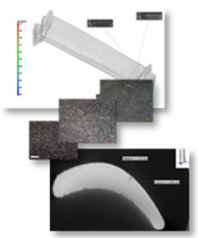
Lesson learned: (Big) Data management

- Process data is needed not only for part acceptance and traceability but also for process improvements
- Increasing the number of parts and machine in production, amount of data will be more difficult to manage (Spreadsheets…PDF…HDD...folders) if not done in a Digital way

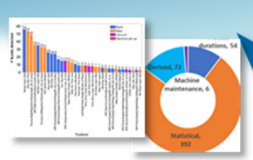


Machine data
Build reports
Full Log files
3D builds
In situ monitoring data / images
Maintenance
Calibration



Part quality data
Microstructure
Chemistry
Dimensional (3D scans…)
CT scan (Reports / full 3D analysis)
Powder CoC, analysis…
Powder Batch used, N. of recycles
HT/ Hip CoC

Data Lake



Analytics

OEE

Digital data collection will help to increase efficiency and reduce costs allowing easy process metrics and advanced analysis

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What's Next

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- ❑ Certification
- ❑ Volumes ramp up
- ❑ Increase further productivity and yield

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