Quality of AM Components

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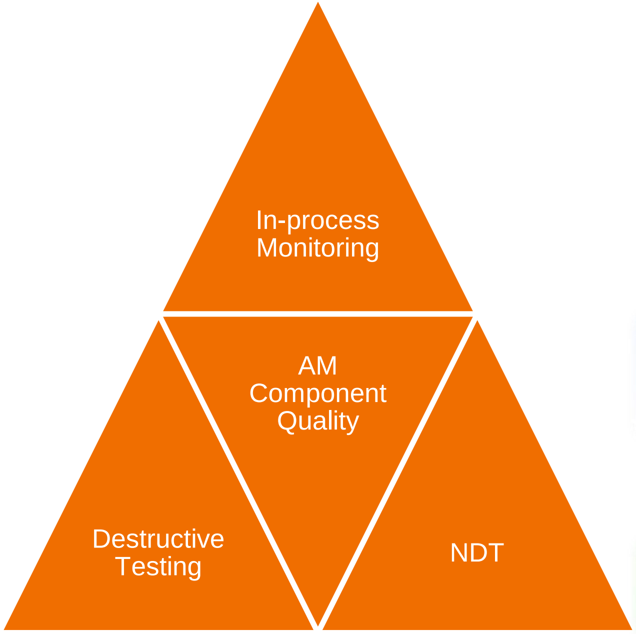
Additive manufacturing in nuclear energy applications -webinar

Why the need of quality?

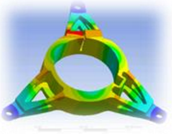
- We need to ensure that Additively Manufactured components are build defect free and fit for purpose consistently and reliably.
- This is true for every industry, but specially for those in which components are safety critical as some applications of nuclear energy are.
- AM enables manufacturing of complex geometries and one-off components which brings added challenges to quality assurance.

Approach to QA/QC in AM



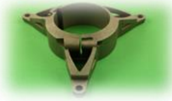
Process Qualification

- We need to ensure that the general process is controlled and repeatable and can produce components within quality requirements
- This includes: Machine, Powder, Operator



Component Qualification

- We need to ensure that a particular part can be printed within quality requirements given a certain design, build preparation, orientation, post-processing, etc.



Individual Part QC

- We need to ensure that every single part is printed within quality requirements. And if it is not, that defects are properly detected and the non-conformity properly recorded.

Standards

AM standardization overview

- Currently the AM standardization has many gaps that limit the adoption of the technologies. However, the SDOs are actively developing new standards to address many of the gaps.
- Application specific standards are being developed mainly for the demands of medical and aerospace industry and nuclear industry specific standards do not exist.

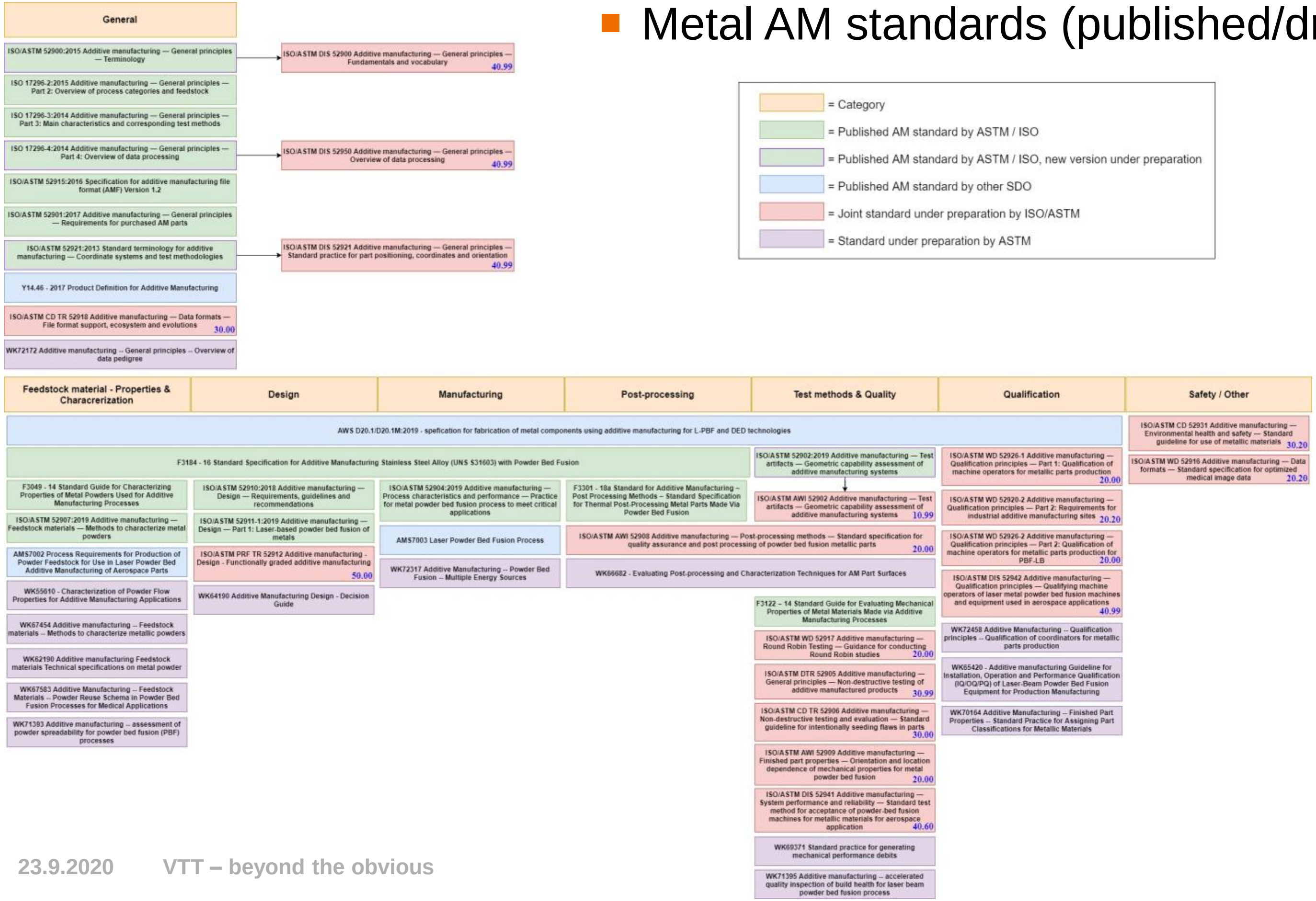
- Few examples of topics that are lacking in AM standardization:
  - Material / application specific standards are needed that include manufacturing specifications and minimum requirements for corrosion, fatigue, fracture toughness of AM metals.
  - AM specific heat treatment procedures and corresponding microstructures
  - Post-processing specifications for complex structures
  - Etc.

- AM standards under development:
  - Feedstock material characterization methods more suitable to AM
  - Specifications for Gradient structures
  - Surface characterization practices
  - NDT methods for AM
  - AM qualification (Industrial machines / machine operators)
  - Safety guidelines
  - Etc.

AM standardization overview

- Metal AM standards (published/draft)

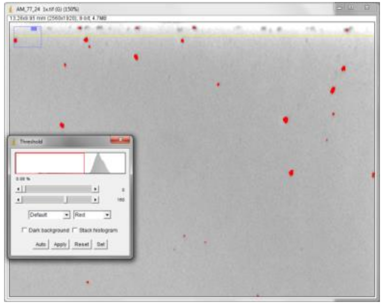
= Category
= Published AM standard by ASTM / ISO
= Published AM standard by ASTM / ISO, new version under preparation
= Published AM standard by other SDO
= Joint standard under preparation by ISO/ASTM
= Standard under preparation by ASTM

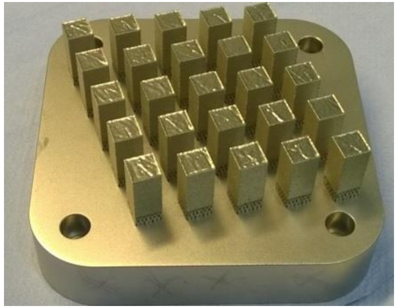


Destructive Testing

Witness samples and microstructural microscopy

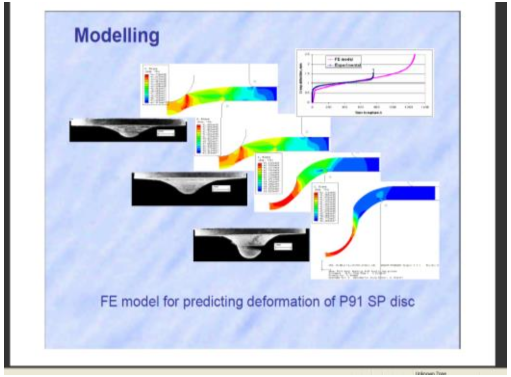
- Mechanical testing following recognized standards
- Specially useful for process qualification
- Usefulness reduced for component qualification and for single part quality control

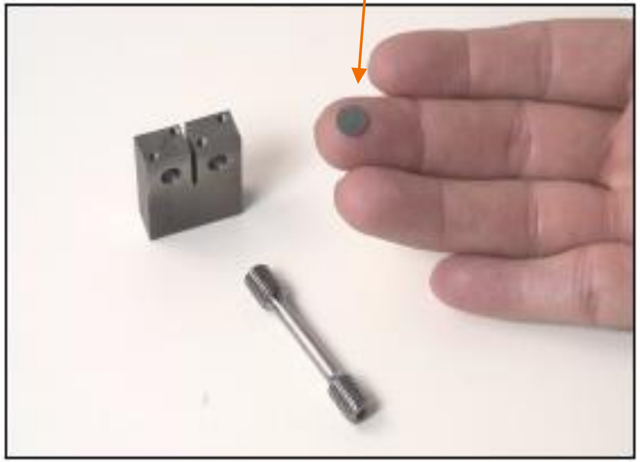




Small Punch Testing

- Allows scooping small samples from critical areas
- Can complement standard methods for process and component qualification
- Can be used as a more cost alternative for batch QC
- **EN 10371** Small Punch Test Method for Metallic Materials to be voted in October 2020.





In-Process Monitoring

AM Process Monitoring

- Detects process variations not necessarily linked to a specific defect. Can be used for AM process qualification leading to reduced NDT requirements

- As it is done simultaneously while manufacturing: it might reduce system downtime.

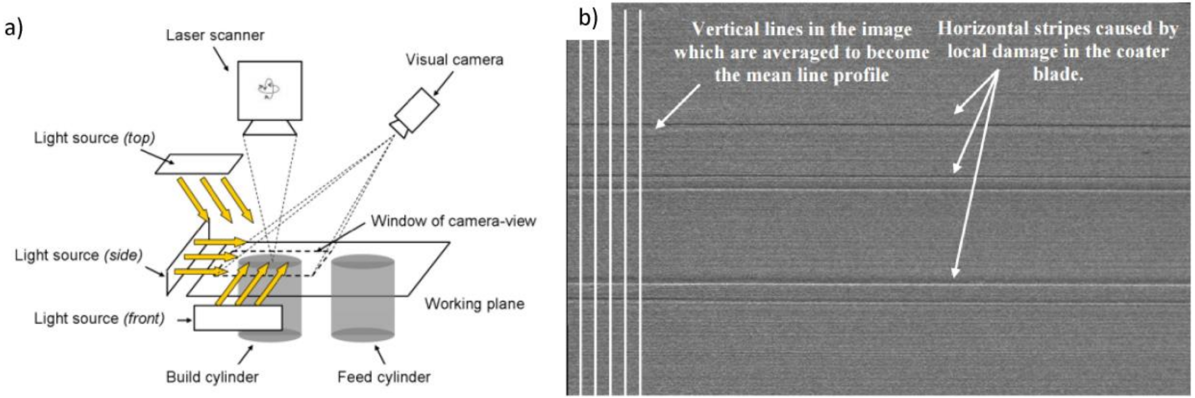
- There are several process monitoring types commercially available. Most machine manufacturers have their own solutions. Some third party offerings available as well.

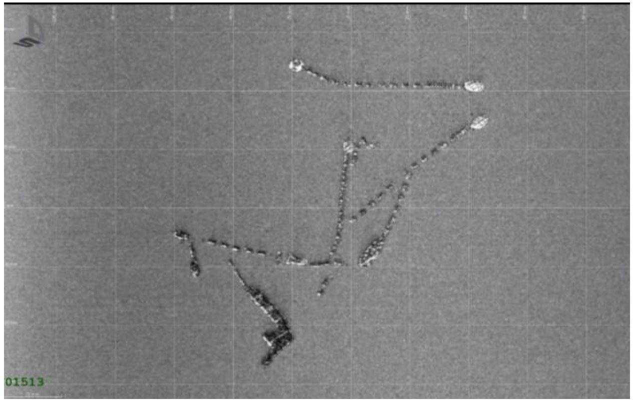
- These process can be real-time, but currently no closed-loop control available.

Examples of existing (commercial) monitoring solutions

- Basic process and environmental sensors:
  - Laser power, oxygen level, gas flow rate, platform temperature
- Powder bed monitoring
  - Images of the powder bed before and/or after re-coating & exposure (usually with CMOS/CCD machine vision cameras)
- Thermal signatures monitoring
  - Off-axis, platform scale field-of-view (usually with IR/near-IR-cameras)
  - On-axis, high spatial and temporal resolution (usually with photodiodes)

Powder bed monitoring



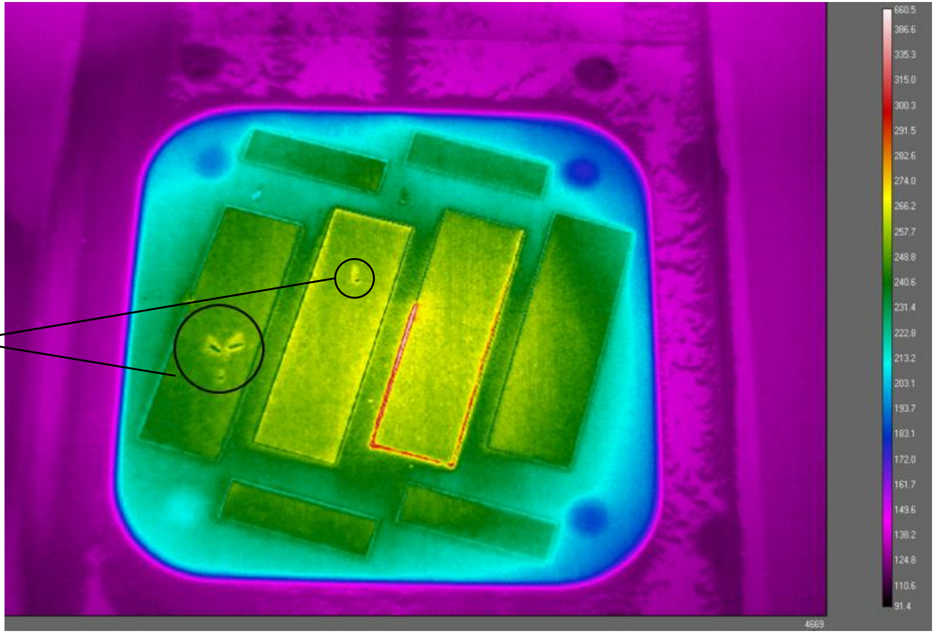


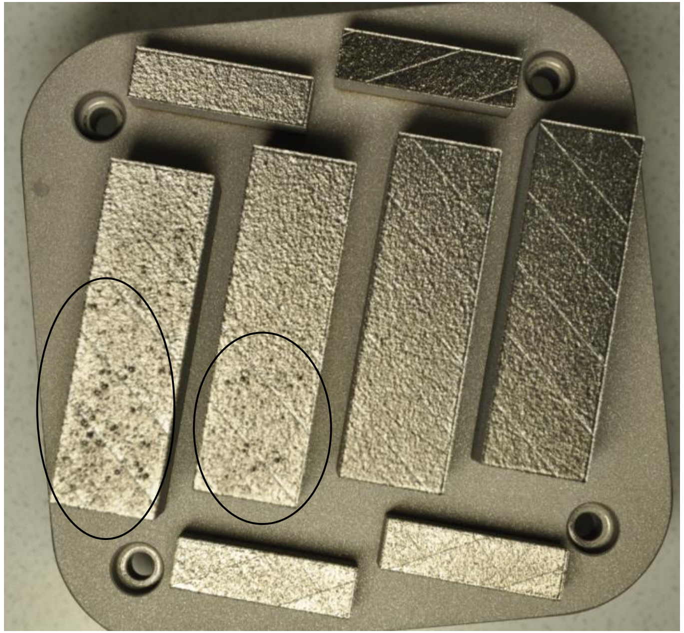
http://sffsymposium.engr.utexas.edu/Manuscripts/2011/2011-17-Craeghs.pdf

https://www.3dsystems.com/dmp-monitoring-solution

Off-axis thermal monitoring

Spatter landing at the left hand side parts





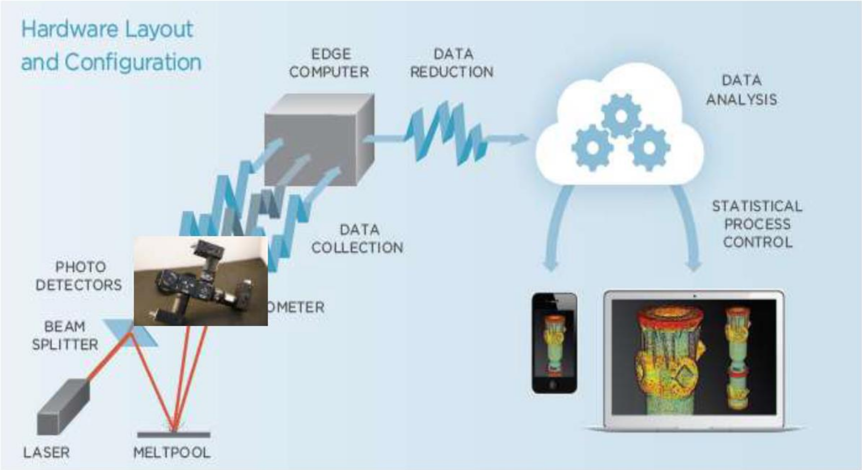
- Thermal camera FLIR A655sc at VTT
- Experimental material, non-optimal powder size & parameters caused excessive spattering

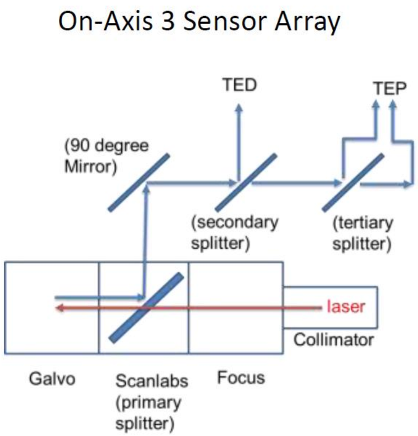
On-axis thermal monitoring: Melt Pool Monitoring

VTT

How Does PrintRite3D® Collect Sensor Data Today?

SIGMA
Quality Beyond In





Sensor	Monitoring	Quality Metric	Measures	Usage
PD1	Melt Pool	TED™ Metric (Thermal Energy Density)	Melt Pool Emissivity	**Process Input System Monitor**
PD2	Melt Pool	Relative Temperature TEP™ Metric (Thermal Energy Planck)	Visible Wavelengths	• **Measure of melt pool quality by characterizing and analyzing spectral data** • **Looks at specific spectral regions of interest** • **Ratio of two wavelengths to calculate relative melt pool temperature** • **TEP™ metric used for analysis and process control**
PD3	Melt Pool		Infrared Wavelengths	

Example of Melt Pool Monitoring

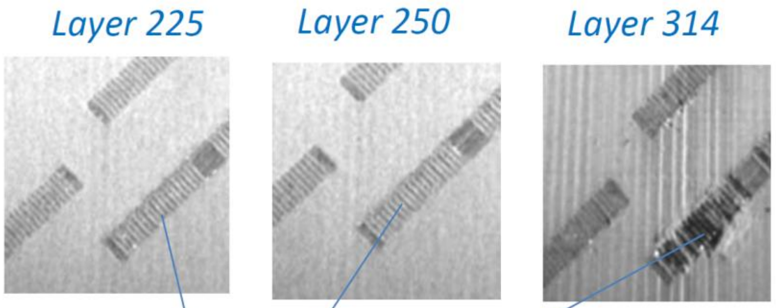
VTT

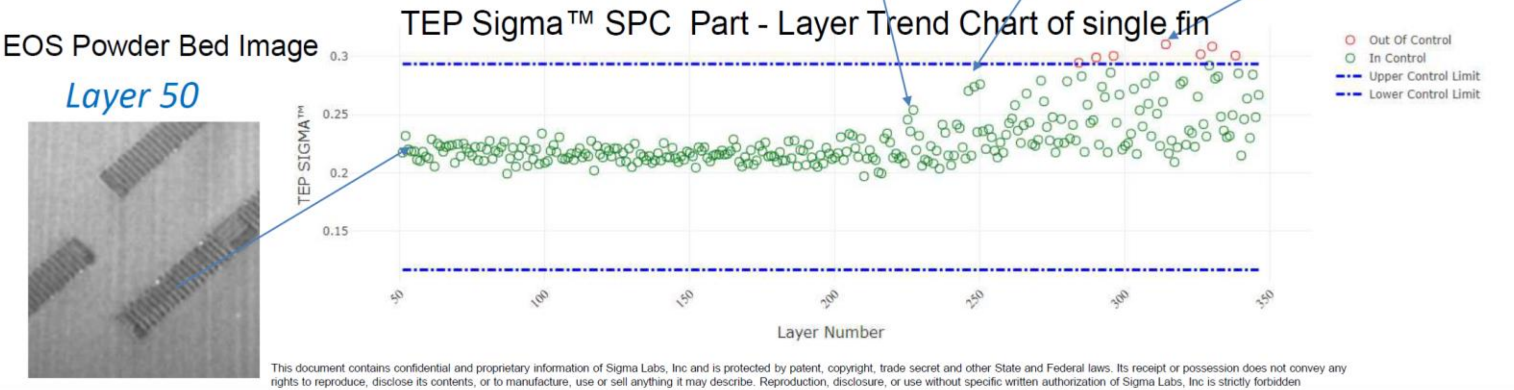
Inconel 625 : Evaluation of Thermal Signatures using Part-Layer SPC (Statistical Process Control) to detect powder disturbance

SIGMA LABS
Quality Beyond Inspection

Qualitative versus Quantitative Approach

Method :- each fin categorized as separate part





Non-Destructive Examination

NDI Technology applied to AM: gaps

- Geometrical complexity
  - AM has practically no geometry-related limitations
- New defect types
  - Porosity: no reliable, cheap and easy-to-use method exists.
- New materials
  - Elastic anisotropy: Several ultrasound related problems
- New reference standards are required
  - NDI devices must be calibrated using known defects
- No POD data
  - Without POD methodology, the actual reliability of inspection cannot be determined

Geometrical complexity

USAF Classification of complexity

GCG	Description	Example
1	Line-of-sight to almost every surface Only few details	Typical CNC manufactured component
2	Line-of-sight to most surfaces	Weight optimized components
3	Line-of-sight to some surfaces Embedded features	Turbine plates with internal cooling channel
4	Full of details Line-of-sight to only few surfaces High total surface area	Thermodynamically optimized heat exchanger.
5	Full of tiny details No line-of-sight to the surfaces Extremely high total surface area	Lattice structures Metal foams

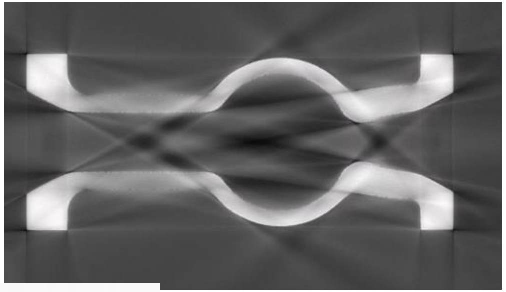
Applicability of NDI to AM

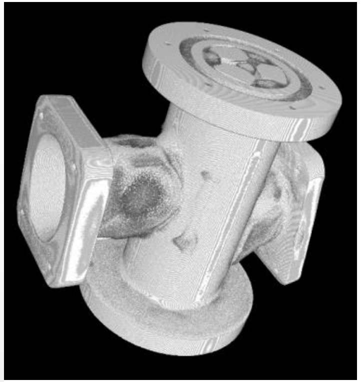
NDI Technique	Geometry Complexity Group					Comments
	1	2	3	4	5	
Visual Testing	Y	Y	P(c)	NA	NA	
Liquid Penetrant Testing	Y	Y	P(a)	NA	NA	
Magnetic Particle Testing	Y	Y	P(a)	NA	NA	Only for ferromagnetic materials
Leak Testing	P	P	P	P	P	Screening for containers, valves etc.
Eddie Current Testing	Y	Y	P(c)	NA	NA	
Ultrasonic Testing / Phased Array Ultrasonic Testing	Y	Y	P(b)	NA	NA	Quantitative methods are possible for GCG 1
Alternate & Direct Current Potential Drop	Y	Y	P(c)	NA	NA	
Process Compensated Resonance Testing	Y	Y	Y	Y	Y	Screening, size restrictions
Radiographic Testing	Y	Y	P(d)	NA	NA	
Computed Tomography	Y	Y	Y	Y	Y	Restrictions how small defects are detectable
µ-focus Computer Tomography	Y	Y	Y	Y	Y	Size restrictions for sample

So, what NDE method to use?.

- CT/uCT is the method of choice currently as is the only method capable of handling complex geometries. But is not completely hassle free.

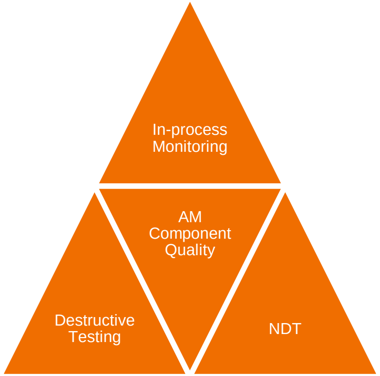
- For GCG1-2 parts, other methods can still have a major role:
  - Advantages in cost
  - Possibilities for in-service inspection.





Summary

- There is no single magic bullet to ensure quality on a component
  - But a combination of in-process monitoring, NDT and destructive testing can support our efforts.
- AM standards are still lacking, but developing steadily.
- QC methods applied to AM are actively being researched



beyond the obvious

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