CHROMALLOY

AM design standard - Standards for AM turbine parts

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March 14-15, 2018 Bukarest

Long live your engine.

Design standard?

Various interpretations

- Technical methods, processes, specifications, and definitions with respect to a physical system on which there is general agreement as promulgated by recognized standards organizations
  - Level to be complied with or reached
  - Document, established by consensus that provides rules, guidelines, or characteristics for activities or their results
- Actual part that includes 'all' challenges process equipment is subjected to during processing
  - Benchmarking

STANDARD / NORM

Design standard

Various (well-known) organizations, worldwide, are working to create standards for the AM industry

ASTM INTERNATIONAL
Helping our world work better

TWI

ISO

NCMS
NATIONAL CENTER FOR MANUFACTURING SCIENCES

NIST

ASME
SETTING THE STANDARD

SAE INTERNATIONAL

FEDERAL AVIATION ADMINISTRATION

bsi.

EASA
European Aviation Safety Agency

Collaborative programs

- Standards Institutes
- Certifying bodies
- Industry Standards
- Regulatory bodies
- Technical branch organisations
- .....

What can we, the ETN community, add?

ETN community

- Various stakeholders with different interest areas
  - No common target

Three routes:

- Independent – develop own set of standards
- Participate – join current activities with an active role
- Follow – link & lobby

Discussion

My suggestion: Third option

Individual members follow own approach

ETN representative to follow development and, when necessary, lobby

DESIGN STANDARD

AM design standard
Standards for AM turbine parts

ETN member base consists of different stakeholders

- Power plant operators
- Oil & gas producers
- Knowledge institutes
- Services organisations
- Original Equipment Manufacturers
- …….

All have a different opinion w.r.t.
the content of a design standard

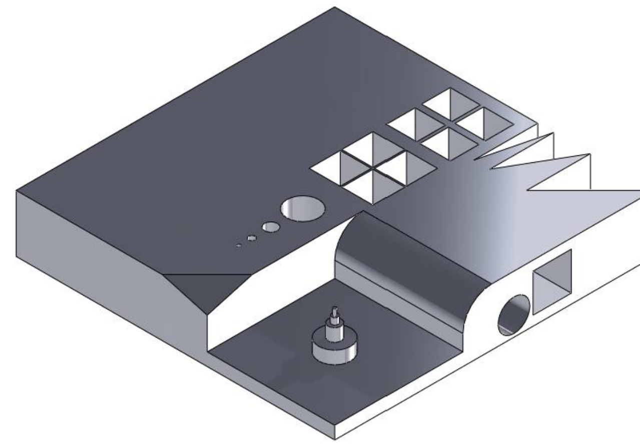
AM design standard

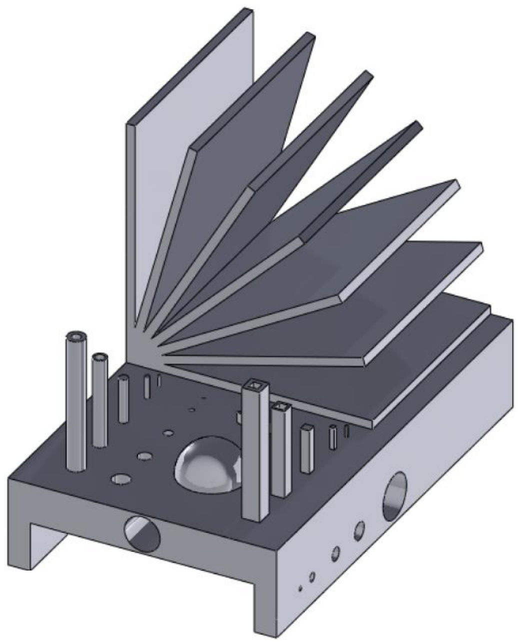
What will be the role of the AM design standard for the stakeholder?

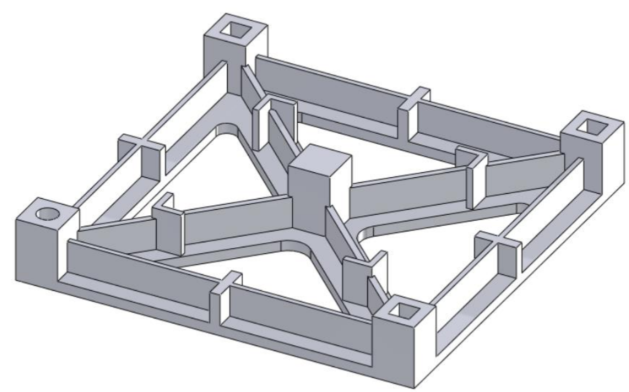
- Comparing systems and technologies for decision making
- Evaluating individual systems
- Evaluating metal-based technologies

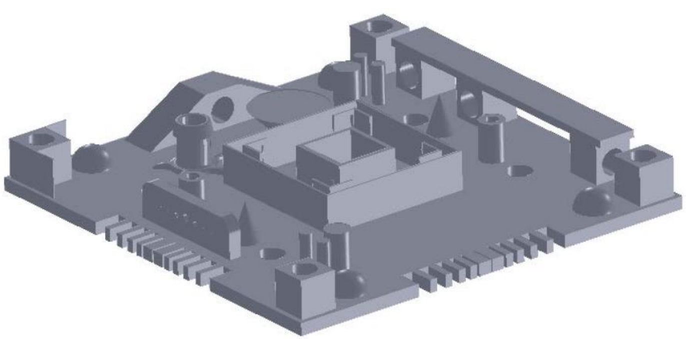
AM industry

Over recent years, various attempts



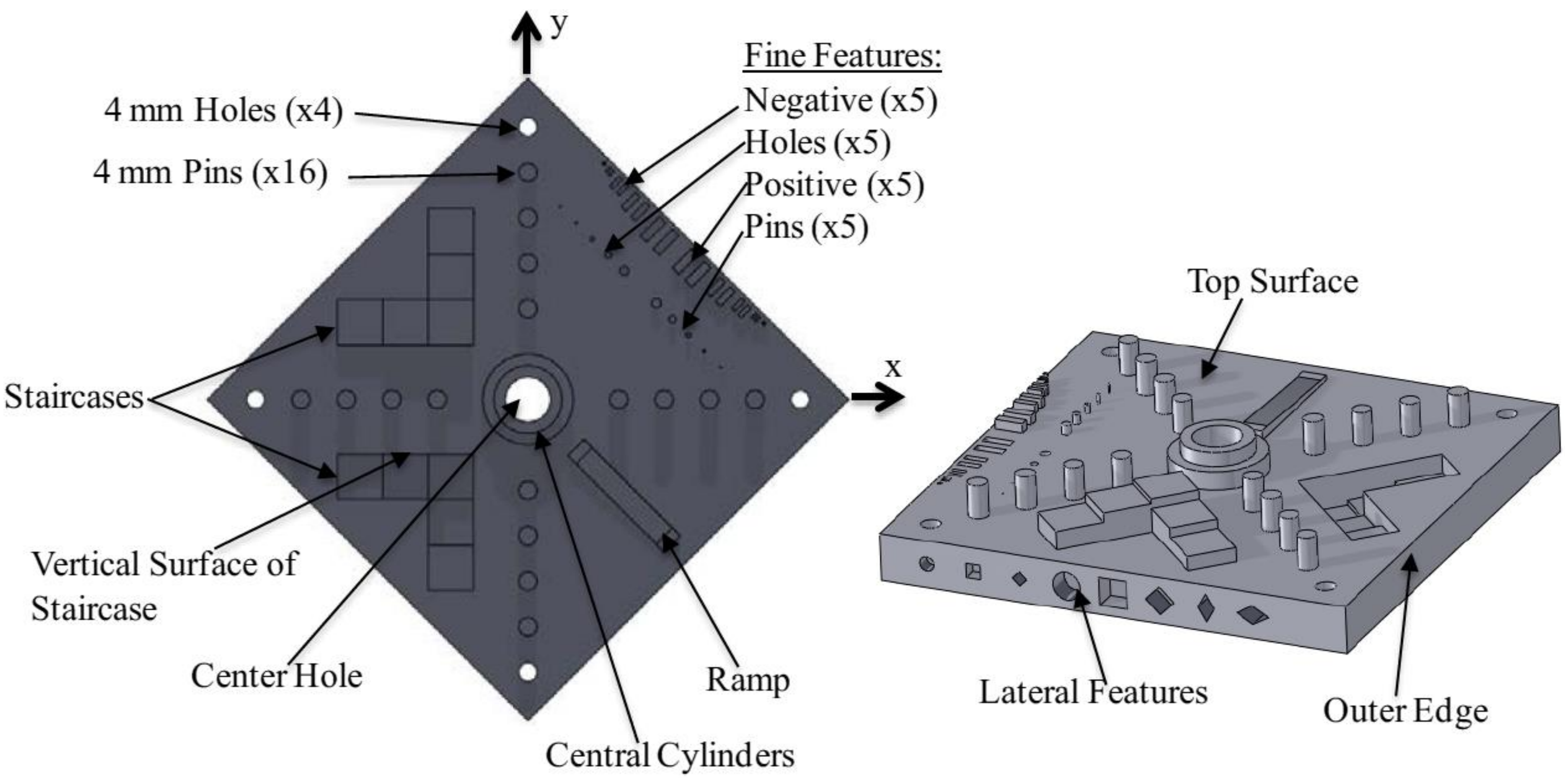






AM industry

Latest result **NIST**



NIST design standard
Functionality

Characteristics investigated	Feature(s) used to demonstrate
Straight features	Vertical walls of staircases; outer edges
Parallel or perpendicular features	Vertical walls of staircases; outer edges
Circular or arced features	Center hole; central cylinders
Concentric circles or arcs	Central cylinders
Fine features	Fine features, holes, and pins
3D or freeform features	Ramp; lateral features
Holes and bosses	4 mm pins and holes; center holes and central cylinders; staircases; fine features
Multiple planes	Lateral features
Location	4 mm pins and holes
Geometric errors of laser positioning axes	4 mm pins and holes
Geometric errors of build platform	Staircases; center hole; ramp
Alignment errors between axes	Top surface and center hole
Errors in beam size	4 mm holes and pins

ASTM F42 subcommittee on Test Methods, WK40419, proposes a new standard titled:
“Performance evaluation of additive manufacturing systems through measurement of a manufactured test piece.”

Benchmarking

- These standards, especially in the area of performance characterization, will be utilized by users to better understand their particular systems as well as the process and technologies in general.
  - helps users to make buy/sell decisions and better allocate resources,
  - define and maintain system capabilities,
  - conduct manufacturability analyses,
  - optimize system performance
- Facilitate the use of AM parts in critical systems, especially in the aerospace and medical industries, by linking part and system data to well characterized materials and processes

AM industry design standard

Does this meet the demands made by the GT (aftermarket) stakeholders?

Query to be executed to determine the goals w.r.t. a design standard for:

- Power plant operators, oil & gas producers
- Knowledge institutes
- Services organizations
- OEM’s (in various roles)
- ……………

PROPERTIES COLLECTION

Properties collection
Reasoning

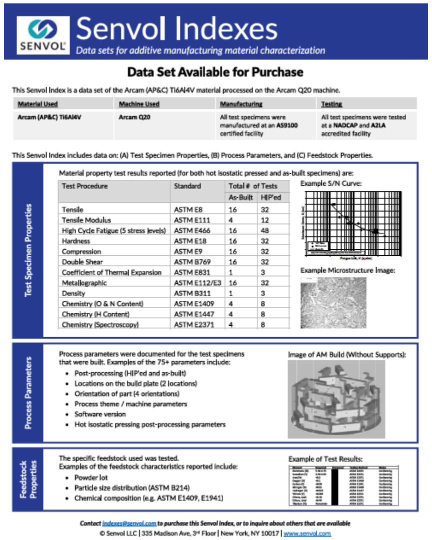
- Creating test data is time consuming and expensive
- In general, restricted
    - limited processing technologies,
    - limited materials,
    - limited test method,
    - limited test conditions
    - long turn around times
- Joining forces, collaboration can be the way forward
- Hurdle:
    - Conflict between openness & commercial position
    - Multitude of processes/technologies
    - Insufficient information to make a judgement call

Need exists

- To include AM in the manufacturing portfolio, data is required
- Compared to standard processing, we are running behind
  - We have to cope with over a century data collection for common processing means
  - An organization on itself cannot cope with this
- Therefore, a multi-lateral action is required

- Market is providing the tools

Example,



Senvol Indexes
Data sets for additive manufacturing material characterization

Data Set Available for Purchase

This Senvol Index is a data set of the Arcam (AP&C) Ti6Al4V material processed on the Arcam Q20 machine.

Material Used	Machine Used	Manufacturing	Testing
Arcam (AP&C) Ti6Al4V	**Arcam Q20**	All test specimens were manufactured at an **AS9100** certified facility	All test specimens were tested at a **NADCAP** and **A2LA** accredited facility

This Senvol Index includes data on: (A) Test Specimen Properties, (B) Process Parameters, and (C) Feedstock Properties.

Test Specimen Properties

Material property test results reported (for both hot isostatic pressed and as-built specimens) are:

Test Procedure	Standard	Total # of Tests	
		As-Built	HIP'ed
Tensile	ASTM E8	16	32
Tensile Modulus	ASTM E111	4	12
High Cycle Fatigue (5 stress levels)	ASTM E466	16	48
Hardness	ASTM E18	16	32
Compression	ASTM E9	16	32
Double Shear	ASTM B769	16	32
Coefficient of Thermal Expansion	ASTM E831	1	3
Metallographic	ASTM E112/E3	16	32
Density	ASTM B311	1	3
Chemistry (O & N Content)	ASTM E1409	4	8
Chemistry (H Content)	ASTM E1447	4	8
Chemistry (Spectroscopy)	ASTM E2371	4	8

Example S/N Curve:

Example Microstructure Image:

Process Parameters

Process parameters were documented for the test specimens that were built. Examples of the 75+ parameters include:

- Post-processing (HIP'ed and as-built)
- Locations on the build plate (2 locations)
- Orientation of part (4 orientations)
- Process theme / machine parameters
- Software version
- Hot isostatic pressing post-processing parameters

Image of AM Build (Without Supports):

Feedstock Properties

The specific feedstock used was tested.
Examples of the feedstock characteristics reported include:

- Powder lot
- Particle size distribution (ASTM B214)
- Chemical composition (e.g. ASTM E1409, E1941)

Example of Test Results:

Contact indexes@senvol.com to purchase this Senvol Index, or to inquire about others that are available

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SENVOL (www.senvol.com)

Large number of known contributors

Possibility to search on equipment and/or materials

- Raw data
- Includes a.o.:
  - Test specimen properties
  - Process parameters
  - Feedstock properties

Tensile,
High cycle fatigue,
Coefficient of thermal expansion,
Chemistry,
Compression,
Density,
Hardness,
Metallographic

Reference only, no pristine data

ETN’s role in this

- Develop
- Participate, even guide / control
- Follow / contribute

Member base has to decide on the way forward

References

- Standardization Roadmap for Additive Manufacturing – version 1.0; February 2017; America Makes & ANSI Additive Manufacturing Standardization Collaborative (AMSC)
- An additive manufacturing test artifact; Moylan, S. et al.; Journal of Research of the National Institute of Standards and Technology; Volume 19 (2014)

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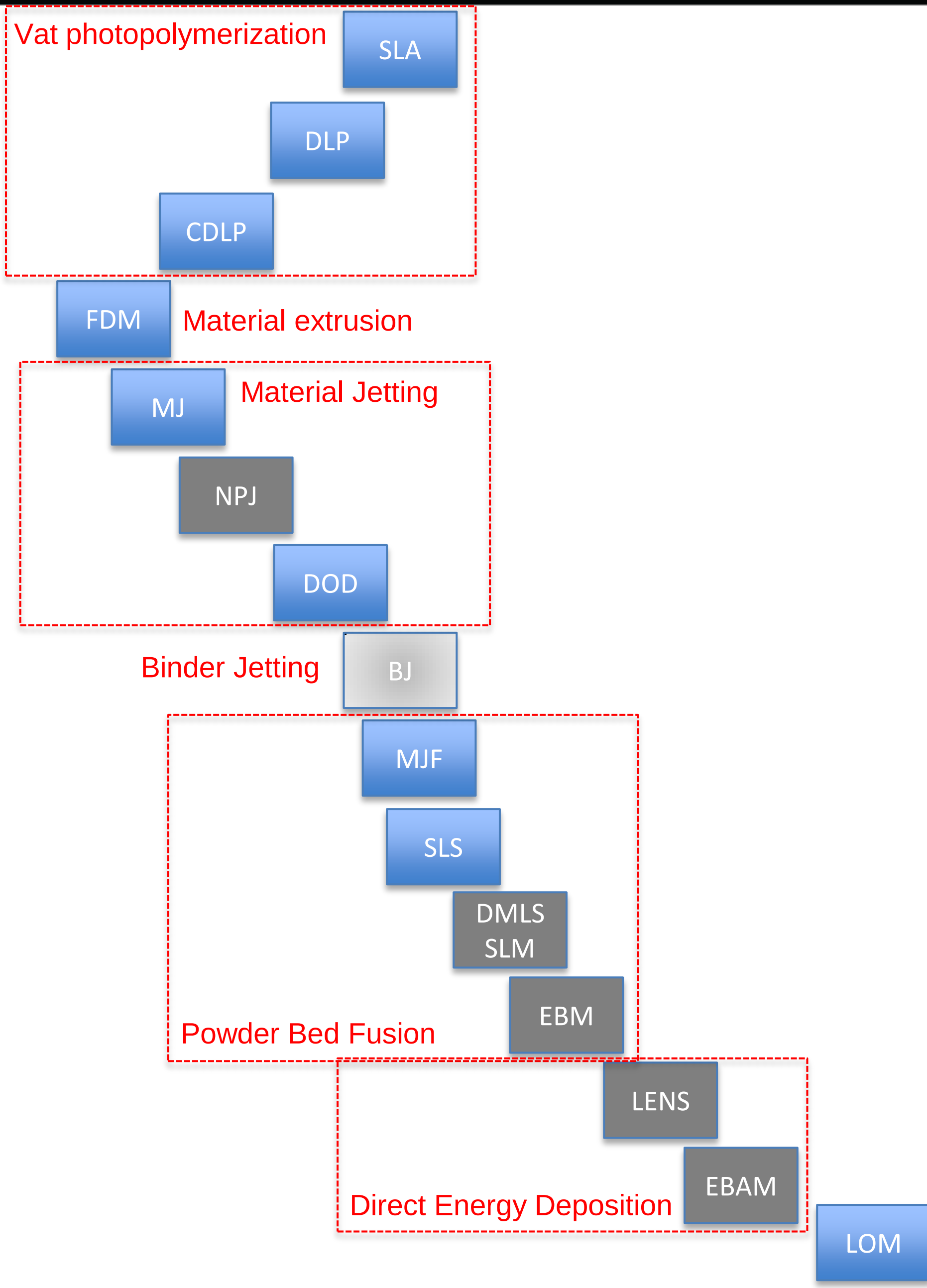
BACK-UP SLIDES



Stereolithography

Digital Light Processing

Continuous Digital Light Processing

Fused Deposition Modelling

Material Jetting

Nano Particle Jetting

Drop on Demand

Binder Jetting

Multi Jet Fusion

Selective Laser Sintering

Direct Metal Laser Sintering / Selective Laser Melting

Electron Beam Melting

Laser Engineering Net Shape

Electron Beam Additive Manufacturing

Laminated Object Manufacturing