Technology Exchange on the Coordination of U.S. Standards Development for Additive Manufacturing
Qualification and Certification Collaboration Session Notes
Facilitator: Michael Maher – DARPA
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1. **What are near term needs for an additive manufacturing performance qualification protocol?**
   - Material feedstock pedigree – C of A, Recyclability, Receiving Inspection
   - What are you putting in the machine – Granularity in the C of C
   - Physics based models to understand micro structure, chemical composition – NDT, phenomenological models for long-term
   - "Near term" defined as today. Parts may not be metallic.
   - "Defining requirements for materials, not process" training, test plan, data managing/publishing

   - Water tight CAD file, clean – unconnected facets in the Slice/STL file
   - Start with solids instead of parts with internal features
   - Final part design
   - What are product requirements? – Test requirements, Functional, Min/Max Operating Environment

   - What specifications need to be "locked down" and represented in MPI's or part drawings
   - Identify what specs need to be communicated or what
   - Qualifying a process as consistent AND identifying what test methods, info, and data can qualify a process as consistent and repeatable
   - Want something aerospace, medical,… can use

   - Determine which process parameters most important
   - Need in process monitoring and controls
   - Clear understanding of qualification requirements

   - Feedstock qualification➔Material
   - Process meets performance requirements➔Process
   - Design system➔Performance

   - Standard witness coupons
   - Standard form for recording process parameters
   - Standard terminology

   - Feedstock certification
   - NDE/NDT
   - Need to define what qualification is required for different classifications of end products
     - Documents to define product classifications
   - Start with solid parts (Not lattice or porous structures)

- Look at density

- Standard terminology
- Characterization of typical defects and understanding their effects
- Standard parameter database and data collection format
- Standard representative mechanical test methods
- Need to be able to compare data sets
- Need participation by experts on standard committees
- Standardization of powder requirements for AM

- NIST techniques and a defect list
- Understanding effects of defects
- Root cause of defects
- Understand process capability
- Critically classification guidance
- Reliable methods to statistically evaluate powder

- Post-Processing Definition

- Certification Agencies / Costumer buy-in at early stages / Fiduciary Duty

2. What existing qualification protocols cover requirements for AM?

- Cold spray at US ARL
- Already has an ARMY mil standard for qualifying parts for repair – mil standard 3049
- Navy Tech PUB 248

- Safety parameters, constraints regulator environment
- Source➔
    - baseline, benchmark, build
    - NIST➔geometric
    - Table-geared toward metals
    - Variability
- Understanding all inputs, changing, defining inputs

Source Build for baseline producibility, variability

Factory Tests

- Many qualification methods are proprietary (that are successful in industry – already exist
- Many exist, (too many to write here) but it will be critical to leverage outside

3rd Party reviewing and disseminating successful common practices for qualification

Qualify procedures, operators, materials, process, and system to help with end product certification

- An NCAMP process similar, or identical to CMH-17 – Shared Databases
- For operators, something similar to what AWS does
- MMPDS as a starting point

Casting – Investment Casting, Fixed Process Controls, Casting drawing before Engineering drawing

- Welding specifications – Essential Process Variables
- Combine CASTING and WELD Best Practices for AM

- AWS B2.1
- ASME B+PVC section IX
    - Welding procedure qualification requirements

Question 3- what is necessary to implement an initial performance qualification protocol for additive manufacturing

- Develop mechanical test methods that accurately reflect AM component feature (i.e., thin lattices)

- Performance
    - Install properly (installation qualification, manufacturer assisted factory accept) – baseline of machine
    - Train to operate properly (calibration – vacuum furnace spec as a template
        - Somewhat similar to Zeiss machine – very controlled very precise
    - Product qualification/process qualification – limit to parameters instead of all process
        - Application specific – load bearing vs non load bearing (criticality)
        - Material process specific
- Traceability- from powder to part strategy

- Understand the material properties holistically – understand how inputs ties to output; understand material properties as a function of process
- Must have the equipment necessary to develop the protocol
    - Existing equipment makes it difficult to capture necessary variables to tie material properties back to processing
- Generate a list of techniques and what can be extracted from each; applicability to each equipment
- Generate complete understanding of process parameters

    - Need to do in short term

- Identifying important process control parameters
- Identifying critical basic controls for each type of platform, basic "~~best~~ minimum properties"
- Need to allow end users to calibrate and tune machines rather than s OEM's only

- Samplings- statistically significant
- Derived end state
- Variability
- Controls
- ASSUMPTION: qualifying a new part

- Performance based qualification
- Model and simulation tools as appropriate
- Coupons can be an oversimplification
- What data do you model become application specific
- Have to understand fundamental, competing physics in process

- Clear understanding of qualification protocol
- Qualification of feedstock
- Qualification of process
- Performance qualification
- Qualification of test methods
    - Appropriate NDT per application
    - Proof test
- Need to determine if lot sampling is appropriate for AM
- Qualification of Inspection

Regulatory framework for the qualification

- Eliminate Variability
- Material standards
- Machine qualification
- Operator qualification
- Know the process parameters
- Grow knowledge

Question 4-How can initial qualification protocol for AM be developed

- Challenge- start with same material/process and cannot reach same properties
    - 1) Identify the variability
        - How do you provide proof of properties

        - How do you now quantify non-bulk properties
    - 2) Correlate the part functional properties to layer properties
    - Ties into understanding process parameters

- First article inspection
- Witness specimens
- Use smaller test cases that are representative of a larger component- scaled approach
- Process monitoring
- Adapt existing protocols
    - Figure out what is out there today:
        - "Torture" part to test vendor capability – can there be a standard part & material that the industry can agree on?
        - NIST benchmark model 1 and 2 that can be downloaded now
        - Working on a 3rd iteration now
        - Need to figure out how to correlate results from benchmark models back to allowables
        - Welding and casting (reference back to Q1 & Q2)

- This will enable consistency and verification of consistency

- Can we put a CT in a machine? In-Situ monitoring/inspection
- Characterization/inspection

- Follow the NCAMP (CMH-17) procedures for the composites
- A database is needed with the pedigree on the process data
- Have a way of accommodating IP issues

- Write draft specs, use those to identify gaps ~~Gap~~ analysis
    - AWS D20 is working on it

Question 5: How do we move forward in qualification protocols for Additive Manufacturing?

- Test, analysis, similarity is used to qualify something, usually links back to testing
- Establish similarity, use the same test
- Process Map input, variables, concerns throughout whole process, know process better
- Iterate and adapt-learn from current state
- Define a tolerance, ex. What impacts performance of finished part, Design understand what impacts performance. Include Process tolerances?
- Standard part families – classification system

- Standard witness coupons – known correlations to properties – Specific to performance of the process. Coupon is representative of the process stability
- You can have a good coupon but bad part. Limitations of the standard test coupon needs to understood
- Common database, with common established data collection process-standard protocol for data collection
- Develop inspection techniques/protocols-more inclusive than CT
- Determine different requirements/critical parameters for different AM process
- Industry collaboration meetings, standards coordination-increase communication, more working meetings and with those operating equipment
- Start building and learning – User groups
- Industry protocol challenge-round robin
- Start with like for like part replacement – low-hanging fruit, contest between parts, part history, logistics, supply chain, availability of a part is more important than cost – DoD perspective,
- Gap analysis between past and future protocols
- Identify common areas, non IP, pre competitive, to build from
- Pressure OEM's to provide mass open machine control
- Once end-users can better control and measure machine consistency themselves, they can set an operational protocol that can inform std. dev.
- Must start with material certification
- Written requirements
- Should DoD write requirement and push technology to meet it? – Ownership of Data, Design Intent, Exceed Limits,
- Establish digital thread and write data to include in tech data package
- System integration and regulators to approve our process
- Adapt and iterate
- Define a process; allow software to operate digitally
- Industry and regulatory approval

Question 6: What are the future goals for quality and certification protocol in Additive Manufacturing?

- Sensors built into machines to determine status in real time, AI, monitoring within process, can't afford to test part after built
- Repeatable, reproducible no matter what material or process is used, control of all variability so as not to affect end product – Open-platform for research purposes?
- System agnostic process parameters
- Future goals-clear and understandable, no room for interpretation
- Understand powder, recycling limits
- In-process monitoring-detect issues before it is too late to correct before part is ruined
- Critical defect study to understand which discontinuities are unacceptable
- Determining when equipment maintenance is required (frequency of calibration, etc.)
- Once something is qualified, what is the permissible range of variation to still allow for meeting quality specifications?
- Enable, develop, in-process inspection and monitoring and make it part of process
- Allow/include validated models/simulations within certification process

- Functional testing
- Statistic and prob. Testing
- Auditable quality Protocols
- Validated simulations-physics based models
- Start with property
- Geometry dependent properties that are impacted by process
- Speed, Technical expertise/ Be able to know/demonstrate part is good