Additive Manufacturing – Standards.

Alex Price, Lead Programme Manager.
So how many standards are there?


BS 185-6:1970 - Glossary of aeronautical and astronautical terms. Ballistic and guided missiles

BS 8445:2012 - Bath and shower mats. Testing. Assessment of slip resistance properties safety signs

BS 8888:2011 - Technical product documentation and specification
Who sets all these standards?

- Someone has an idea?

National Standards Body
Why adopt a standard/s:

• **Required:**
  - The standard may form part of a contract,
  - The Standard may be part of obligation to CE or some other quality mark,
  - The Standard may be referred to in legislation,
  - The Standard may be required within the supply chain.

• **Recommended:**
  - A good rationale would be presented, adoption of the standard may improve business performance,
  - May improve business practice,
  - A very large percentage of export is influenced by the European and international standards business,
  - May form part training potentially for employees,
  - Interoperability with other standardised products or components.

• **Information:**
  - Elements from a standard could be taken into company best practise without full adoption,
  - May form part training potentially for employees,
  - Could form guidance to day to day business.
Additive Manufacturing – where’s the hype

Image courtesy of NIST Economist February 2011.

Image new scientist July 2012.
Why Standardisation?

• Any number of reports have highlighted the need.
• Industry request.
• Key Challenges hindering advancement of AM over the next ten years.
• Report by the IQPC
  • 76% of respondents highlighted certification of finished parts and products.
  • 48% Quality & standardisation of material inputs
  • 36% Questionable quality of finished parts
So many processes, materials and outputs under the additive manufacturing banner.

There are a number of processes which fall under the Additive Manufacturing label. Which vary in material, process, final shape, surface finish, geometrical shape required. The American Society for Testing and Materials (ASTM) group “ASTM F42 – Additive Manufacturing”, formulated terminology defining range of Additive Manufacturing processes into 7 categories: ISO/ASTM52900-15 Standard Terminology for Additive Manufacturing – General Principles – Terminology:

- VAT Photopolymerisation
- Binder Jetting
- Material Jetting
- Material Extrusion
- Powder Bed Fusion
- Sheet Lamination
- Directed Energy Deposition
Top level overview of the development of standards.

Structure of AM Standards

General AM Standards
- Terminology
  - ASTM F2792-12a
  - ISO 17296-1
  - ISO/ASTM 52921-13

Processes/Materials
- ISO 17296-2
- Qualification and Certification Methods
- Requirements for Purchased AM Parts
- Non-Destructive Evaluation Methods

Test Methods
- ISO 17296-3
- Test Artifacts
- General Test Methods
- Performance Test Methods

Design/Data Formats
- ISO 17296-4
- ISO/ASTM 52921-13
- Data Structures and Metrics for AM Models

Raw Materials
- Material Category-Specific
  - Metal Powders
  - Polymer Powders
  - Photopolymer Resins
  - Ceramics
  - etc.

Process Category/Material-Specific
- Powder Bed Fusion
  - Ti-6Al-4V
  - IN718
  - Others

Material Extrusion
- Directed Energy Deposition
  - etc.

Material-Specific Standards
- Material-Specific Size Specification
- Material-Specific Chemical Composition
- Material-Specific Viscosity Specification
  - etc.

Process/Material-Specific Standards
- Process-Specific Performance Test Methods
- Process-Specific Test Artifacts
- System Component Test Methods
  - etc.

Application-Specific Standards
- Aerospace
- Medical
- Automotive
  - etc.

General Top-Level AM Standards
- General Concepts
- Common Requirements
- Generally Applicable

Category AM Standards
- Specific to material or process category

Specialized AM Standards
- Specific to material, process, or application

NIST publication on AM.
What new areas is Additive manufacturing linked to?

- Machine Safety
  - Laser safety
  - Contained atmospheres
- Metrology:
  - Both established mechanical properties
  - State of the art ultra-high accuracy
  - Multi-sensory coordinate measurement machines.
- Non Destructive Evaluation in-process and post process:
  - For post build inspection for both surface and sub-surface monitoring, digital x-ray, X-ray CT ultrasound. Eddy current may be used for surface and close to surface monitoring.
  - For in-process sensors, thermal and optical imaging.
- Intelligent automation:
  - Complex automation
  - Robotics
  - Sensor technology, embedded.
What is Quality management for AM?

- **System:**
  - Level of assurance of part.
    - Aerospace
  - Robust systems of traceability.
    - Standards
  - Training and
    - New technology requires it

- **Process:**
  - What AM process is the most appropriate for your task.
  - Choice of materials.
  - Knowing your key parameters.
    - In process monitoring.
  - Post processing.
    - What needs to be done to get the part up to required levels.
  - Next process consideration.

- **Materials:**
  - What AM material can be used.
    - Is it the most appropriate for your task.
  - Choice of materials.

System: Some possible certification type standard. Possibly ISO 9001 or equivalent industrial sector such as aerospace (AS 9120) or medical (ISO 13485) for example.

Material: Consistent and reliable feedstock material. Key characteristics reported such as; chemical composition and size.

Process: With currently seven different processes, and variations of different materials and grades of in the use.
So what are the standards program currently?

- ISO 17296-3:2014 Additive manufacturing -- General principles -- Part 3: Main characteristics and corresponding test methods
- ISO/ASTM 52900:2015 Additive manufacturing -- General principles -- Terminology 60.60
- ISO/ASTM DIS 52901.2 Additive manufacturing -- General principles -- Requirements for purchased AM parts
- ISO/ASTM NP 52902
  - Additive manufacturing -- General principles -- Standard test artifacts
- ISO/ASTM DIS 52903-1 Additive manufacturing -- Standard specification for material extrusion based additive manufacturing of plastic materials -- Part 1: Feedstock materials
- ISO/ASTM NP 52905 Additive manufacturing -- General principles -- Non-destructive testing of additive manufactured products
- ISO/ASTM DIS 52910.2 Guidelines for additive manufacturing design
- ISO/NP TR 52912 Design of functionally graded additive manufactured parts
- ISO/ASTM 52921:2013 Standard terminology for additive manufacturing -- Coordinate systems and test methodologies
How can standards support the development?

- In process monitoring
- Post-process monitoring
- Mechanical, thermal, etc. Testing
- Dimensional metrology
- Guidance and best practise
- Data formats and retention
- Types of AM processes and calibration
- Consistent raw materials
- Machinery safety
Types of AM process

• Material extrusion
  • ISO/ASTM CD 52903-2 Additive manufacturing -- Standard specification for material extrusion based additive manufacturing of plastic materials -- Part 2: Process -- Equipment

• Powder bed fusion
  • Draft DIN 35224: Welding for aerospace applications – Acceptance inspection of powder bed based laser beam welding machines for additive manufacturing”
  • Draft DIN TBD: Aerospace — Powder for additive manufacturing with powder bed process – Technical specification

• Material jetting

• Binder jetting

• Directed Energy deposition

• Sheet lamination

• Vat polymerisation
  • Draft DIN TBD: “Welding for aerospace applications – Qualification of operators for additive manufacturing equipment”
  • Draft DIN TBD: “Testing and Inspection of additively manufactured products”
  • ISO 17296-2:2015 Additive manufacturing -- General principles -- Part 2: Overview of process categories and feedstock
In process monitoring

• AM NDT standards will require consideration of particular number of defects and assessment of the surface monitoring during the build, where thermal monitoring, optical imaging and geometrical monitoring would be useful. For in-process sensors to provide non-destructive evaluation and allow for early detection of flaws/defects, also modelling on residual stresses based on work at the STFC, neutron source.

• Thermography:
  - BS ISO 18434-1:2008 Condition monitoring and diagnostics of machines. Thermography. General procedures
  - ASTM E1311-14 Standard Practice for Minimum Detectable Temperature Difference for Thermal Imaging Systems

• Visual inspection:
  - Very much an objective method based human experience and hence virtually impossible to standardise.

• Ultrasonic:
  - BS EN 583-1:1999 Non-destructive testing. Ultrasonic examination. General principles

• Computer tomography (CT):
Post processing monitoring

- AM NDT standards will require consideration of particular number of defects and assessment of the surface monitoring during the build, where thermal monitoring, optical imaging and geometrical monitoring would be useful. For post build inspection the following techniques may be used for both surface and sub-surface monitoring, digital x-ray, X-ray CT ultrasound. Eddy current may be used for surface and close to surface monitoring.

- Generate best practice guide showing NDT methods potential to inspect AM defects not covered by current standards.


- WK47031 – Standard Guide for Nondestructive Testing of AM Metal Parts Used in Aerospace Applications
Machine Safety

• Many of the Additive machines are on the market, so obviously comply with the machinery directive 2006/42/EC, making use of the standards below:

• Some considerations on machinery safety:
  • Laser
  • Explosive atmospheres
  • Hot melt flow of materials
  • Residual powders

• **EC Directive 2006/42/EC standards dealing with the essential requirements.**
Consistent raw materials

- The raw materials are often in the form of powders or wires that can be melted and shaped by a laser.
- Consistent raw materials.
  - Goes someway to consistent outputs.
  - Guarantees process consistency.
- Characterization of Additive Manufacturing Materials involves developing measurements and standards for characterizing powdered metals—raw materials for additive manufacturing—in terms of particle size and shape, chemical consistency and size consistency.
- Work undertaken by NIST.
Data formats and retention

• 3D printing uses digital chain of information
• Many CAD formats extant, only some used for data transfer.
  • Information
  • Process
  • Geometry

• Additive manufacturing file formats:
  • STL: proprietary, but de-facto standard through frequent adoption by CAD software providers
  • STEP-NC: ISO 14649-1:2003 Industrial automation systems and integration -- Physical device control -- Data model for computerized numerical controllers -- Part 1: Overview and fundamental principles
  • 3MF: industry consortium including Microsoft, HP, Fit, formLabs, etc.
Guidance and best practise

• With the number of processes out there to choose from which one is the best?

• Considerations (Design for manufacturer/Design for testing):
  • Distinguishing Intermittent Stages of AM
  • Processing
  • Geometry Characteristics Specific to Additive
  • Material Definition
  • Datum/s
  • Functional Requirements
  • Post and pre Inspection
Why a standards is needed.

Technical Report for the Design of Functionally Graded Additive Manufactured Parts:

• Ensuring interoperability
  • The report will review of current capabilities and limitations of existing CAD and Finite Element Method (FEM) software that can support the production of Functionally Graded Additive Manufactured parts and existing software has been used to simulate FG materials that have variation of mechanical properties such as varying elastic modulus of the FGM piece.

• Creating market access
  • It will be relevant for those directly involved in the process of product design development and for those responsible for the material formulation and engineering.

• Provide source of knowledge
  • The report is aimed at all those involved in Additive Manufacturing industry to describe the concept of functionally Graded Additive Manufacturing.

• Creating market acceptance
  • The report will discuss existing gaps in knowledge, the current limitations and suggesting areas for future work. In particular, the report will recommend how future guidelines or standards could be developed from this study.
Dimensional metrology

• The principal check in manufacturing.

• Dimensional metrology instrumentation and post-measurement analysis techniques that will allow them to keep processes under tight control.

• Why are checking?
  • Reducing scrap rate and therefore enhancing environmental sustainability.

• What are checking for?
  • Quality.

• 378 published standards:
  • BS 8888 Technical product documentation and specification
  • BS 8887-1:2006 Design for manufacture, assembly, disassembly and end-of-life processing (MADE) - General concepts, process and requirements
  • BS 6808-3:1989 Coordinate measuring machines - Code of practice
Mechanical, thermal, chemical Testing-AM matrix.

- List of materials properties:
  - Anelasticity
  - Ductility
  - Elastic deformation
  - Elastic recovery
  - Strain
  - Stress
  - Hardness
  - Modulus of elasticity
  - Plastic deformation
  - Poisson’s ratio
  - Proportional limit
  - Shear
  - Tensile strength
  - Strength
  - Toughness
  - Yielding
  - Yield strength
Standards in systems

• The final guidance also includes recommendations for standards in systems.
  • Connector materials
    • BS EN 13544-2:2002+A1:2009 Respiratory therapy equipment. Tubing and connectors
    • BS ISO 17256. Anaesthetic and respiratory equipment. Respiratory therapy tubing and connectors
    • ISO 80369-2:2012, Small-bore connectors for liquids and gases in healthcare applications — Part 2: 62 Respiratory small-bore connectors
  • Flow
    • BS EN ISO 15002:2008 Flow-metering devices for connection to terminal units of medical gas pipeline systems
  • Inadequacy of color-coded and labelled connectors
    • ISO 7000:2004, Graphical symbols for use on equipment – index and synopsis.
  • Labelling
    • EN 980, Symbols for use in the labelling of medical devices
  • Usability and human factors testing
    • BS EN 1041 Information supplied by the manufacturer of medical devices
So where else are AM/3DP standards heading

• Legacy parts
  • Reverse engineering
  • Documents retention
  • Comparison testing

• 3D Hubs
  • 27,813 printers on the network
  • 90% are not fully utilized
  • At least of one of these printers chocolate

• Printing at scale
  • Nano scale printing

• Functional materials printing
  • Embedded electronics
  • Printed electronics
Definition of Digital Manufacturing: e-Enablement of value chain optimisation

- Digital manufacturing is the **collaborative** transformation of manufacturing through the exploitation of advances in ICT

- Digital manufacturing transformation enables new supply chain and operations capabilities (scenarios) to emerge that exploit advances in digital technologies, devices, data analytics, data integration and management across the value chain in many sectors

- Digital manufacturing requires the development of new systems engineering competencies (systems modeling, simulation and interface design) and skills (attitudes) across the manufacturing value chain (R&D, design, supply, production, distribution, in service, disposal)

- Digital manufacturing offers significant national and corporate competitive advantage through affordable flexibility, personalisation and product/service tailoring
### 10 scenarios for digital adoption by manufacturing supply chains

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