Additive Manufacturing Standards

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Purpose of Standards

- make the development, manufacturing and supply of products and services **more efficient, safer and cleaner**
- **facilitate trade** between countries and make it **fairer**
- provide governments with a technical base for **health, safety and environmental legislation**, and conformity assessment
- **share** technological advances and good management practice
- disseminate **innovation**
- **safeguard consumers**, and users in general, of products and services
- make life simpler by providing **solutions** to common problems

http://www.iso.org/iso/about/discover-iso_what-standards-do.htm

Standards Evolution

- Internal Standards
  - Product quality control = better yields, lower costs, better reputation
- Supply Chains
  - For open-loop MFG, consistent output requires consistent inputs
- Spontaneous Industry-wide
  - Promote specialization, reduce costs of competition
- Standards Organization Products
  - Foster inter-industry exchange
  - Typ. Voluntary compliance
- Governmental Adoption
  - Develop own / adopt from Stds. Orgs
  - Public health & safety
  - “Picking winners” / corruption

Standards Organizations

- International
  - BIPM (Private non-profit)
    - Maintains SI units system by international treaty (Metre Convention)
  - ISO (Private non-profit)
    - The UN of standards orgs – HQ in Geneva
    - NGO network of national standards institutes in 161 nations
    - 1 member / nation, some governmental, some industry partnerships
  - SAE International (Private non-profit)
  - ASTM International (Private non-profit)
  - IEEE (Private non-profit)
  - IEC - International Electrotechnical Commission (Private non-profit)
- National (US)
  - ANSI (Private non-profit)
  - NIST (Governmental)
  - EIA (Private non-profit trace association)
    - ECA – The Electronic Components, Assemblies, and Materials Association
    - GEIA – The Government Electronics and Information Technology Association
    - JEDEC – The JEDEC Solid State Technology division, formerly Joint Electron Devices Engineering Councils
    - TIA – The Telecommunications Industry Association
    - ISA – Internet Security Alliance
- Industry Groups
  - USB Specification - HP, Intel, LSI, Microsoft, NEC, ST-Ericsson, etc.

Additive Manufacturing Standards

- From Standards Orgs:
  - SAE Intl. AMS4999- **Titanium Alloy Laser Deposited Products - 6al - 4v – Annealed**
  - ISO laser sintering of test specimens? (cannot find)
- Industry-wide "Spontaneous"
  - STL "Stereolithography format" (see http://www.ennex.com/~fabbers/StL.asp)
    - Developed by 3D Systems for STereoLithography in 1989 for CAD data export
    - Triangular tesselation of surface
    - No microstructure or material heterogeneity supported
  - SLC "Slice format" (see http://rpdrc.ic.polyu.edu.hk/old_files/slc_introduction.htm)
    - Developed by 3D Systems for data transfer for machine control
    - Describes stack of slices, with layer thickness, and pw. Linear boundaries
- Failed (academic)
  - SIF – Solid Interchange Format (S. McMains, UC Berkely, ca. 1998) (http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.2.575)
  - Briefly pursued by NIST initiative in 1998

Product Model Data Standards

- IGES – Initial Graphics Exchange Specification (NIST, USA)
  - Includes “product data” – not just geometry
- ISO 10303 STEP – **St**andard for the **E**xchange of **P**roduct Model Data
  - International follow on to IGES
  - Very (too?) generic – see http://www.steptools.com/library/standard/step_2.html
  - Connect CAD to CAE and CAM in streamlined way
- Functional Representation “F-Rep”
  - http://hyperfun.org/wiki/doku.php?id=hyperfun:main
  - Allows for complex, multi-material, multi-scale designs
  - No good design tools available

CAM/Automation Standards

- ISO TC184 – Automation Systems and Integration
  - TC 184/SC 1 Physical device control
  - TC 184/SC 2 Robots and robotic devices
  - TC 184/SC 4 Industrial data
  - TC 184/SC 5 Architecture, communications and integration frameworks
- EIA RS274D / ISO 6983 “G-Code”
  - Explicit low level commands to machine for motion and aux. actions
  - Mid-level commands like offsetting and arcs
  - No semantic content
- ISO 14649-1:2003 “STEP NC” (http://www.steptools.com/library/stepnc/)
  - Industrial automation systems and integration -- Physical device control -- Data model for computerized numerical controllers
  - Define “process steps” rather than low level motion commands
  - Allows semantic content, e.g. reference to part geometry
  - Trying to replace G-Code and place more intelligence in machine tool
- PLCOpen – Open Automation Standard, TC2 committee on Function Blocks, TF Motion Control
  - http://www.plcopen.org/pages/tc2_motion_control/
  - International
- IEC 61131-3
  - Programming languages for Programmable Controllers (Industrial Controllers)
  - See e.g. CoDeSys (http://www.3s-software.com/)

Why Formal AM Standards?

- No dedicated technical committees in industry or standards orgs
- Industry size is increasing > $\$10^9$ ($1.2B, 2008)
- Some existing standards inapplicable or restrictive
  - ABS from FDM process != extruded, cast, etc.
  - STL does not handle microstructure, heterogeneity, etc.
- Acceptance hindered by product variability

ASTM F42

- 1998: NIST sees need for standards in RP
  - http://www.mel.nist.gov/msidlibrary/summary/9818.html
- 1999-2007
  - ?
- 2008: SME Rapid Technologies Additive Manufacturing (RTAM) sees need for standards in RP
  - selected ASTM after review of standards developing organizations (worldwide)
  - 14 individuals met Nov 2008 for preliminaries
  - Identified 4 key areas:
    - Terminology
    - Testing
    - Materials
    - Process-specific specs
  - 80+ industry / academic met in January ‘09 and formed ASTM F42 – Additive Manufacturing

F42 Members

- 3D Systems Corporation
- Air Force Research Laboratory
- Arcam AB
- Aspect
- ASTM International
- BMW Group
- C.R.P. Technology
- Cornell University
- Custom-Fit
- Denel Dynamics
- Edmonds Community College
- EOS GmbH
- EOS of North America, Inc.
- Exatech, Inc.
- Fab@Home Project / NextFab Organization
- Forecast3D / Directed MFG Forecast3D / Directed MFG
- GE Aviation
- GE Global Research
- General Pattern
- Georgia Institute of Technology
- Honeywell
- Huntsman
- INSPIRE
- Loughborough University
- Materialise NV
- Medical Modeling, Inc.
- Met-L-Flo, Inc.
- NASA Huntsville
- Naval Air Warfare Center
- NCMS
- NIST
- North Carolina State University
- Objet Geometries
- Paramount Industries, Inc.
- Prototypes Plus R
- apid Quality Manufacturing, Inc.
- RPM and Associates, Inc.
- Saddleback Community College
- Siemens AG
- Society of Manufacturing Engineers
- Stratasys, Inc.
- Stryker Orthopaedics
- The Ex One Company, LLC
- University of Texas at Austin
- University of Tokyo
- Utah State University
- V.K.G. Wholers Associates Z Corporation

Check out ASTM.org to join..

ASTM F42 Structure

- Subcommittee on Terminology
  - Unify acronyms/process names (v. contentious)
  - Define terminology
- Subcommittee on Test Methods
  - How to measure standards compliance
- Subcommittee on Processes
  - What process params need to be monitored? Allowed ranges?
- Subcommittee on Materials
  - AM-specific materials issues, e.g. powder material morphology
- Subcommittee on Design
  - Design for AM
  - Data formats and exchange