Development of Standards Education Modules for Additive Manufacturing

Hannah Budinoff, Ph.D

Assistant Professor
Department of Systems and Industrial Engineering

Andrew Wessman, Ph.D.

Assistant Professor
Department of Materials Science and Engineering

Cholik Chan, Ph.D.

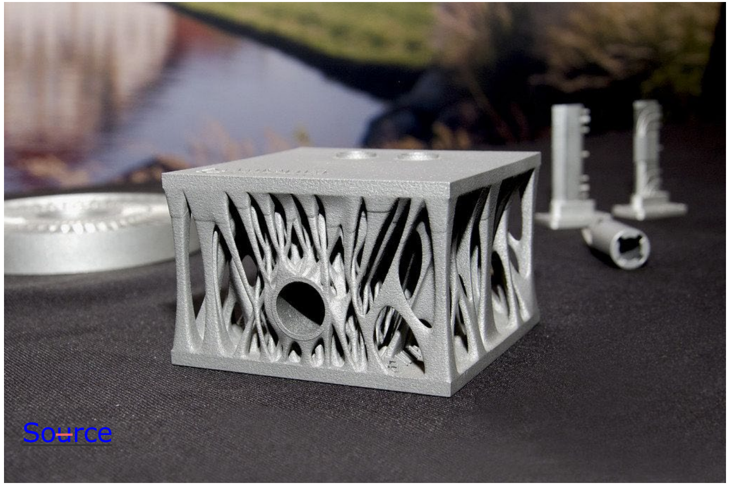
Professor
Department of Aerospace and Mechanical Engineering

THE UNIVERSITY OF ARIZONA

How can we improve the design and production of parts manufactured using additive manufacturing?

3D Printing + COVID

Metal AM applications



Additive manufacturing: A broad and fast-changing area

About us

Name:	Hannah Budinoff	Andrew Wessman	Cholik Chan
Background:	**Department:** Systems & Industrial Engineering **Research**: Engineering design; makerspaces **Industry**: Honeywell Aerospace **Teaching**: Ugrad/grad Design for AM course	**Department:** Materials Science & Engineering **Research**: Metallurgy; high-temp alloys **Industry**: GE Additive **Teaching**: Ugrad/grad Metal AM course	**Department:** Aerospace and Mechanical Engineering **Research**: Heat transfer; Energy storage **Industry collaborators**: Raytheon, Air Force Research Laboratory **Teaching**: Ugrad/grad Intro to AM course

Our courses

MSE 540 - Metal Additive Manufacturing

Description
Metal additive manufacturing is a technology experiencing rapid adoption across a number of industries where high design complexity, customization and rapid turn times are desirable such as aerospace, biomedical, motorsports and functional prototyping. This course will examine the various industrially relevant metal additive manufacturing processes, the fundamental interactions between processing parameters, alloy chemistries, materials structures and application, and the post processing operations and computation tools used to obtain finished parts that meet engineering design intent.

THE UNIVERSITY OF ARIZONA

SIE 481/581 Design for Additive Manufacturing
Time & Location: M&Wed 12-1:15PM, ENGR 301

Hannah Budinoff, Ph.D.
Assistant Professor, Department of Systems and Industrial Engineering
Office: ENGR 129; hdb@email.arizona.edu; Phone (office): 520-621-2826
Office Hours: 10-10:50am Tu/Thu

Course Description
This course is an introduction to the engineering design process with a focus on understanding constraints and opportunities associated with additive manufacturing (AM). Students will gain an understanding of how to exploit AM to manufacture parts with complex geometry, while also considering economic viability and manufacturability. Opportunities and constraints associated with various AM technologies, from fused-filament fabrication (often called 3D printing) to metal AM processes, will be surveyed. The course will culminate in a hands-on design project where students will use design-for-additive-manufacturing (DfAM) frameworks and tools to design a novel product. This course aims to promote creativity and critical thinking, which are necessary to effectively use AM technology in the context of product design.

AME410

Download as PDF

AME410 - Introduction to Additive Manufacturing

Aerospace & Mechanical Engr • Undergraduate • UA - UA General

General

Course Description
Additive Manufacturing (AM), as defined by ASTM International Committee F42, is the process of joining materials to make objects from three-dimensional (3D) model data, usually layer by layer, as opposed to subtractive manufacturing methodologies. Traditional manufacturing processes are subtractive, creating the object by machining, forming, casting, etc. AM converts computer-aided design (CAD) models to Standard Tessellation Language (STL), the de facto standard. The STL file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices. Thus, it can be used to construct the 3D objects layer by layer using various materials (e.g. metallic, plastic).

In this course, engineering materials and their properties are first reviewed. Traditional manufacturing such as casting, forming, machining, and joining processes are introduced and discussed. Additive manufacturing is then presented. Both general process chain and specific processes are presented (e.g. photopolymerization, powder bed fusion process). Materials properties of each manufacturing process are examined and compared to each other. Design and optimization for AM is highlighted. Real engineering applications are reviewed and discussed. A final project is required so that student can gain experiences in the entire AM process.

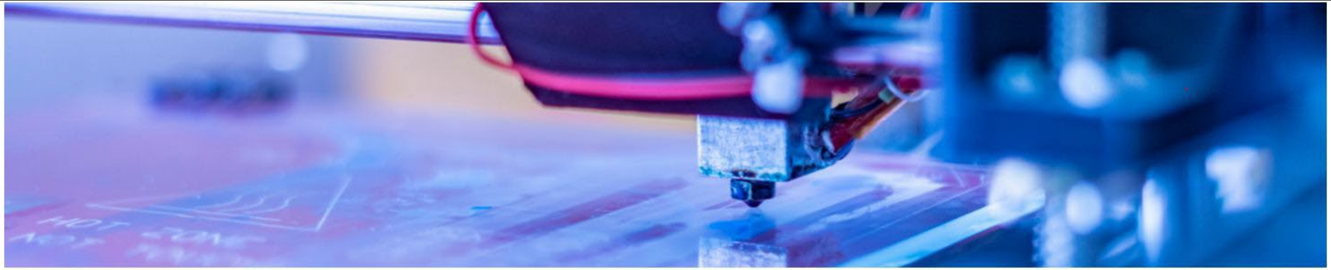
Our overarching goal:

To prepare engineers who can utilize technical standards to guide their use of additive manufacturing technologies

Our 5 specific objectives

01	Develop 4 e-learning modules
02	Deploy each of the developed modules in one or more courses at UArizona
03	Improve students' ability to identify, locate, evaluate, and use standards for technical problems related to AM
04	Distribute e-learning modules to other institutions of higher education with guidance for they can replicate our methods
05	Disseminate project results in a final summary paper to a wide audience

Our learning module format



Introduction

Module Introduction

In this module, you will learn about t
explore the range of technical standa
standards.

Learning Outcomes

At the end of this module, you will be

Activity List

1. **Watch and Do:** Follow along with the interactive tutorial *Standards: How Do I Find & Use Them?* (15 minutes)
2. **Read:** Development Process for Technical Standards (5 minutes)
3. **Read and Reflect:** Case Study (20 minutes)
4. **Do**: Complete Module 1 reflection (20 minutes)
5. **Bonus Resource:** To learn more, check out the Additional Resources at the end of the module

Topics in our e-learning modules

Learning module focus	Topics and relevant standards
Module 1: Introduction to engineering standards	**Topics**: Standards development organizations; standard development process; How to identify and access standards; ASTM F42 committee
Module 2: Intro to additive manufacturing standards	**Topics**: AM terminology; Design and data formats; AM test samples; GD&T; AM applications **Relevant standards**: ISO/ASTM52900-15, ISO/ASTM 52921-13; ISO 17296-4; ISO/ASTM 52915-13; ASME Y14.5; ISO/ASTM 52942-20
Module 3: Additive manufacturing process development	**Topics**: AM processes; AM feedstocks; Preparing and testing test specimens **Relevant standards**: F2971-13; ISO/ASTM52904-19; F3049-14
Module 4: Testing and evaluation for additively manufactured parts	**Topics**: Mechanical properties; Requirements for purchased AM Parts **Relevant standards**: ISO/ASTM52901-16; F3302-18; F3122-14; ASTM A370 - 20

Collaboration with industry

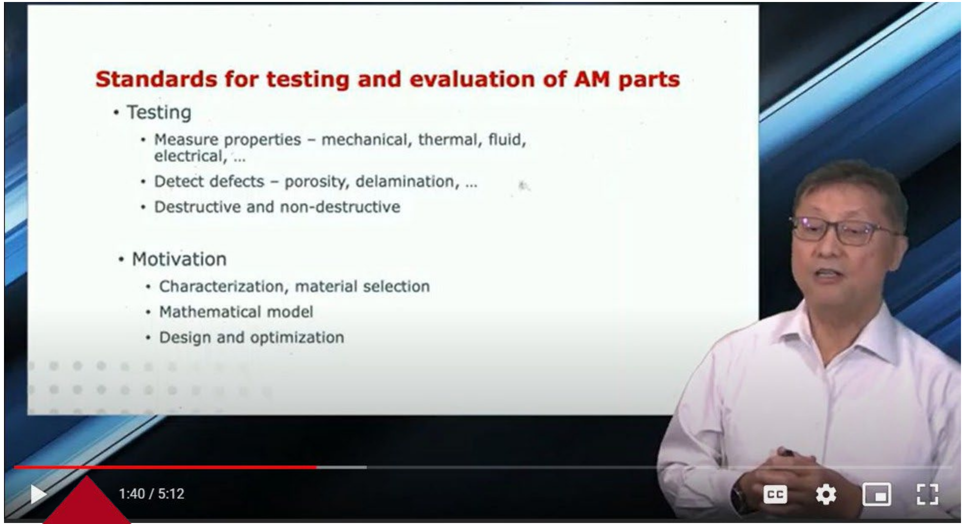
- Dr. Wessman came from GE Aerospace’s AM group
- Leveraged his connections to get informal feedback from representatives in industry and SDOs
    - ASTM

ASTM INTERNATIONAL

GE Additive

Short, interactive videos

- We ended up breaking long lectures into short clips for online learning/
- Utilizing PlayPosit to add interactivity
- Filmed in recording studio with professional equipment



Our videos

Adding resources to help with applied projects

- Detailed project descriptions
- Descriptions of project deliverables, with descriptions of expected incorporation of standards
  - E.g., progress reports, PDR/CDR, final reports etc.
- Rubrics to support grading

Good feedback from students

Improvements in % of students' who feel confident in identifying and using standards from pre-test to post-test

- I feel that I can **define** what a technical standard is
  (Pre: 37% Post: 77%)
- I feel that I can **locate** technical standards in online databases
  (Pre: 33% Post: 73%)
- I feel that I can **determine what type of technical standard** to use as I conduct engineering work
  (Pre: 36% Post: 59%)
- I feel confident that I can **utilize technical standards** as I conduct engineering work
  (Pre: 44% Post: 68%)

Comments give us ideas for improvement

- “The best activities were the interactive videos and quizzes.”
- "Even though the material is necessary and every engineer will use standards, it is a bit dry to dive into.”
- “Honestly, I like short readings (1-8 pages), after that it starts getting harder to retain the information”
- “I liked the case studies from Monday the most since it was a real-world problem and it had me thinking about what standards could be applied to solve it- I looked at the COVID mask one.”

Implementing in classes

- Online sections can use modules directly
- For in person courses, instructors can adapt different approaches:
  - Active learning day on laptops in class
  - Flex at home day to complete activities
  - Adapt material to lecture format

Course growth

- For SIE 481/581
  - F2020, enrollment was 11
  - F2022, enrollment was 18
  - F2025, enrollment was 29
- Similar growth in AME 410 and MSE 440/540

- AME 410 S2025 enrollment was 49

- MSE 440/540 F2025 enrollment was was 24

Takeaways

- Better to embed standards in content **throughout the semester**, rather than in a few specific class days
- Students need a variety of activities for online modules, not just videos–should be a **mix of content**
- Keep videos **short** and **focused**
- Students connect more with **applications** than theory
- Students want more opportunities to **use standards** during **hands-on, applied projects**

Adoption at other IHE

- AM courses exist at many institutions of higher education
- Dissemination to share developed resources with other engineering instructors, plus lessons learned
  - Deshpande Symposium
  - American Society for Engineering Education
  - Direct contact
- Feedback received: general need for standard education content more broadly across engineering due to ABET requirements

Final Message

- Students will be **better prepared for engineering jobs** if they can utilize **standards** to guide their work
- **More content** and **opportunities** to utilize standards **are needed** in undergraduate curricula
- Many **free resources exist** that can be incorporated into a variety of courses
- Instructors can easily **improve** the **industry-relevance** of courses by **incorporating standards** into their courses

Thanks!

Suggestions? Questions?

Hannah Budinoff
hdb@arizona.edu

We thank the NIST Standards Coordination Office Curricula Development Cooperative Agreement Program for their support. All opinions are our own.