Technician Education in
Additive Manufacturing & Materials
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Additive Manufacturing:
Processes and Standard Terminology

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Abstract
This module provides an introduction to Additive Manufacturing Terminology used in manufacturing and in the classroom. Using the standard terminology developed by ASTM International, the student will explore the basic processes used in additive manufacturing and will compare and contrast these processes. The lesson can be used for large or small groups.

Objective:
The student will be able to:
Define the basic terms used in additive manufacturing in oral and written communications.
Explain and illustrate the various additive manufacturing processes.
Compare and contrast the various additive manufacturing processes.
Define the acronyms used in additive manufacturing.

AM core competencies addressed (most important in bold)
8a1 **Define the basic terms used in additive manufacturing in oral and written Communications**
8a2 Explain and illustrate the various additive manufacturing processes
8a3 Compare and contrast the various additive manufacturing processes
8a5 Define the acronyms used in additive manufacturing

Key Words: Additive manufacturing, rapid prototyping, 3D printing

Type of Module: Lecture

Time Required: 1 hour

Grade Level
Grades 6 through college

Equipment and supplies needed
Standard classroom set-up (computer, overhead projection)

Introduction to Additive Manufacturing

Processes and Terminology

A. Please refer to the accompanying PowerPoint presentation titled: Introduction to Additive Manufacturing and Standard Terminology

B. **Additive Manufacturing** (See Slide 2)

a. **Definition**: (AM), n--process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication.
   i. May be wrongly referred to as Rapid Prototyping

b. **Advantages:** (See Slide 3)
   i. Virtually No machine setup or Tooling needed
   ii. Creates composite materials
   iii. Is a freeform fabrication method of manufacturing

C. **Rapid Prototyping** (See Slide 4)

a. **Definition** --additive manufacturing of a design, often iterative, for form, fit, or functional testing, or combination thereof.
   i. May be wrongly used in place of Additive Manufacturing

b. **Advantages**: (See Slide 5)
   i. Provides a one-off original part for true form, fit or functional testing or a combination of thereof.

D. **Additive Manufacturing Processes**

a. **3D Printing** (See Slide 6)
   i. Definition: n-fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology.
   ii. Three dimensional printing was developed at MIT. It's often used as a direct manufacturing process as well as for rapid prototyping.
   iii. The process starts by depositing a layer of powder object material at the top of a fabrication chamber. To accomplish this, a measured quantity of powder is first dispensed from a similar supply chamber by moving a piston upward incrementally. The roller then distributes and compresses the powder at the top of the fabrication chamber. The multi-channel jetting head subsequently deposits a liquid adhesive in a two dimensional pattern onto the layer of the powder which becomes bonded in the areas where the adhesive is deposited, to form a layer of the object.
   iv. Once a layer is completed, the fabrication piston moves down by the thickness of a layer, and the process is repeated until the entire object is formed within the powder bed. After completion, the object is elevated and the extra powder brushed away leaving a "green" object. No external supports are required during fabrication since the powder bed supports overhangs.
   v. Three dimensional printing offers the advantages of speedy fabrication and low materials cost. In fact, it's probably the fastest of all RP methods. Recently color output has also

become available. However, there are limitations on resolution, surface finish, part fragility and available materials. The closest competitor to this process is probably fused deposition modeling.

b. **Stereolithography** (See Slide 7)

i. Definition: n—process used to produce parts from photopolymer materials in a liquid state using one or more lasers to selectively cure to a predetermined thickness and harden the material into shape layer upon layer.
ii. Stereolithography is the most widely used rapid prototyping technology. Stereolithography builds plastic parts or objects a layer at a time by tracing a laser beam on the surface of a vat of liquid photopolymer. This class of materials originally developed for the printing and packaging industries, quickly solidifies wherever the laser beam strikes the surface of the liquid. Once one layer is completely traced, it's lowered a small distance into the vat and a second layer is traced right on top of the first. The self-adhesive property of the material causes the layers to bond to one another and eventually form a complete, three-dimensional object after many such layers are formed.
iii. Some objects have overhangs or undercuts which must be supported during the fabrication process by support structures. These are either manually or automatically designed and fabricated right along with the object. Upon completion of the fabrication process, the object is elevated from the vat and the supports are cut off.
iv. Stereolithography generally is considered to provide the greatest accuracy and best surface finish of any rapid prototyping technology. Over the years, a wide range of materials with properties mimicking those of several engineering thermoplastics have been developed. Limited selectively color changing materials for biomedical and other applications are available, and ceramic materials are currently being developed. The technology is also notable for the large object sizes that are possible.
v. On the negative side, working with liquid materials can be messy and parts often require a post-curing operation in a separate oven-like apparatus for complete cure and stability.
vi. Recently, inkjet technology has been extended to operation with photopolymers resulting in systems that have both fast operation and good accuracy. See the section on inkjets.

c. **Fused Deposition Modeling (**See Slide 8)

i. Definition: n--making of thermoplastic parts through heated extrusion and deposition of materials layer by layer.
ii. FDM is the second most widely used rapid prototyping technology
iii. A plastic filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. The nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical directions.
iv. As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic.

v. Several materials are available for the process including ABS and investment casting wax. ABS offers good strength, and more recently polycarbonate and poly(phenyl)sulfone materials have been introduced which extend the capabilities of the method further in terms of strength and temperature range. Support structures are fabricated for overhanging geometries and are later removed by breaking them away from the object. A water-soluble support material which can simply be washed away is also available.

vi. The method is office-friendly and quiet. FDM is fairly fast for small parts on the order of a few cubic inches, or those that have tall, thin form-factors. It can be very slow for parts with wide cross sections, however. The finish of parts produced with the method have been greatly improved over the years, but aren't quite on a par with stereolithography. The closest competitor to the FDM process is probably three dimensional printing. However, FDM offers greater strength and a wider range of materials than at least the implementations of 3DP from Z Corp. which are most closely comparable.

d. Selective Layer Sintering (See Slide 9)

i. Definition: n—denotes the LS process and machines from 3D Systems Corporation.

ii. Thermoplastic powder is spread by a roller over the surface of a build cylinder. The piston in the cylinder moves down one object layer thickness to accommodate the new layer of powder. The powder delivery system is similar in function to the build cylinder. Here, a piston moves upward incrementally to supply a measured quantity of powder for each layer.

iii. A laser beam is then traced over the surface of this tightly compacted powder to selectively melt and bond it to form a layer of the object. The fabrication chamber is maintained at a temperature just below the melting point of the powder so that heat from the laser need only elevate the temperature slightly to cause sintering. This greatly speeds up the process. The process is repeated until the entire object is fabricated.

iv. After the object is fully formed, the piston is raised to elevate it. Excess powder is simply brushed away and final manual finishing may be carried out. No supports are required with this method since overhangs and undercuts are supported by the solid powder bed. That's not the complete story, though. It may take a considerable length of cool-down time before the part can be removed from the machine. Large parts with thin sections may require as much as two days of cooling time.

v. SLS offers the key advantage of making functional parts in essentially final materials. However, the system is mechanically more complex than stereolithography and most other technologies. A variety of thermoplastic materials such as nylon, glass filled nylon, and polystyrene are available. Surface finishes and accuracy are not quite as good as with stereolithography, but material properties can be quite close to those of the intrinsic materials. The method has also been extended to provide direct fabrication of metal and ceramic objects and tools.

vi. Since the objects are sintered they are porous. It may be necessary to infiltrate the part, especially metals, with another material to improve mechanical characteristics.

e. Direct Metal Laser Sintering (See Slide 10)

i. Definition: n--use of laser sintering to make metal parts, directly from metal powders without intermediate “green” or “brown” parts; term denotes metal-based laser sintering systems from EOS GmbH – Electro Optical Systems. Synonym: direct metal laser melting.

E. Additive Manufacturing Terms (See Slides 11- 13)

a. **3D Printer:** n—machine used for 3D printing.

b. **3D Scanning:** n—method of acquiring the shape and size of an object as a 3-dimensional representation by recording x,y,z coordinates on the object’s surface and through software the collection of points is converted into digital data.

c. **Build Cycle**: n—single cycle in which one or more components are built up in layers in the process chamber of the machine.

d. **Build Platform**: n—of a machine, any base which provides a surface upon which the build is started and supported throughout the build process.

e. **Build Surface**: n—area where material is added, normally on the last deposited layer which becomes the foundation upon which the next layer is formed.

f. **Computer Aided Design (CAD):** The use of computers for the design of real or virtual objects.

g. **Computer Aided Manufacturing (CAM):** Typically refers to systems that use surface data to drive CNC machines, such as digitally-driven mills and lathes, to produce parts, molds, and dies.

h. **Machine**: n—a system including hardware, machine control software, required set-up software and peripheral accessories necessary to complete a build cycle for producing components.

i. **Machine Coordinate System**: n—a three-dimensional Cartesian coordinate system as defined by a fixed point on the build platform “with the three principal axes labeled X, Y, Z, with rotary axes about each of these axes labeled A, B C, respectively”.

j. **Prototype Tooling**: n—molds, dies, and other devices used to produce prototypes; sometimes referred to as bridge tooling or soft tooling.

k. **Rapid Tooling**: n—in machining processes, the production of tools or tooling quickly by subtractive manufacturing methods, such as CNC milling, etc.

l. **STL:** n—file format native to the stereolithography computer-aided drafting (CAD) software that is supported by many software packages; it is widely used for rapid prototyping and computer-aided manufacturing.

m. **Subtractive Manufacturing**: n—making objects by removing of material (for example, milling, drilling, grinding, carving, etc,) from a bulk solid to leave a desired shape, as opposed to additive manufacturing.

n. **Tool, Tooling:** n—mold, die, or other device used in various manufacturing and fabricating processes such as plastic injection molding, thermoforming, blow molding, vacuum casting, die casting, sheet metal stamping, hydroforming, forging, composite lay-up tools, machining and assembly fixtures, etc.

o. **X Axis:** n—of a machine, shall run perpendicular to the Z axis and parallel to the front of the machine.

p. **Y Axis**: n—of a machine, shall run perpendicular to the Z and X axes with positive direction defined to make a right hand set of coordinates as specified in ISO 841.

q. **Z Axis**: n—of a machine, for processes employing planar layer wise addition of material, shall run normal to the layers.

Evaluation:

1. Define Additive manufacturing.
2. What is the difference between the term additive manufacturing and rapid prototyping?
3. What are the advantages to using additive manufacturing technology in the workforce?
4. What are the X,Y, Z axes' when designing a 3-D part?

References:

1. The core competencies used in the development of this module were taken from the draft of the Additive Manufacturing Core Competencies for Technicians soon to be released by The National Resource Center for Materials Technology Education (MatEdU), Technician Education in Additive Manufacturing (Project TEAM), under NSF Grant: DUE #1003530

2. Standard Terminology for Additive Manufacturing Technologies ASTM Standard: F2792-12a