MATERIALS™ EXPLORERS

ADDITIVE MANUFACTURING

Additive manufacturing is transforming design and production across a variety of industries and, with access to 3D printers becoming even more common, additive manufacturing may also change the way consumers access custom items or bring their own ideas to life. Learn more about this revolutionary technology in this chapter.

In this module students will be able to:

- Describe the difference between subtractive processes, forming processes, and additive manufacturing
- Identify various forms of additive manufacturing
- Identify applications of additive manufacturing
- Create and evaluate a prototype
- Explain some potential benefits and limits of additive manufacturing

Class Activity

TEAM DESIGN CHALLENGE

Background:
What do you think of when you hear the term 3D printing? Did you know 3D printers are being used to create beautiful works of art? Or that NASA is looking into 3D printing shelter for future astronauts on Mars?

Over the last few years, access to 3D printers has exploded, and they can now be found in many schools, office supply stores, and even homes. You can also design your own products and have them printed for you through online vendors. In industry, 3D printing is referred to as **additive manufacturing**, a relatively new process which literally adds materials layer by layer until the desired object is fabricated.

While much of 3D printing uses plastic as the material for fabrication, additive manufacturing for many industrial applications uses metal powder with the layers joined together, or sintered, using a laser. This process is known as Selective Laser Melting. The process begins with the use of 3D modeling software to create a **Computer Aided Design (CAD)** file. The software allows for mathematically precise designs that can take into account exactly how the part will be used and the potential stresses it will need to manage in order to work effectively. The additive manufacturing machine reads this digital file and slices it into virtual layers that serve as the blueprints for the product. Each of these layers defines the path the laser point of light follows as it moves rapidly along the surface of the metal powder to sinter the powder into a solid layer of metal. This process is repeated one layer at a time, with material being added until the three-dimensional part is ready.

To understand what makes additive manufacturing so groundbreaking, it is helpful to first understand more traditional manufacturing processes. **Subtractive manufacturing** dates as far back as prehistoric society. Ancient hunter-gatherers produced survival tools such as spears or arrows by chipping away at wooden sticks until a sharp point was formed. Similarly, they learned to create sharp stone arrowheads by using even harder stones to chip away at the material until it obtained the desired shape. Today, such processes are carried out much more quickly and with greater precision using automated machines, and on more durable materials, such as the metals and alloys used throughout industry. However, the basic principle of creating a product by subtracting from a larger block of material remains the same.

As the ability to generate higher temperatures by fire was attained, the Iron Age and Bronze Age saw the development of **forming processes** such as casting liquid metal and hammering heated metal.

Class Activity

This provided the ability to make more varied and useful shapes, as well as elaborate artwork. In modern industry, these processes are highly automated and are the backbone, along with machining (subtractive processes), of mass production, which makes many of the products that we enjoy today possible

So where does additive manufacturing come in? Additive manufacturing is the next chapter in the ongoing progression of manufacturing toward improved products. Unlike subtractive and forming processes which produce wasted material which must be recycled or discarded, additive manufacturing saves on cost and materials by producing no waste.

Initially, the focus of additive manufacturing was to create models or prototypes before they were produced on a large scale. However, the purpose of additive manufacturing has shifted to fabricating final products that require customization or exacting precision for use in biomedical applications, transportation, and even fashion. In addition to deciding what material is best for an application, scientists and engineers also think about the particle size, or **voxel**, being used. This activity will ask you to consider the challenges of working with different sized particles.

Problem

You and a classmate have entered a gameshow and your challenge is to use an additive manufacturing process to create two identical prototypes using sugar and glue.

Task:
You and your partner are tasked with creating two identical shapes using glue and sugar. The shapes can be either a heart, diamond or triangle but your designs must match one another's. One prototype will be created by gluing together layers of sugar cubes, while the second prototype will be created by gluing layers of sugar granules.

Requirements:
1. The prototypes must clearly resemble the intended shape.
2. The prototypes should be sturdy enough that they can be picked up without falling apart.
3. Both prototypes must have the same shape and dimensions (width, length, and height).

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Class Activity

Questions

1. **List one advantage and one disadvantage of each material used (sugar cubes and sugar granules).**

2. **The engineering design process entails identifying a problem, brainstorming solutions to the problem, creating solutions to the problem, evaluating the solutions, and refining the solutions. After evaluating your prototypes how would you change your process in the following scenarios?**
   - **i.** You are only given 5 minutes to construct the same prototype. Which method would you select and why?
   - **ii.** You have unlimited time but are asked to create an accurate copy of any given shape. Which method would you select and why?

3. **While there are many benefits to additive manufacturing, it is not always the best process for the job.**
   - **i.** Research subtractive, forming, and additive manufacturing processes and briefly describe each process.
   - **ii.** For each of the processes above, identify one application where it is the preferred production process and explain why that may be.

4. **How would this experiment differ if you had to replicate the subtractive method of manufacturing by chipping away at a block of sugar to create your shape? What challenges would you expect?**

5. **A wide range of materials are being used for additive manufacturing, with new materials being frequently added.**
   - **i.** List 3 types of materials that can be used for additive manufacturing.
   - **ii.** For any one material listed in part i., identify one product it is currently being used to create and discuss why that material was chosen.

Definitions

Additive Manufacturing (AM)
A technology used to build 3D objects by adding layer by layer of material.

Computer Aided Design (CAD)
A technology used to create, modify, or analyze a design.

Forming Processes
Manufacturing processes that use stresses such as tension, to cause deformation of materials and produce desired shapes.

Subtractive Manufacturing
A process used to construct 3D objects by cutting away material from a solid block of material.

Voxel
A point in three-dimensional space.

Extension Activity

LAYERS OF COMPLEXITY: MAKING THE PROMISES POSSIBLE FOR ADDITIVE MANUFACTURING OF METALS

It is a vending machine like no other, dispensing the physical embodiment of ideas and imagination at the touch of a button. Powered by four Makerbot 3D printers, the DreamVendor beckons Virginia Tech students from its vantage point in a busy lobby to design and create everything from prototypes for classroom projects, to chess pieces, to smartphone stands.

Christopher Williams, Director of the Virginia Tech Design, Research, and Education for Additive Manufacturing Systems (DREAMS) Laboratory stresses that he and his team developed the DreamVendor 3D printing station to reach individuals who never thought to step into an engineering laboratory. "The vending machine interface is very important. It lowers the barrier to the technology and engages students in public making," said Dr. Williams. "No longer are these machines behind a laboratory's locked doors. No permission is needed for students to design and build. Countless students from across the university have used the machine to build parts and some have reported learning Computer Aided Design (CAD) just to use the DreamVendor."

Similar to inserting coins to buy a snack, Virginia Polytechnic Institute and State University (Virginia Tech) students like Amy Elliot (above) insert an SD card with their design into DreamVendor, and the machine fabricates and dispenses a finished part. Amy is researching additive manufacturing of copper for her Ph.D. work in the Virginia Tech DREAMS Laboratory. (Photo courtesy of Virginia Tech.)

DreamVendor's intent to empower anyone to design and produce anything at any time is also the beating heart of what has become known as the Maker Movement. Using 3D printing techniques and computer-aided tools, a rapidly growing community of independent inventors, called makers, is rewriting the rule book on how, where, and when products are manufactured.

Great Potential in Need of a Workforce

The excitement seen in community makerspaces— shared workshops that provide affordable access to fabrication tools—is evident in many advanced industrial settings as well. Rather than the 3D printers typically used by makers, these companies are adopting many similar technologies, collectively known as additive manufacturing (AM), for large-scale fabrication of parts.

Simply stated, additive manufacturing works by joining materials, layer by layer, to build components according to 3D

Extension Activity

modeling data. This helps design drive the manufacturing process, rather than the other way around. From a production standpoint, AM techniques can eliminate the time, equipment, and waste of proving out a mold, milling a piece from solid block, and other subtractive machining methods. The parts also tend to be lighter weight and lower maintenance since they can be produced in one piece, reducing the need for welding and joining. The potential cost and time savings in effectively adopting this new approach to manufacturing could be enormous, while the ability to render one-piece, complex components opens design possibilities that were never possible with conventional manufacturing methods.

A Lighter Way to Fly: *GE Aviation used additive manufacturing technology to design and fabricate fuel nozzles for its LEAP-56 engines. Fuel nozzles that had been traditionally manufactured consisted of 20 separate components joined together. The additively manufactured fuel nozzle is one, continuous piece that is "grown," layer by layer. The weight savings of the new fuel nozzle over the previous model is estimated at around 25 percent. Among expected benefits of using the additive approach for fabricating it is a decrease in fuel burn due to weight reductions and design improvements resulting from the elimination of so many points of joining. (Photo courtesy of GE Aviation)*

Interest in harnessing the possibilities offered by additive manufacturing has skyrocketed over the last few years. However, there is concern that a shortage of appropriately prepared workers may be a barrier to fully adopting the technology. "In order to further the application of AM, we must educate the workforce on when, why, and how to make use of this powerful technology," said Dr. Williams. "The need for AM education spans many levels. This ranges from training technicians for machine operation, maintenance, and repair, to educating Ph.D.s to advance the core science and technology that will drive improvements in machine precision, as well as material quality and selection."

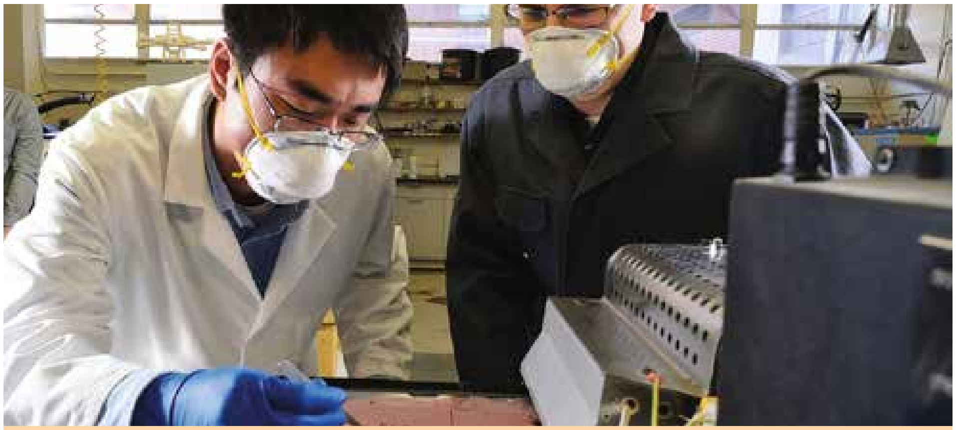
With metal AM still very much in its infancy, the challenges of understanding the science, perfecting the engineering, and addressing related policy and educational issues are just now coming into focus. Even so, there is great optimism that metal AM can transform how many manufactured goods are produced.

The Right Tool for the Job

For the aerospace sector, the current primary applications for structural AM are tooling, fixtures, form-fit models, and prototyping. AM can significantly reduce lead

Mary Kinsella demonstrates the use of a desktop 3D printer. A focus of Air Force research is 3D printing and additive manufacturing technology for prototyping, tooling, fixtures, and some noncritical parts.
(U.S. Air Force photo by Lori Hughes [88ABW-2013-3348])

Extension Activity



To accelerate the rate of adoption, we need to train future engineers on when to use AM, which technologies/materials they should select, and how to design," said Christopher Williams, Virginia Tech University. (Photo courtesy of Virginia Tech)

times for all of these applications and, in some cases, enhance capability through more complex geometries, such as for **casting tooling**. There are also some non-critical part and **niche applications** in which component life requirements are reduced or otherwise limited.

"In the future, we plan to apply AM for new design, enabling multi-material and multi-functional components and location-specific properties," said Mary E. Kinsella, Additive Manufacturing IPT Leader and Senior Manufacturing Research Engineer, U.S. Air Force Research Laboratory (AFRL). "This is down the road, though, and we have much work to do."

More than a decade ago, the AFRL was the first to qualify and fly a metallic part on a military aircraft—a pylon rib for the F-15. "We had a situation where a replacement part was needed, but lead time for tooling was excessive. Also, the part was already intended to be redesigned for a different material—from an aluminum forging to titanium—to solve corrosion fatigue problems," said Dr. Kinsella. "This niche application provided an opportunity to try out a process called laser additive manufacturing. It was difficult and expensive, but necessary to meet mission requirements. We learned a great deal about the challenges of using AM technologies for aerospace applications."

A key takeaway from this and subsequent experiences is that AM is not suitable for all applications, noted Dr. Kinsella. "It is a new tool to place in the manufacturing toolbox and to use only as appropriate," she said. "If you are trying to replace an existing part, it is important to remember that the original part was designed with a different manufacturing process in mind, and you need to respect the original design intent. For new designs, materials and manufacturing approaches can be optimized for AM to meet part requirements. But it will be some time before we can take full advantage of AM's unique benefits for critical aerospace structures."

This article was excerpted from "Layers of Complexity: Making the Promises Possible for Additive Manufacturing of Metals" by Lynne Robinson and Justin Scott, published in JOM, *November 2014, Volume 66, Issue 11, pp 2194-2207.*

In addition to making new items, additive manufacturing can be used to extend product life and repair damaged components. (Photo courtesy of Optomec)

Extension Activity

Questions

1. **Describe the process of fabricating a component, such as the LEAP fuel nozzle, using additive manufacturing technologies.**

2. **Military laboratories are not the only places using additive manufacturing. Research mills, plants, universities, or laboratories close to your school that utilize additive manufacturing techniques. What parts do they produce and what are the parts utilized for?**

3. **Why is additive manufacturing not always suitable for all applications?**

4. **Think about a product problem you encounter in everyday life. What is the problem and how could additive manufacturing help you solve the problem?**

Definitions

Casting Tooling
Casting tooling involves the molds and cores used to produce castings. Casting involves pouring molten metal into the mold and allowing it to solidify, forming a part that has the shape of the cavity inside the mold.

Niche Application
Applies to the very specific wants and needs of a small group of people.

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