Unit 45: Additive Manufacturing Processes

Delivery guidance

Approaching the unit

This unit may be new learning for many students or a subject where they have seen the process but never had to design or manufacture using it. This unit could follow on from units such as *Unit 10: Computer Aided Design in Engineering* or *Unit 43: Manufacturing Computer Numerical Control Machining Processes*, or could be taught concurrently with one or both of these. Learners may also bring their knowledge of non-industrial 3D printers. They may not realise that the aeronautical industry produces components for modern aircraft from titanium using additive manufacturing processes. Learners may also have experienced the use of CAD through previous education or perhaps as employees.

You should encourage learners to develop their theoretical knowledge of various processes and materials as well as the practical skills. A third of the content of this unit comprises practical activities. Encourage learners to develop their rationale for completing tasks in a specific way, so that the final product can be successfully manufactured on the hardware and software that they are able to use. They should consider the ways in which this enhances or limits the models that can be created.

To complete this unit your learners will need access to computer software and additive manufacturing hardware. It is envisaged that most centres will use Fused Deposition Modelling 3D printers for the practical activities.

You can use a range of delivery methods for this unit, such as:

- discussions – class and small group discussions on additive manufacturing
- individual or group presentations– covering the practical drawing skillsrequired
- demonstrations of the set-up and safety issues associated with additive manufacturing
- case studies illustrating components created by additive manufacturing. Learners may benefit from accessing internet sources that provide training videos.

There are also specialist books available for additive manufacturing that mainly cover 3D printing.

An industrial visit to a manufacturing company or to a technological exhibition could support the learners' skills base.

You can also involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, introduce the topic by demonstrating what can be achieved with additive manufacturing and the benefits of industrial manufacturing. Perhaps pose the question 'Will it replace subtractive machining?' Learners need to consider how additive manufacturing spans many sectors, from health care to aerospace, and explore the different processes and materials used. Learners can share any prior knowledge and experiences of working with 3D printers or with items created by these printers. You could then provide initial input for your learners on the different types of additive manufacturing systems and how these relate to the size of the machine, materials, operational speed and complexity of the components generated. In small groups, your learners could then carry out research on additive manufacturing by looking at machine manufacturers, component manufacturers and hobbyist websites, many of which have detailed pages that contain useful information regarding manufacturing. It is important that

learners understand the influence that materials and product design have on the different processes. It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturingprocess.

For learning aim B, introduce the topic by discussing the major differences between subtractive manufacture and additive manufacture. Discuss components and assemblies that can be manufactured in one piece against using a separate manufacturing and assembly process for products created using subtractive manufacture. You could then move on to discuss the reduction, or in some cases the removal of specialist tooling that is required for additive manufacturing.
Show learners components created in an additive manufacturing program that demonstrate the reduction in component mass, compared with similar components created using traditional subtractive machining.

Compare these to the disadvantages, such as high start-up costs, for some industrial applications, against the relatively low cost of 3D printers. Introduce ideas like 'topology optimisation' and the reduction of mass within a design space, possibly using the finite element analysis (FEA). Alternatively, allow the learners to use 'design iteration' to improve their models and to overcome manufacturing problems and issues. Explore what can be achieved with 3D printers compare with industrial additive manufacturing.

For learning aim C, introduce the topic by demonstrating what can be achieved with a CAD or graphics package and the benefits of creating additive manufacturing components for businesses across different sectors. Follow this with links to an additive manufacturing process. Invite learners to share any knowledge and experiences of working within different additive manufacturing environments. You could then provide initial input for your learners on the different CAD or graphics packages available and introduce them to setting up the various parameters such as swept volume, allowance for shrinkage and any support requirements. In small groups, your learners could then carry out short tasks to draw or download various items such as nameplates or key tags. This could be followed by developing more complex parts and assemblies of multiple parts. These should aim to show the structural support requirements, so that components and assemblies do not collapse. Explain the time requirements related to manufacture, cooling time and the amount of finishing processes required to create an acceptable final product. Particular skills will need to be demonstrated and explained. Setting the machine's resolution, time management and control of aliasing will all need consideration, particularly with the final components in mind. Learners will need an explanation of how to set up a 3D printer to give the required resolution, product orientation, datum and moulding temperatures.

It is essential that learners choose to develop the final assembly within an area they are familiar or conversant with. Alternatively, you could provide learners with suitable ideas for a 3D model to draw or give them a 2D representation of one.

It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process.

An industrial visit to a design exhibition based around additive machining and 3D printers could support the learners' skills base.

Learning aim	Key content areas	Recommended assessment approach
A Examine the technology and characteristics of additive manufacturing processes as used in industry	**A1** AM processes **A2** Safe working practices for AM processes	A report examining the technology and characteristics of AM processes, including sustainability and safe working practices.
B Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes	**B1** Design considerations for AM processes **B2** Component finishing processes post-additive manufacturing	A report focusing on product or component design considerations and finishing processes required to effectively manufacture a component using additive processes.
C Develop a component using additive manufacturing processes safely	**C1** Component design for additive manufacture **C2** Manufacture of a component using an AM process	Design and manufacturing evidence for the development of a product or component using additive processes. To include: a developmental log book, observation records/witness statements, the finished component, annotated photographs and/or drawings, set-up planning notes, and complete quality control documents.

Assessment guidance

This unit is internally assessed through a number of independent tasks. Each task should cover one entire learning aim and it is essential that a learning aim is assessed as a whole and not split into tasks or sub-tasks per criterion. There are three suggested assignments for this unit, each covering one learning aim.

All learners must independently generate individual evidence that can be authenticated. The main sources of evidence are likely to be reports, a printed or plotted portfolio of drawings, and the annotated photographs of the process of creating an additive machined component or assembly. Learners should also produce screenshots to show process and editing. BTEC assessors should complete observation records and learners' colleagues in placements or part- time work could complete witness statements. Note that observation records alone are not sufficient sources of learner evidence; the original learner- generated evidence must also support them.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 45: Additive Manufacturing Processes

Introduction

You could introduce the unit to learners through a group discussion exploring their knowledge of the use of additive manufacturing processes and the practical skills they may already have developed. This could be followed by outlining the learning aims of the unit.

Learning aim A – Examine the technology and characteristics of additive manufacturing processes as used in industry

- You could ask learners to collaborate in small groups to come up with examples of different additive manufacturing processes that they have experienced.
- You could ask learners to consider individually what they think are the advantages of additive manufacturing and the different types available. Lead a discussion on the various forms of additive manufacturing, and allow learners to research the basic features. In small groups, learners could then explore the physical resources, the associated materials and the different types of output, and link the different additive manufacturing processes to their respective sectors.
- You could then provide input for your learners on the different types of additive manufacturing processes. This could include how these relate to the size of the machine, materials, operational speed and complexity of the components generated. This will need linking to the differing manufacturing volumes of the various processes.
- Using learners' examples from earlier, and continuing in small groups, your learners could then carry out research on additive manufacturing by looking at machine manufacturers, component manufacturers and hobbyist websites. This research could then be developed to investigate the applications of the different processes.
- You could then provide input on the different technologies available to manufacturers, such as material extrusion (FDM). Learners may be partially familiar with this as it is a commonly used process, for home or small project 3D printing.
- Learners could extend their knowledge by means of research to cover some of the industrial processes, such as selective laser sintering or photo polymerisation. They could then look at wire deposition and related industrial processes, particularly within the aerospace industry. These processes will need relating to component requirements such as surface texture and tolerances. Learners should consider why some processes are suitable for manufacturing certain components and others are not.
- These processes will need to be linked to manufacturing capacity. Some processes are capable of producing large components relatively quickly whilst processes with small footprints are limited in production size. Learners should understand how accuracy is related to processing speed and the large differences in processing speed between different processes.
- Learners can then link these process to how FDM is used for personalised fabrication, home and machine repairs and biomedical products (for example, dental work and prosthetics) and the materials that are available for use.

- You could then explain how materials can be used sustainably, for example the recycling of metallic powder and polymer-based materials as part of the powder bed fusion process. Learners should understand that limited waste material is produced by some of these processes. You could start a class debate relating to the statement that 'less energy is required to manufacture components using additive machining'.
- You could then explain and demonstrate the finishing techniques, the structural support and post-processing activities, sustainability and safe working practices, relating to the different processes of manufacture.
- You should explain the required safe working practices, and the key features of health and safety regulations for additive manufacturing processes and the typical safe working practices required.
- It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process, including aspects such as COSHH (or international equivalent), necessary PPE and related safety hazards.

Learning aim B – Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes

- You can begin this learning aim by exploring the advantages of additive manufacturing processes over traditional secondary manufacturing processes.
- Ask learners to consider the manufacture of the same component and then to consider traditional methods of manufacture and compare these with additive manufacture. This could be in relation to a reduction in mass. You could follow this up with a consideration of possible reductions in cost. Introduce the subject of time taken to manufacture a component and compare with the time taken to manufacture the same component using traditional subtractive techniques.
- Direct learners to explore the integration of parts and the ability to manufacture assembled items as one piece, which cannot be achieved using traditional processes without multiple operations and an assembly process.
- You could explain and demonstrate, through products and case studies, how assembled items can be manufactured as one piece and how this impacts on the design process. This often involves optimising a design for 3D printing and testing, after an initial manufacture, to ensure that the product is as strong and as stable as a conventional product.
- Use a case study. A typical example, such as a door hinge, could be used. Conventional manufacture would require three separate parts to be manufactured – a frame side plate, a door side plate and a central hinge pin. These would need to be assembled using either a manual or automated process. With additive manufacture (provided a suitable material could be sourced), the complete assembly can be manufactured in one operation.
- Use the case study to discuss the factors that a designer needs to consider. For example, when manufacturing an item such as a door hinge by additive manufacture, the designer should consider:
  - what suitable materials are available
  - clearances within the hinge
  - whether the product is an improvement over the traditional design
  - that there is a cost reduction due to drill jigs or assembly fixtures not being required
  - that complex moulds will not be required due to the removal of the casting operation.
- Introduce the disadvantages of additive manufacturing processes over traditional

manufacturing processes, including: that products and components may need to be redesigned to realise the advantages; the choice of materials may be limited by the process; and the initial capital cost is quite high and has a low process speed.

- Allow learners to investigate the advantages of additive manufacturing processes over traditional manufacturing processes, including: reduction in mass and cost can be achieved by redesigning the component; and the ability to manufacture assembled items together that cannot be manufactured together using traditional processes without multiple operations.
- Consider a case study to show that many components using traditional sources need multiple operations to produce them. For example, having a tooth crowned at the dentist is a long process. A crown is a cap that is cemented on top of a damaged tooth, and the process usually involves the dentist drilling into the damaged tooth to obtain a good fit. After drilling, a mould is made of the tooth, and this mould is sent to a laboratory, where the tooth is cast in a temporary material. The cast is returned to the dentist who makes any modifications needed before the final cast is made. This process traditionally takes two weeks and, in the meantime, you walk around with a temporary crown in place. With 3D printing, a scan can go directly to the 3D printer and be ready within an hour, as you sit in the waiting room.
- Direct the learners to research and report to the group on the common finishing processes such as shot-blasting, vibro-energy and chemical processes.
    - It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process.

Learning aim C – Develop a component using additive manufacturing processes safely
• This unit can build on previous units in which learners may have used CAD/graphic packages and computer-controlled machinery. Learners can start by creating designs and being introduced to the basic machining parameters. • Build on the previous theory to explain to the learners the requirements of a product's structural integrity, for example: laminar structure; allowing for product shrinkage and warping; and any support requirements for overhanging surfaces. • Learners could then start to develop a design for a component or product suitable for an additive manufacturing process, with consideration of the complexity of its form and ensuring that suitable materials are available. • You could use a practical demonstration to explain the machine's parameters during operation, its swept volume and the capacity of the machine. In addition, use the demonstration to explain how stepping (aliasing), surface finish and accuracy are affected by the resolution selected. • You could use a practical demonstration to demonstrate data transfer from a CAD or graphics package and follow this with a typical component set-up. • You could demonstrate the necessary finishing processes for the machine and material in use. • You should allow learners to develop their confidence and skills by manufacturing a small component, so they can appreciate the relationship between design and machine parameters. • You should explain any quality control checks that will be required and where and how to record them. • It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process and the typical safe working practices required.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC International Level 3 Qualifications in Engineering:

- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 10: Computer Aided Design in Engineering*
- *Unit 39: Modern Manufacturing Systems*
- *Unit 40: Computer Aided Manufacturing and Planning*
- *Unit 41: Manufacturing Secondary Machining Processes*
- *Unit 42: Manufacturing Primary Forming Processes*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC International Qualifications in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

The special resources required for this unit are:

- access to additive manufacturing machines, for example FDM
- software suitable to produce and process 3D models, for example: AutoCAD, AutoCAD Inventor, Tinkercad, Adobe photoshop, Adobe illustrator, Google SketchUp, plus post processing software and software to control the additive manufacturing process
- auxiliary equipment, for example equipment required to finish the components or those needed for the additive manufacturing process
- a range of equipment suitable for measuring the dimensional accuracy, for example Vernier calipers
- access to a range of health and safety regulations, as required by the learning aims and unit content.

There are numerous versions and varieties of software that could be used to complete this unit. It is nearly impossible to list every textbook and video but some particularly useful ones are listed below.

Textbooks

Various textbooks are available for CAD and graphics package software command structures. Learning materials are available from the different companies that supply CAD software and the different versions of the software packages that they produce. Books and magazines are available on additive manufacturing, particularly 3D printing.

- Barnatt C – *3D Printing: The Next Industrial Revolution* (CreateSpace Independent Publishing Platform, 2013) ISBN 9781484181768.

- Hopkinson N, Hague R and Dickens P (Editors) – *Rapid Manufacturing: An Industrial Revolution for the Digital Age* (Wiley-Blackwell, 2005) ISBN 9780470016138.

Videos

There are many videos for CAD, graphics packages, 3D printing and additive manufacturing. Some examples are given below.

- https://www.youtube.com/watch?v=kKQ5KwFwW_s
- https://www.youtube.com/watch?v=_mhN1d768o8
- https://www.youtube.com/watch?v=Ul8JNrMrtP8

Websites

There are many links available on the web to some of the many software houses producing CAD and graphics software. Many of these provide free educational software. There are also numerous links to additive manufacturing pages inclusive of commercial processes and 3D printing. Some examples are listed below.

- www.autodesk.co.uk
- www.solidworks.co.uk
- www.solidworks.com/sw/products/draftsight-getting-started-guide.htm
- www.turbocad.co.uk/windows-range/turbocad-deluxe-2d-3d

The links below are for CAD blogs and online magazines. Some require a subscription, some are free, and some allow limited use prior to a subscription.

- http://caddprimer.com/magazine
- www.caduser.com/

Additive machining

There are also numerous links to additive manufacturing pages inclusive of commercial processes and 3D printing. For example:

- www.stratasys.com/
- www.renishaw.com/en/additive-manufacturing-systems--15239