Unit 146: Manufacturing of Advanced Composite Materials

Unit code: L/504/6241

QCF Level 3: BTEC Nationals

Credit value: 10

Guided learning hours: 60

Aim and purpose

This unit aims to give learners an understanding of the materials typically associated with advanced composites, and the processes and design considerations required to manufacture them. The purpose of the unit is for learners to be able to summarise key aspects of composite materials without investigating any particular aspect in great detail.

Unit introduction

A holistic understanding of composite materials is essential for technicians and those seeking employment in industries that utilise or have exposure to these materials. The aerospace, marine, automotive, construction, renewable energies and consumer goods industries exploit the use of composites in a number of forms. Composite materials are becoming more important in widespread engineering and learners need to appreciate their principles and fabrication methods.

This unit covers the various forms of matrix and reinforcements most commonly used across the spectrum. The unit looks at the typical manufacturing methods used in industry, from wet lay-up to infusion, and briefly covers the more niche areas of techniques such as filament winding and automated tape laying. Learners will look at vacuum bagging in detail. The unit covers other key components of the composite production line, including trimming, bonding, finishing and inspection. An overview of design for manufacture is maintained throughout the course.

The unit is a mix of theoretical teaching and practical work. Learners do not need specialist knowledge to take the unit but an understanding of general engineering terms would be an advantage.

Learning outcomes

On completion of this unit a learner should:

1 Know the different types of matrices and re-inforcements commonly used in composite manufacture

2 Understand the differences, advantages and disadvantages of key manufacturing processes

3 Understand the effects of design decisions on component manufacturability

4 Understand bonding materials, finishing processes, inspection and repair techniques.

Unit content

1 Know the different types of matrix and re-inforcements commonly used in composite manufacture

Composites: advantages; disadvantages; relevant applications in localised industry and global markets

The fibre: nature and purpose; general types of fibre, eg glass, carbon, aramid, natural; types of cloth weave available, eg chopped strand, plain weave, 5-harness, uni-directional, non crimp/bi-axial; uses of fibres, eg when and where to use 5-harness carbon vs chopped strand glass

The matrix: nature and purpose of the resin; differences and selection of thermosets and thermoplastic resins; general types of resin available, eg polyester, epoxy, vinyl-ester, phenolic, bismaleimides, cyanate-ester, nylon, polypropylene, polyetheretherketone

Laminate theory: balanced lay-ups; unbalanced lay-ups

Health and safety: personal protective equipment (PPE); storage considerations; handling of resins, dry fibres and other chemicals; contamination and respiration when carrying out trimming /finishing operations

2 Understand the differences, advantages and disadvantages of key manufacturing processes

Lay-up preparations: workshop considerations; release agents; gel-coats

Wet lay-up: advantages; disadvantages; typical applications; resin metering, mixing and de-gassing; cloth handling; roller applications; brush applications; squeegee resin application; porosity

Vacuum bagging: advantages; disadvantages; typical applications; breather fabrics; release fabrics; consumables, eg peel plies, bagging films; quality escapes, eg bridging, vacuum integrity

Pre-preg lay-up: advantages; disadvantages; typical applications; processing requirements, eg autoclave, out-of-autoclave; clean room and storage conditions

Resin transfer infusion (RTI): advantages; disadvantages; applications including closed moulding and applications to larger structures; tool design; flow media; RTI-specific fabrics; core considerations; advances in RTI

Resin transfer moulding (RTM) and vacuum-assisted resin transfer moulding (VARTM): advantages; disadvantages; typical applications of RTM vs VARTM; tool design; flow media; RTI specific fabrics; core considerations; single part resin systems

Other manufacturing process: compression moulding; pre-forming and hot-drape forming; automated tape laying; filament winding and 3D weaving; process comparisons

3 Understand the effects of design decisions on component manufacturability

Sandwich structures: advantages; disadvantages; types of core materials including timbers, foams, honeycombs and specialist cores; implications of cores on manufacturing complexity

Tooling: geometrical effects of component design on part de-moulding; male and female moulds; plug materials and construction including timbers, foams, metals; mould materials and construction including timbers, foams, metals, composites; co-efficients of thermal expansion; glass transition temperature

Costs: raw materials; labour; capital equipment; overheads; effects of design decisions on lifecycle costs, tooling, manufacturing processes; finishing

4 Understand bonding materials, finishing processes, inspection and repair techniques

Bonding: mechanical surface preparations including techniques and advantages; chemical surface preparations including standardised techniques and limitations with various methods; types of adhesives commonly used, eg epoxy, acrylic, polyurethanes, silicones; design of interfaces for adhesive joints and bonded joints

Cutting and trimming: trimming of composites post de-moulding including techniques, speeds, cutting tools and waste removal; drilling of composites; drill bit types; delaminations; surface finishing techniques, eg wet sanding, polishing and painting

Inspection: types of damage associated with composites including delaminations, porosity, disbond and inclusions; methods of inspecting such as visual inspection, tap test, phased array, mechanical impedence, thermography

Repair: repair methods; surface preparations; layer identification; new material preparation; curing methods; repair specifications.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Detail reasons for use of composites, typical applications and uses in local industry [RL]	**M1** Explain why balanced laminates are important in composite design	**D1** Distinguish between asymmetric and symmetric laminates
P2 Describe how the function of thermoset and thermoplastic resins in a composite differ to the function of the fibre [RL]	**M2** Explain the limitations of thermoset resins	**D2** Investigate why certain features exist on a tool used for composite production within a local company
P3 Numerically explain the contribution of fibre and resin to composite strength [IE]	**M3** Explain how a finished product could be different visually depending on the method of manufacture used	**D3** Investigate repair processes currently used in industry and any limitations of the process, particularly in structural components
P4 Describe measures to be taken to ensure a safe working environment when working with composites [RL]	**M4** Explain the process of producing a tool from CAD drawing to manufacturing the finished tool, including key costs within the process	
P5 Describe the key factors affecting release agent selection [RL]	**M5** Numerically explain why sandwich panels can be stiffer than thin laminates	
P6 Describe the process of vacuum bagging, including the uses of various consumable materials in the process [RL, EP]	**M6** Explain one form of damage that a honeycomb sandwich panel can suffer during manufacturing	
P7 Describe possible quality escapes during the wet lay-up process [RL, EP]		
P8 Explain the advantages and disadvantages of various composite manufacturing processes [RL]		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P9 Detail the various types of tooling material commonly used [RL]		
P10 Compare the various types of core materials [RL]		
P11 Describe the characteristics and safety precautions to be observed when handling and using various adhesives and sealants [RL]		
P12 Describe pre-treatments required for bonding of metallic and carbon fibre parts [RL]		
P13 Detail typical process parameters for drilling of solid carbon fibre laminates [RL, EP]		
P14 Compare methods of composite inspection [RL]		

PLTS: This summary references where applicable in the pass criteria, in the square brackets, the elements of the personal, learning and thinking skills. It identifies opportunities for learners to demonstrate effective application of the referenced elements of the skills.

Key	IE – independent enquirers	RL – reflective learners	SM – self-managers
	CT – creative thinkers	TW – team workers	EP – effective participators

Essential guidance for tutors

Delivery

This unit is best delivered using a combination of theoretical teaching, practical demonstrations, investigative assignments and practical assessments. It can be linked to *Unit 10: Properties and Applications of Engineering Materials* and *Unit 20: Engineering Primary Forming Processes*.

Practical work should be a central theme. To enable learners to experience the feel of materials, potential pitfalls and challenges, practical demonstrations in a workshop environment should be included. For example, when working with the wet lay-up process, a practical demonstration should be given, allowing learners to participate in the demonstration. This will show them the challenges faced with proper cloth wet-out, edge fraying and weave alignments.

It is recommended that learning outcome 1 be taught theoretically with practical demonstrations. Learners should complete a written assignment.

For learning outcomes 2 and 3, a combination of theoretical and practical work is required. For example, for the aerospace industry a small representative wing could be manufactured by individual learners or in groups.

It is recommended that learning outcome 4 be taught theoretically with practical demonstrations. Learners should complete a written assessment.

Tutors should ensure that learners are aware of the hazards and safe working practices associated with the use of uncured fibrous materials, chemicals and airborne particles of cured fibrous materials in particular.

The learning outcomes are designed to be integrated across a range of assignments. For employed learners, assignments could be designed to reflect aspects of their work. Industrial visits can be used to enhance learners' knowledge of the processes carried out by local companies.

Centres should have access to an appropriate range of specialist equipment to allow learners to perform laminating, vacuum bagging, infusion and elevated curing operations as a minimum. It is recommended that pre-preg curing facilities are available, although this is not an essential requirement. Centres should also have facilities for trimming of composite components and address the required health and safety considerations at all times.

Outline learning plan

The outline learning plan has been included in this unit as guidance and can be used in conjunction with the programme of suggested assignments.

The outline learning plan demonstrates one way in planning the delivery and assessment of this unit.

Topic and suggested assignments/activities and/assessment
Whole-class teaching: Introduction to unit content, scheme of work, including breakdown of theory/practical classes and assessment strategy. Guide learners around practical workshop and workstations. Highlight key pieces of equipment, potential HS&E hazards and direct all learners to PPE. Use physical examples to explain what composites are, including simple composites such as a ply-wood, cured carbon, kevlar and glass fibre parts. *Individual learner activities:* Brief assignment requiring learners to point out notable use of composites in their workplace with respect to a specific component
Prepare for and complete Assignment 1: Types of matrix and re-inforcements commonly used in composite manufacture (P1, P2, P3, P4, M1, M2, D1)
Whole-class teaching: Use physical examples to explain the types, applications, limitations, advantages, costs, etc, of the fibre in a composite. Use physical examples to explain the types, applications, limitations, advantages, costs, etc, of the matrix in a composite. In a workshop, demonstrate activities that could be potentially hazardous and the measures to take to limit risk. *Individual learner activities:* Written completion of Assignment 1
Prepare for and complete Assignment 2: Component manufacturing planning (covering differences, advantages and disadvantages of key manufacturing processes and the effects of design decisions on component manufacturability) (P5, P6, P7, P8, P9, P10, M3, M4, M5 D2)

Topic and suggested assignments/activities and/assessment
Whole-class teaching: With diagrammatical aids and physical specimens where possible, describe all notable manufacturing processes. Teach theory and carry out practical demonstrations, ensuring that learners participate in the practical classes on understanding vacuum bagging. Demonstrate a wet lay-up process. Demonstrate a pre-preg lay-up process. Demonstrate an infusion process. Use physical examples to explain the types, applications, limitations, advantages, costs, etc, of tooling materials used to manufacture composites. Use physical examples to explain the types, applications, limitations, advantages, costs, etc, of core materials in a composite. *Individual / group learner activities*: (depending on the product, this may be undertaken in a group or individually) Select product to base manufacturing assignment on. Select representative product to base practical assessment on. Manufacture and evaluate representative product. Written completion of Assignment 2.
Prepare for and complete Assignment 3: Bonding materials, finishing processes and quality in composites (P11, P12, P13, P14, M6, D3)
Whole-class teaching: Using physical examples, photographs, failed materials, etc, demonstrate the various types of adhesives available, their limitations and advantages, and the costs associated with them. Use physical examples, photographs and cases studies to explain the types, applications, limitations, advantages, costs, etc, of various surface treatments used within the composites industry. Demonstrate and ensure that learners participate in practical classes to show surface treatment and subsequent bonding operations. Demonstrate and ensure that learners participate in practical classes to show cutting, drilling and trimming of composite materials. Carry out a practical demonstration of the repair of a damaged composite laminate. Demonstrate composite inspection methods on damage components. *Individual learner activities:* Investigate a particular method of composite inspection and complete the specialist aspect of the assignment Written assignment on various topics, including bonding, finishing and quality in composites.

Assessment

It is expected that a range of assessment methods will be used for this unit. Evidence can be gathered from written responses to investigative assignments and formal timed assessment (if required). Reflective learning from participation in practical work is recommended, particularly for learning outcomes 2 and 3. This forms the basis of Assignment 2.

Three assignments could be set for the assessment of this unit. Assignment 1, encompassing learning outcome 1, could be a series of formal written tasks. The assignment could be split into four different sections for the purposes of achieving each pass criterion. The basic part of the assignment will require learners to investigate the use of composites and their application in local industry (P1). Learners will then need to distinguish between the function of the fibre and the matrix in the composite, while noting the difference in thermoset and thermoplastic polymer resins (P2). Learners will numerically distinguish and present an argument for the loading of composites axially and perpendicular to the fibre orientation (P3). It is recommended that at least two scenarios are chosen. The importance of balancing composite laminates must be explained for a merit (M1). (M2) is achieved by describing the limitations of thermoset polymer resins; for example describing their impact on future recyclability. Health and safety is a key consideration throughout and learners must display knowledge of measures taken to reduce any hazards within the workshop environment (P4). A distinction (D1) is achieved when the learner distinguishes between asymmetric and symmetric composites laminates.

The second assignment, covering learning outcomes 2 and 3 could be a small project. Learners could plan the manufacture of a component (relative to their places of work, if appropriate) with reference to fibre, resin, core materials, method of manufacturing, tooling and cost. In this phase, it is recommended that a practical exercise is undertaken but assessed on completion of a small report in a reflective manner. For example, for the aerospace industry, a small representative wing could be manufactured by individual learners or in groups.

The project should be given to learners with a design concept in mind. The design concept should have key indicators that will influence them in planning the appropriate method of manufacture to meet key design criteria such as performance, quality, cost, volume etc. This assignment will require the submission of a written report, incorporating selection of release agent materials (P5) and discussion on the reasons behind the selection of a specific manufacturing process. It is recommended that the representative part (simplified so that it can easily be incorporated into the unit) is used to base evidence on and reinforce any arguments made in the written report. The design criteria should be set so that vacuum bagging is incorporated into the overall process (for example wet lay-up and vacuum bagging, RTI, VARTM, pre-preg laminating). The vacuum bagging process should be described for the purposes of fulfilling the second pass criterion (P6). It must incorporate the reason for selecting various materials. Participation in a practical wet lay-up class, with assessment based on a reflective learning report, would be useful for developing baseline knowledge of key composite processing parameters (P7). A description for the selection of the actual method of manufacture should then be presented and it is recommended that three processes are compared (P8). The finer points of the effect of the chosen method on finished part quality (for example, specific surface finish features) should be presented for a merit (M3).

Detailing of the various types of tooling material should be given for (P9). The process in which a CAD model is taken from design to manufacture of the tool and subsequent part must be presented for (M4). Individual learners can achieve a distinction if they give written evidence showing that they understand the reasons why certain composite tooling is used in a local company (D2). If learners have no access to a local company, this work should be completed independently or through a visit arranged by the tutor.

Sandwich panels should form part of this assignment and a comparison of the core materials used should be given for (P10). Learners should be capable of numerically describing why sandwich panels are stiffer than solid laminates of similar ply thickness for the purposes of receiving a merit (M5).

For learning outcome 4, a third assignment should be set. This assignment could be segregated into three key areas or, in a similar way to the second assignment, it could incorporate the analysis of a practical scenario. Practical evidence such as photographs, anecdotal experience etc, should be used in all applicable cases

to support written submissions. The assignment should cover the analysis of two types of adhesives as a minimum, with particular reference to structural components in the aerospace industry (P11). The surface preparations for bonding of these adhesives, including mechanical and chemical preparations, should be detailed, with particular reference to bonding of metallic and carbon fibre substrates (P12).

Typical characteristics of drilling of composite components and possible quality defects with particular interest in carbon fibre should be noted for (P13).

Learners should specify and describe the advantages and disadvantages of three forms of inspection used within the composite industry (P14). They should detail the type of damage that sandwich panels are exposed to (M6) and investigate procedures that are used for their repair or the repair of other laminates within the industry (D3).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, M2, D1	Types of matrix and re-inforcements commonly used in composite manufacture	You are working for a local company manufacturing metallic products and have been asked by your manager to investigate the use of composite materials in future products. It is expected that you would explain reasons for using composites in the product line, the function of various aspects of the composite and measures the company should take to ensure HS&E compliance. For successful completion of D1, learners must investigate the required material in their own time.	Written responses to set written tasks, carried out under controlled conditions. To achieve a distinction for D1, a written section of the final report resulting from the investigation could be used to provide evidence.
P5, P6, P7, P8, P9, P10, M3, M4, M5, D2	Component manufacturing planning	Following your initial evaluation of composites in Assignment 1, your manager has now asked that you describe composites manufacturing in more detail. Your manager expects you to provide an overview of the processing methods, release agents, tooling and core materials that could be used for converting the existing product range to composite materials. For successful completion of D1 and D2, learners must investigate the required material in their own time.	Evidence gathered by tutor observations and/or learners' written reports and written responses to set tasks. To achieve a distinction for D2, a written section of the final report resulting from the investigation could be used to provide evidence.

Criteria covered	Assignment title	Scenario	Assessment method
P11, P12, P13, P14, M6, D3	Bonding materials, finishing processes and quality in composites	You are a manufacturing engineer planning the assembly of two pre-cured composite components. You must describe the potential bonding methods and surface preparation practices, steps you would take to trim and finish the materials as well as post-assembly inspection. For successful completion of D3, learners must investigate the required material in their own time.	Written responses to set written tasks, carried out under controlled conditions. To achieve a distinction for D3, a written section of the final report resulting from the investigation could be used to provide evidence.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit forms part of the BTEC Engineering sector suite. This unit has particular links with:

Level 1	Level 2	Level 3
		Engineering Primary Forming Processes
		Aircraft Materials and Hardware
		Inspection and Repair of Airframe Components and Structures

Essential resources

Learners will require access to a composites engineering workshop environment suitably equipped with:

appropriate PPE and equipment/hardware to meet health and safety legislation

various types of resins, cloths, release agents and associated wet lay-up hand tools

a lay-up table

vacuum bagging hardware and consumables

pre-preg materials and associated storage facilities

autoclave / out-of-autoclave curing capability

resin transfer infusion hardware and consumables

hand tools for composite repair

physical specimens of un-cured and cured composite components for demonstration of each teaching matter where possible

access to industry representative standard operating procedures

adhesives, applicators and surface preparation materials

a minimum of two forms of composite inspection

hand tools, drills, heatguns, scissors, knives.

Employer engagement and vocational contexts

Liaison with employers can help centres arrange on-site visits so that learners can observe first hand a range of composite materials and the methods of production that are typically used in the industry. Much of the work for this unit can be set in the context of learners' work placements or be based on case studies of local employers.

Further information on employer engagement is available from the organisations listed below:

Work experience/workplace learning frameworks – Centre for Education and Industry (CEI – University of Warwick) – www.warwick.ac.uk/wie/cei/

Learning and Skills Network – www.vocationallearning.org.uk

Network for Science, Technology, Engineering and Maths Network Ambassadors Scheme – www.stemnet.org.uk

National Education and Business Partnership Network – www.nebpn.org

local, regional business links – www.businesslink.gov.uk

work-based learning guidance – www.aimhighersw.ac.uk/wbl.htm

Indicative reading for learners

Textbooks

Mazumdar, Sanjay K – *Composites Manufacturing, Materials, Product and Process Engineering* (CRC Press, 2000) ISBN 0-8493-0585-3

Ramalingam, K K – *Handbook of Mechanical Engineering Terms* (New Age International Publishers, 2009) ISBN 978-81-224-2874-2

Delivery of personal, learning and thinking skills

The table below identifies the opportunities for personal, learning and thinking skills (PLTS) that have been included within the pass assessment criteria of this unit.

Skill	When learners are ...
Reflective learners	describing quality escapes within the wet lay-up process
Effective participators	participating in practical workshops to complete P7

Although PLTS are identified within this unit as an inherent part of the assessment criteria, there are further opportunities to develop a range of PLTS through various approaches to teaching and learning.

Skill	When learners are ...
Reflective learners	setting goals with success criteria for their development and work

Functional Skills — Level 2

Skill	When learners are ...
ICT — Use ICT systems	
Select, interact with and use ICT systems independently for a complex task to meet a variety of needs	Typically completing all assignments. Completing written reports for achievement of pass, merit and distinction criteria; For example, writing of a report for achieving criteria in Assignment 1 'Types of matrix and re-inforcements commonly used in composite manufacture'.
Use ICT to effectively plan work and evaluate the effectiveness of the ICT system they have used	For example using Microsoft Excel to evaluate mathematical problems in P3.
Manage information storage to enable efficient retrieval	Identifying particular lectures for retrieval of information when completing Assignments 1, 2 and 3.
Follow and understand the need for safety and security practices	Undertaking all practical work in the completion of P4.
Troubleshoot	For example investigating various tooling features for D2.
ICT — Find and select information	
Select and use a variety of sources of information independently for a complex task	Typically completing all assignments, for example in the retrieval of information from lecture slides, online sources and practical experience for P7.
Access, search for, select and use ICT-based information and evaluate its fitness for purpose	
ICT — Develop, present and communicate information	
Enter, develop and format information independently to suit its meaning and purpose including: text and tables images numbers records	Typically completing all reports for Assignments 1, 2 and 3 where written reports are required. A comparison table, for example, could be useful in comparing the fibre and resin in P2, numbers useful in P3 and M5 and text required in all assignments.
Bring together information to suit content and purpose	Achieving the majority of pass criteria; for example P7, where information from lecture notes and practical workshops could help in describing the wet lay-up process.
Present information in ways that are fit for purpose and audience	Clearly presenting information when completing written reports for Assignments 1, 2 and 3.
Evaluate the selection and use of ICT tools and facilities used to present information	
Select and use ICT to communicate and exchange information safely, responsibly and effectively including storage of messages and contact lists	

Skill	When learners are ...
Mathematics	
Understand routine and non-routine problems in a wide range of familiar and unfamiliar contexts and situations	Completing formulae for calculation of composite strengths for example, in various loading scenarios presented in Pass Criteria 3.
Identify the situation or problem and the mathematical methods needed to tackle it	Completing formulae for calculation of composite strengths for example, in various loading scenarios presented in Pass Criteria 3.
Select and apply a range of skills to find solutions	
Use appropriate checking procedures and evaluate their effectiveness at each stage	
Interpret and communicate solutions to practical problems in familiar and unfamiliar routine contexts and situations	
Draw conclusions and provide mathematical justifications	Completing P3 when describing the contribution of a fibre and the resin to the composite. Completing M5 when numerically describing sandwich panel stiffness.
English	
Speaking and listening – make a range of contributions to discussions and make effective presentations in a wide range of contexts	Requesting clarifications on taught material.
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	Researching and investigating any form of composite materials from lecture notes in achieving all pass criteria. For example, in P8, comparisons are required on a number of processes and details, and will need to be understood through reading of lecture materials or online sources.
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	Explaining the manufacture of representative component or completing any of the other formal written assignments 1, 2 and 3.

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