Next Generation Higher National Unit Specification

Advanced Materials (SCQF level 8)

Unit code: J7C1 48

SCQF level: 8 (24 SCQF credit points)

Valid from: session 2024 to 25

Prototype unit specification for use in pilot delivery only (version 2.0) December 2024

This unit specification provides detailed information about the unit to ensure consistent and transparent assessment year on year.

This unit specification is for teachers and lecturers and contains all the mandatory information required to deliver and assess the unit.

This edition: December 2024 (version 2.0)

Unit purpose

This unit provides learners with knowledge, understanding and skills in mechanical engineering principles, with a focus on the strength and selection of engineering materials.

The target group for the unit is learners who want to develop their core engineering design and analysis skills to support a career in fields such as mechanical engineering, systems engineering, manufacturing engineering, or instrumental and control engineering. It is also suitable for learners doing modern apprenticeships and those who want to develop the practical, personal and professional skills required for a successful career as an engineering technician.

Entry to the unit is at your centre's discretion. However, we recommend that learners have one or more of the following:

- broad knowledge and understanding of mechanical engineering concepts and theorems at SCQF level 7, for example Advanced Higher Engineering or Physics, or a Higher National Certificate (HNC) in Mechanical Engineering
- relevant, equivalent workplace experience in the mechanical engineering sector or an equivalent qualification in Engineering at SCQF level 7

We recommend that learners have completed the Engineering Mechanics and Materials unit at SCQF level 7.

Unit outcomes

Learners who complete this unit can:

1 understand the relationship between atomic structures and material properties, and the relationship between molecular structures and material properties
2 determine material properties specifications for applications, and select materials using property charts, data sheets and process compatibility charts
3 understand how altering material structures can enhance or degrade material properties
4 analyse and calculate material strength and stress factors in engineering applications
5 understand the causes of material failure in service, and how they may be mitigated

Evidence requirements

You should assess the unit holistically, using a portfolio of evidence generated by learners.

Learners must produce evidence in an appropriate written or oral format. Learners generate evidence under controlled or supervised, open-book conditions, and it must be authenticated as being all their own work. The evidence must contain a mix of knowledge and skills items to match the evidence requirements of the unit, and include various forms of evidence, such as:

- assignments
- case studies
- reports
- essays
- simulations
- structured controlled tests
- practical evidence
- other relevant sources of evidence

Outcome 1

- Relate the atomic, molecular and crystalline structures of materials to their properties, including:
  - Young’s modulus
  - resilience
  - permeability
  - melting and glass transition temperatures
  - expansivity
  - specific heat capacity
  - temperature stability
- Interpret phase diagrams for different materials.
- Perform unit conversions for material properties.

- Differentiate between thermoplastics and thermoset plastics in relation to their chain structures.
- Differentiate between homopolymers, copolymers and terpolymers.
- Explain the significance of bonding between the matrix material and reinforcement material for a composite.
- Describe the following primary interatomic bonds:
  - ionic bonds
  - covalent bonds
  - metallic bonds
- Describe the following secondary bonding types:
  - Van der Waals bonds
  - hydrogen bonds
- Describe molecular structures including:
  - polymer chains
  - polymer chain length and molar mass
  - secondary bonds between chain molecules
  - amorphous and crystalline polymer structures
- Describe the following crystalline structures:
  - body-centred cubic lattice
  - face-centred cubic lattice
  - hexagonal close-packed lattice
- Describe how distinct materials can be combined to form composite materials.

Outcome 2

- Establish suitable criteria for material selection, based on product requirements.
- Effectively use charts such as:
  - material property charts
  - material attribute charts
  - process compatibility charts
- Utilise material data sheets or other manufacturers' literature to establish material properties.
- Make use of their understanding of material properties and available information sources to select suitable materials for specific purposes.

Outcome 3

- Metals: incorporate an understanding of more than one of the following into a material selection or product design process:
  - heat treatment (such as annealing, quenching, tempering or normalising)
  - hot working processes (such as hot forging or hot rolling)
  - cold working processes (such as cold forging or cold rolling)
  - casting (such as sand casting or die casting)

- Polymers: addition polymerisation, condensation polymerisation, blending.
- Ceramics: hydroplastic forming, slip casting, drying and firing, powder pressing, heat treatment.
- Describe additives and their functions, such as:
  - fillers
  - plasticisers
  - stabilisers
  - flame retardants
  - blowing agents
  - colourants
  - cross-linking
  - vulcanising agents
- Describe how heat treatment changes the properties and structure of carbon steel.
- Carry out a heat treatment or hot working process on a material, or produce a suitable plan for doing so.

Outcome 4

- Calculate reactions, deflection and slope for complexly loaded beams and cantilevers, using appropriate formulae and Macaulay's method.
- Determine and analyse thin and thick cylinder conditions, including wall thickness, internal radius and stress calculations.
- Determine hoop, axial and radial stress in combined cylinder situations using graphical solutions.
- Draw and apply Mohr's circle for stress and strain analysis, including determining stress and strain values practically or from given conditions.
- Describe strain gauge configuration and evaluate factors of safety in engineering design.

Outcome 5

- Describe material failure types such as:
  - brittle and ductile failure
  - impact failure
  - creep rupture
  - fatigue failure
  - environmental effects
  - time-dependent behaviour of polymers
  - Tresca criterion
- Describe working and environmental conditions that lead to material failure.
- Describe how changes to service conditions such as load, time, temperature and environment can lead to material failure.
- Plan appropriate preventative measures to extend the service life of a material for a particular product.
- Select preventative measures that can be used to extend the service life of materials.

Knowledge and skills

The following table shows the knowledge and skills covered by the unit outcomes:

Knowledge	Skills
Outcome 1 Learners should understand: ♦ primary interatomic bonds: — ionic bonds — covalent bonds — metallic bonds ♦ secondary bonding types: — Van der Waals bonds — hydrogen bonds ♦ molecular structures: — structure of polymer chains — polymer chain length and molar mass — secondary bonds between chain molecules — amorphous and crystalline polymer structures ♦ crystalline structures: — body-centred cubic lattice — face-centred cubic lattice — hexagonal close-packed lattice ♦ how distinct materials can be combined to form composite materials ♦ International System of Units (SI) base units of material properties	**Outcome 1** Learners can: ♦ interpret phase diagrams for metallic alloys, ceramics and polymers ♦ relate the atomic, molecular and crystalline structures of materials to their properties ♦ differentiate between thermoplastics and thermoset plastics in relation to their chain structures ♦ differentiate between homopolymers, copolymers and terpolymers ♦ explain the significance of bonding between the matrix material and reinforcement material for a composite ♦ perform unit conversions for material properties

Knowledge	Skills
Outcome 2 Learners should understand: ♦ how product requirements relate to material properties ♦ which data sources are relevant and reliable	**Outcome 2** Learners can: ♦ establish suitable criteria for material selection, based on product requirements ♦ effectively use charts for material selection ♦ utilise material data sheets or other manufacturers' literature to establish material properties ♦ make use of their understanding of material properties and available information sources to select suitable materials for specific purposes
Outcome 3 Learners should understand: ♦ metals: — heat treatment — hot working processes — cold working processes — casting ♦ polymers: — addition polymerisation — condensation polymerisation — blending ♦ additives and their functions ♦ ceramics: — hydroplastic forming — slip casting — drying and firing — powder pressing — heat treatment	**Outcome 3** Learners can: ♦ plan out an appropriate heat treatment, or hot working process for a metal ♦ describe methods of polymerisation ♦ describe ceramic forming methods ♦ describe additives and their functions ♦ describe how heat treatment changes the properties and structure of carbon steel ♦ plan out a heat treatment or hot working process for a material

Knowledge	Skills
Outcome 4 Learners should understand: ♦ reaction forces, deflection and slope calculations for complex loading on simply supported beams and cantilevers ♦ Macaulay's method for determining deflection and slope in various beam and cantilever scenarios ♦ thin and thick cylinder conditions, calculations and stress analysis ♦ stress–strain relationship, and Mohr's circle of stress and strain ♦ strain gauge configuration and factors of safety	**Outcome 4** Learners can: ♦ calculate reactions, deflection and slope for complexly loaded beams and cantilevers, using appropriate formulae and Macaulay's method ♦ determine and analyse thin and thick cylinder conditions, including wall thickness, internal radius and stress calculations ♦ determine hoop, axial and radial stress in combined cylinder situations using graphical solutions ♦ draw and apply Mohr's circle for stress and strain analysis, including determining stress and strain values practically or from given conditions ♦ understand strain gauge configuration and evaluate factors of safety in engineering design
Outcome 5 Learners should understand: ♦ reasons why engineered components fail in service ♦ working and environmental conditions that lead to material failure ♦ common mechanisms of failure for metals, polymers, ceramics and composites ♦ time-dependent behaviour of polymers ♦ brittle and ductile failure ♦ impact failure ♦ creep rupture ♦ fatigue failure ♦ environmental effects ♦ changes to service conditions such as load, time, temperature and environment	**Outcome 5** Learners can: ♦ predict failure types based on the environment a product is used in ♦ describe material failure types, including Tresca criterion ♦ select preventative measures that can be used to extend service life of materials ♦ describe how changes to service conditions can lead to material failure ♦ describe working and environmental conditions that lead to material failure

Meta-skills

Throughout the unit, learners develop meta-skills to enhance their employability in the engineering sector.

Self-management

Learners develop the meta-skills of adapting and initiative through critical reflection and independent thinking as they work through the course material and case studies.

Social intelligence

Learners develop the meta-skills of communicating and collaborating as they work with other learners on case studies and assignments.

Innovation

Learners develop the meta-skills of critical thinking, curiosity and sense-making as they analyse problems relating to mechanical engineering principles.

Literacies

Learners develop core skills in the following literacies:

Numeracy

Learners develop numeracy skills by performing calculations during materials testing.

Communication

Learners develop their written and oral communication skills by studying the course material, engaging with other learners, and writing academic and reflective reports.

Digital

Learners can develop their digital literacy throughout the unit by accessing course materials through a virtual learning environment (VLE), collaborating online, keeping an e-portfolio, or using engineering design or simulation software.

Delivery of unit

This unit is part of the Higher National Diploma (HND) in Engineering. The framework includes mandatory and optional units, and you can tailor the selected combination of units to specific engineering pathway needs.

While the exact time allocated to the unit is at your centre's discretion, the notional design length is 120 hours.

The amount of time you allocate to each outcome is also at your discretion (particularly as we recommend a holistic approach). We suggest the following distribution of time, including assessment:

Outcome 1 — Understand the relationship between atomic structures and material properties, and the relationship between molecular structures and material properties
(24 hours)

Outcome 2 — Determine material properties specifications for applications, and select materials using property charts, data sheets and process compatibility charts
(18 hours)

Outcome 3 — Understand how the alteration of material structures can enhance or degrade material properties
(24 hours)

Outcome 4 — Analyse and calculate material strength and stress factors in engineering applications
(40 hours)

Outcome 5 — Understand the causes of material failure in service, and how they may be mitigated
(14 hours)

Additional guidance

The guidance in this section is not mandatory.

Content and context for this unit

Understand the relationship between atomic structures and material properties, and the relationship between molecular structures and material properties (outcome 1)

This outcome focuses on how the different scales of material structures relate to their physical and mechanical properties. You can integrate it with outcomes 3 and 4, giving learners the opportunity to alter material structures and test how these alterations affect the properties of the material.

Determine material properties specifications for applications, and select materials using property charts, data sheets and process compatibility charts (outcome 2)

You should give learners material property charts, graphs and data sheets for them to use to select appropriate materials for a particular product or application. Ideally, you would integrate this into a design project for another unit.

Understand how the alteration of material structures can enhance or degrade material properties (outcome 3)

You should provide learners with the opportunity to discover how certain alterations of material structures affect material properties through hands-on testing. If this is not feasible, learners may also benefit from having the chance to plan out processes with the goal of achieving specific material properties.

Analyse and calculate material strength and stress factors in engineering applications (outcome 4)

You can integrate this outcome into any engineering design or analysis project from another unit. You should provide learners with real-world examples of complex loading scenarios, beam and cantilever structures, and cylinder conditions to enhance their understanding and application of the concepts. Encourage learners to use these techniques and concepts to optimise their designs by considering factors of safety, and selecting appropriate materials and configurations.

Understand the causes of material failure in service, and how they may be mitigated (outcome 5)

You can integrate this outcome into any design project from another unit. You should provide learners with case studies on material failure in service, and encourage them to relate this information to their own designs by selecting appropriate preventative measures to extend the service life of their product’s materials.

Approaches to delivery

Understand the relationship between atomic structures and material properties, and the relationship between molecular structures and material properties (outcome 1)

We recommend you teach outcome 1 first, as it gives learners a foundation of knowledge and understanding that they need for the other outcomes. You should give learners the opportunity to engage in simple destructive tests and examine various material types to deepen their understanding of the relationship between a material's bonding types, structure and properties. For example, learners could snap an annealed medium carbon steel rod and a quench-hardened medium carbon steel rod, then visually compare the grain structures of the two samples. Encourage learners to devise their own simple workshop tests for material properties covered in this outcome. At this stage, you can introduce learners to concepts from outcome 3, such as grain structures and heat treatment of metals, through material inspection and process demonstrations.

Determine material properties specifications for applications, and select materials using property charts, data sheets and process compatibility charts (outcome 2)

We recommend you teach this outcome as, or incorporated into, a design task. Learners should have the opportunity to select materials for different products or applications. You could combine this outcome with outcome 4 by incorporating destructive property testing into the material selection process.

Understand how the alteration of material structures can enhance or degrade material properties (outcome 3)

We recommend that before starting this outcome, learners have already achieved a strong understanding of material structures and properties in outcome 1. This provides a foundation for understanding the specific properties and processes related to metals, polymers and ceramics. You could incorporate practical demonstrations and hands-on activities to give learners the opportunity to observe the effects of heat treatment and various working processes on different materials. For example, learners could be shown how to perform a heat treatment on a carbon steel sample and observe the changes in its properties and structure. Or you could give them the opportunity to participate in hot and cold working processes, such as hot forging or cold rolling, to see the effects on the materials first hand.

Analyse and calculate material strength and stress factors in engineering applications (outcome 4)

You should encourage learners to explore the concepts of material strength and stress analysis through a combination of lectures, discussions and computer simulations. To achieve this, you could present them with various beam and cantilever scenarios in a theoretical context, highlighting the application of Macaulay's method for determining deflection and slope. To deepen understanding of thin and thick cylinder conditions and stress analysis, learners can analyse and solve relevant case studies or engage in group discussions, comparing the implications of different cylinder conditions in various engineering scenarios. You could use computer-based simulations and graphical software tools to help learners visualise and understand Mohr's circle of stress and strain.

Understand the causes of material failure in service, and how they may be mitigated (outcome 5)

You should introduce learners to the different types of material failure, such as brittle and ductile failure, impact failure, creep rupture, and fatigue failure, through lectures, demonstrations or first-hand examination of sample materials that have undergone different types of failure. Learners could participate in case studies or group projects where they consider the service life of a material when designing a product, or plan appropriate preventative measures to extend the service life of a material.

Approaches to assessment

You can assess this unit in conjunction with other HND Engineering units by incorporating materials selection and testing into a design project.

You can assess outcomes holistically or individually. If you use a holistic approach, learners should collate their evidence in individual portfolios. Learners should have the option to present and submit portfolios in a digital format.

If you want to assess the unit holistically through a project, but it is not feasible to meet all the knowledge and skills requirements of one or more outcomes, you can carry out additional formative assessment to meet these requirements.

Equality and inclusion

This unit is designed to be as fair and as accessible as possible with no unnecessary barriers to learning or assessment.

You should take into account the needs of individual learners when planning learning experiences, selecting assessment methods or considering alternative evidence.

Guidance on assessment arrangements for disabled learners and/or those with additional support needs is available on the assessment arrangements web page: www.sqa.org.uk/assessmentarrangements.

Information for learners

Advanced Materials (SCQF level 8)

This information explains:

- what the unit is about
- what you should know or be able to do before you start
- what you need to do during the unit
- opportunities for further learning and employment

Unit information

This unit provides you with knowledge and skills specific to engineering materials. It is part of the Higher National Diploma (HND) in Engineering, which is aimed at learners who want to become engineering technicians in mechanical engineering. The unit also provides you with knowledge and skills to go on to further study.

Before starting the unit, we recommend that you have a basic knowledge and understanding of relevant mechanical engineering concepts. For example, you may have completed the Engineering Mechanics and Materials unit at SCQF level 7 (HNC level).

Unit outcomes

On completion of the unit, you can:

1 understand the relationship between atomic structures and material properties, and the relationship between molecular structures and material properties
2 determine material properties specifications for applications, and select materials using property charts, data sheets and process compatibility charts
3 understand how the alteration of material structures can enhance or degrade material properties
4 analyse and calculate material strength and stress factors in engineering applications
5 understand the causes of material failure in service, and how they may be mitigated

In outcome 1, you learn about the different structures of materials, from the atomic to the macroscopic scale, and how the structure of a material relates to its properties. The understanding of material structures you develop in this outcome provides a foundation that you build on in the other outcomes.

In outcome 2, you learn how to apply your understanding of material properties to product design. You learn how to translate product requirements into relevant material properties, and use charts, tables and other data sources to select materials for a specific product or application.

In outcome 3, you learn how various manufacturing processes can enhance or degrade the properties of materials. You expand on what you learned in outcome 2 by examining how material structures can be altered, and how this impacts material properties.

In outcome 4, you learn how to calculate reaction forces, deflection and slope for complexly loaded beams and cantilevers, using both standard formulae and Macaulay's method. You also examine thin and thick cylinder conditions, stress analysis and understand the stress–strain relationship.

In outcome 5, you learn about common causes of material failure once the material is in use. Additionally, you learn how these failures can be mitigated to prolong the lifespan of materials in service.

You can be assessed in a variety of ways. You may be asked to produce written and/or oral evidence, perhaps involving a design project.

Meta-skills

Throughout the unit, you can develop meta-skills to enhance your employability in the engineering sector.

Meta-skills include self-management, social intelligence and innovation.

Self-management

You develop the meta-skills of adapting and initiative through critical reflection and independent thinking as you work through the course material and case studies.

Social intelligence

You develop the meta-skills of communicating and collaborating as you work with other learners on case studies and assignments.

Innovation

You develop meta-skills including critical thinking, curiosity and sense-making as you analyse problems relating to mechanical engineering principles.

Administrative information

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Superclass: XA

History of changes

Version	Description of change	Date
2.0	♦ Evidence requirements updated to clarify conditions of assessment.	Dec 2024

Note: please check SQA's website to ensure you are using the most up-to-date version of this document.