Unit 20: Properties and Applications of Engineering Materials

NQF Level 3: BTEC National

Guided learning hours: 60

Unit abstract

In-depth knowledge of the structure and behaviour of engineering materials is vital for anyone who is expected to use or specify them for industrial applications within the engineering industry. This unit will provide learners with an understanding of the structures, classifications and properties of materials used in engineering and will enable them to correctly select materials for different applications.

The unit is appropriate for learners engaged in manufacturing and mechanical engineering, particularly where materials are sourced in the form of stock to be used in a production process. The unit covers a range of materials, some of which learners may not initially be familiar with. This approach will help broaden their perspective when selecting materials for given applications.

This unit will enable learners to identify and describe the structures of metals, polymers, ceramics and composites and classify them according to their properties. Learners will also be able to describe the effects of processing on the behaviour of given materials. Smart materials whose properties can be altered in a controlled fashion through external changes — such as temperature and electric and magnetic fields — are also covered.

Learners will apply their understanding of the physical and mechanical properties of materials, design, cost and availability to specify materials for given applications.

All materials have limits beyond which they will fail to meet the demands placed on them. The common modes of failure will be both demonstrated and described to enable learners to recognise where an informed choice can make the difference between the success or failure of a product.

Learning outcomes

On completion of this unit a learner should:

1 Be able to describe the structure of and classify engineering materials

2 Understand material properties and the effects of processing on the structure and behaviour of engineering materials

3 Know how to use information sources to select materials for engineering uses

4 Know about the modes of failure of engineering materials.

Unit content

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1 Be able to describe the structure of and classify engineering materials

Atomic structure: element; atom eg nucleus, electron; compound; molecule; mixture; bonding mechanisms eg covalent, ionic, metallic

Structure of metals: lattice structure; grain structure; crystals; crystal growth; alloying eg interstitial, substitutional; phase equilibrium diagrams eg eutectic, solid solution, combination; intermetallic compounds

Structure of polymeric materials: monomer; polymer; polymer chains eg linear, branched, cross-linked; crystallinity; glass transition temperature

Structure of ceramics: amorphous; crystalline; bonded

Structure of composites: particulate; fibrous; laminated

Structure of smart materials: crystalline; amorphous; metallic

Classification of metals: ferrous eg plain carbon steel, cast iron (grey, white, malleable, wrought iron), stainless and heat-resisting steels (austenitic, martensitic, ferritic); non-ferrous eg aluminium, copper, gold, lead, silver, titanium, zinc; non-ferrous alloys eg aluminium-copper heat treatable – wrought and cast, non-heat-treatable – wrought and cast, copper-zinc (brass), copper-tin (bronze), nickel-titanium alloy

Classification of non-metals (synthetic): thermoplastic polymeric materials eg acrylic, polytetrafluoroethylene (PTFE), polythene, polyvinyl chloride (PVC), nylon, polystyrene; thermosetting polymeric materials eg phenol-formaldehyde, melamine-formaldehyde, urea-formaldehyde; elastomers; ceramics eg glass, porcelain, cemented carbides; composites eg laminated, fibre reinforced (carbon fibre, glass reinforced plastic (GRP), concrete, particle reinforced, sintered; smart materials eg electro-rheostatic (ER) fluids, magneto-rheostatic (MR) fluids, piezoelectric crystals

Classification of non-metals (natural): eg wood, rubber, diamond

2 Understand material properties and the effects of processing on the structure and behaviour of engineering materials

Mechanical properties: strength (tensile, shear, compressive); hardness; toughness; ductility; malleability; elasticity; brittleness

Physical properties: density; melting temperature

Thermal properties: expansivity; conductivity

Electrical and magnetic properties: conductivity; resistivity; permeability; permittivity

Effects of processing metals: recrystallisation temperature; grain structure eg hot working, cold working, grain growth; alloying elements in steel eg manganese, phosphorous, silicon, sulphur, chromium, nickel

Effects of processing thermoplastic polymers: polymer processing temperature; process parameters eg mould temperature, injection pressure, injection speed, mould clamping force, mould open and closed time

Effects of processing thermosetting polymers: process parameters eg moulding pressure and time, mould temperature, curing

Effects of processing ceramics: eg water content of clay, sintering pressing force, firing temperature

Effects of processing composites: fibres eg alignment to the direction of stress, ply direction; de-lamination; matrix/reinforcement ratio on tensile strength; particle reinforcement on cermets

Effects of post-production use: smart materials eg impact (piezoelectric), electric field (electro-rheostatic), magnetic field (magneto-rheostatic), temperature (shape memory alloys), colour change (temperature or viscosity)

3 **Know how to use information sources to select materials for engineering uses**

Information sources: relevant standard specifications eg British Standards (BS), European Standards (EN), International Standards (ISO); material manufacturers' and stockholders' information eg data sheets, catalogues, websites, CD ROMs

Design criteria: properties eg mechanical, physical, thermal, electrical and magnetic; surface finish; durability eg corrosion resistance, solvent resistance, impact resistance, wear resistance

Cost criteria: initial cost eg raw material, processing, environmental impact, energy requirements; processing eg forming, machining, casting, joining (thermal, adhesive, mechanical); quantity; mode of delivery eg bulk, just-in-time (JIT); recycling

Availability criteria: standard forms eg sheet and plate, bar-stock, pipe and tube, sectional, extrusions, ingots, castings, forgings, pressings, granular, powder, liquid

4 **Know about the modes of failure of engineering materials**

Principles of ductile and brittle fracture: effects of gradual and impact loading eg tensile, compressive, shear; effects of grain size; transition temperature; appearance of fracture surfaces

Principles of fatigue: cyclic loading; effects of stress concentrations eg internal, external; effects of surface finish; appearance of fracture surfaces

Principles of creep: primary; secondary; tertiary; effects of temperature; strain versus time curve; creep limit; effect of grain size; effect of variations in the applied stress

Tests: destructive eg tensile, hardness, impact, ductility, fatigue, creep; non-destructive eg dye penetrant, ultrasonic, radiographic (x-ray, gamma ray), magnetic powder, visual

Degradation processes: on metals eg oxidation, erosion, stress corrosion; on polymers eg solvent attack, radiation and ageing; on ceramics eg thermal shock, sustained high temperature

Grading grid

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

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 describe the structure (including the atomic structure) associated with a given metal, polymer, ceramic, composite and smart material	M1 explain how the properties and structure of different given engineering materials affect their behaviour in given engineering applications	D1 justify your selection of an engineering material for one given application describing the reasons the selection meets the criteria
P2 classify given engineering materials as either metals or non-metals according to their properties	M2 explain how one destructive and one non-destructive test procedure produces useful results	D2 evaluate the results of one test procedure.
P3 describe mechanical, physical, thermal and electrical and magnetic properties and state one practical application of each property in an engineering context	M3 explain how two given degradation processes affect the behaviour of engineering materials.	
P4 describe the effects on the properties and behaviour of processing metals, polymers, ceramics and composites and of post-production use of smart materials		

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:**
P5 use information sources to select a different material for two given applications, describing the criteria considered in the selection process P6 describe the principles of the modes of failure known as ductile/brittle fracture, fatigue and creep P7 perform and record the results of one destructive and one non-destructive test method using one metal and one non-metallic material P8 describe a different process of degradation associated with each of metals, polymers and ceramics.		

Essential guidance for tutors

Delivery

Ideally this unit would be delivered using a combination of practical demonstrations and investigative assignments.

To enable learners to understand both the mechanical and physical properties of engineering materials, workshop-based tests can be used to demonstrate the properties in a practical context. As an example, the differing effects of hot and cold working on the properties of copper and carbon steel can be demonstrated by lightly hammering specimens of both metals. Comparing the effort required to bend the cold-worked and untreated specimens, learners will gain first-hand experience of the effects of work hardening. If the specimens are then heat treated and cooled at different rates the results should provide evidence that can be evaluated during classroom-based theory sessions.

Delivery of the structure and properties of materials could be related to applications that learners are familiar with, giving flexibility in terms of the sources of evidence used to satisfy the grading criteria.

Tutors should ensure that learners are aware of the hazards and safe working practices associated with the use of heating equipment and common hand tools before supervising practical activities.

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. The use of industrial visits can also 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 both destructive and non-destructive tests. Learners will require instruction in the safe operation of such equipment. Radiographic and ultrasonic tests may not necessarily be commonly available; however, if they are known to exist within a local industrial setting, centres may wish to arrange visits to enable learners to gain further experience.

Note that the use of 'eg' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'eg' needs to be taught or assessed.

Assessment

To achieve a pass grade, all the pass criteria must be met. Centres have the option to decide on the number of tasks and the order in which the criteria are covered.

The evidence to satisfy the pass criteria P1, P2 and P3 could be achieved by means of a written assignment following a combination of tutor-led practical and theory sessions and individual research. P2 would require the range of materials given to include at least one ferrous, one non-ferrous, one non-ferrous alloy, one thermoplastic polymer, one thermosetting polymer, an elastomer, one ceramic, one composite, one smart material and one natural material.

Achievement of P4 could involve learners in both practical and theoretical tasks in which they relate the effects of processing on the properties of materials with real engineering applications. For smart materials they need to consider the effects on the properties of the materials use after production. Examples here may be related to their change in properties from the effects of external stimuli. For example, when a force is applied to a piezoelectric material it produces an electric charge which can be used to trigger a car's airbag in the event of an accident. In many applications the behaviour is reversible eg a colour change in response to a change in temperature or a variation in the viscosity of a liquid in response to the application of an electric or magnetic field. To satisfy P5, it is likely that learners would apply the knowledge gained in meeting criteria P1 to P4. Written responses would satisfy these criteria.

P6 and P7 could be met using a combination of practical and research activities involving tutor-led demonstrations of available laboratory tests. Learners could then carry out a series of tests and produce a written record of the test results. A witness statement could confirm the learners' involvement. Depending on available resources it may be best to carry out the destructive test on the non-metallic material and the non-destructive test on the metallic material. This would allow a wider choice of tests for the latter. To achieve P8, learners could be given the opportunity to research degradation processes reflected in local conditions eg a marine environment, or, for employed learners, degradation pertinent to their companies products.

To achieve a merit grade, learners will need to explain how the structure and properties of given materials will affect their behaviour in use. This evidence would be best demonstrated by a written task related to the activities carried out to meet P1, P2 and P3. To satisfy M2, learners could produce a written explanation of the test procedures followed in P7 and the usefulness of the results. In producing evidence for some of this criterion it may be appropriate to include the responses to oral questions. However, centres should ensure that such questions and the responses are recorded for verification and also that they are not the sole source of evidence. M3 could be achieved through an extension of the task given for P8. The processes used in the explanation could be selected to meet local conditions or industrial applications.

To achieve distinction criteria D1, learners need to justify their selection of one of the materials used to satisfy P5, giving reasons why other materials considered for the application were not selected. To satisfy D2, learners are expected to complete a written task to evaluate the results of one of the tests used to meet P7 and M2. The evidence would depend on the test used but it could include the mathematical results of a tensile test, the values of a hardness test or detailed information gained from a non-destructive test.

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

This unit does not have any direct links with the Level 3 National Occupational Standards. It may however contribute to the knowledge requirements of some of the units within the SEMTA Level 3 NVQ in Materials Processing and Finishing and SEMTA Level 3 NVQ in Mechanical Manufacturing Engineering.

Essential resources

Centres will need access to equipment to conduct at least one destructive and one non-destructive test and related materials as specified in the unit content.

Indicative reading for learners

Textbooks

Higgins R — *Materials for Engineers and Technicians* (Newnes, 2006) ISBN 0750668504

Timings R L — *Engineering Materials, Volume 1* (Longman, 1998) ISBN 0582319285

Timings R L — *Engineering Materials, Volume 2* (Longman, 2000) ISBN 0582404665

Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skill evidence are given here. Staff should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

Communication Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• describing the effects of processing on the properties and behaviour of materials • describing the principles of the modes of failure known as ductile/brittle fracture, fatigue and creep.	C3.3 Write **two** different types of documents. each one giving different information about complex subjects. One document must be at least 1000 words long.