Unit 7: Properties and Applications of Engineering Materials

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

In-depth knowledge of the structure and behaviour of engineering materials is vital for anyone who is expected to select or specify them for applications within the engineering industry. This unit will give an understanding of the structures, classifications and properties of materials used in engineering and will enable them to 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 be familiar with initially.

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 requirements, 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 explained to enable learners to recognise where an informed choice can make the difference between the success or failure of a product.

Note that the use of 'e.g.' 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 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the structure and classification of engineering materials

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

3 Be able to use information sources to select materials for engineering uses

4 Understand about the modes of failure of engineering materials.

Unit content

- 1 **Know the structure of and classify engineering materials**

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

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

  Structure of polymeric materials: monomer; polymer; polymer chains e.g. 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 e.g. plain carbon steel, cast iron (grey, white, malleable, wrought iron), stainless and heat-resisting steels (austenitic, martensitic, ferritic); non-ferrous e.g. aluminium, copper, gold, lead, silver, titanium, zinc; non-ferrous alloys e.g. 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 e.g. acrylic, polytetrafluoroethylene (PTFE), polythene, polyvinyl chloride (PVC), nylon, polystyrene; thermosetting polymeric materials e.g. phenol-formaldehyde, melamine-formaldehyde, urea-formaldehyde; elastomers; ceramics e.g. glass, porcelain, cemented carbides; composites e.g. laminated, fibre reinforced (carbon fibre, glass reinforced plastic (GRP)), concrete, particle reinforced, sintered; smart materials e.g. electro-rheostatic (ER) fluids, magneto-rheostatic (MR) fluids, piezoelectric crystals

  Classification of non-metals (natural): e.g. 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 e.g. hot working, cold working, grain growth; alloying elements in steel e.g. manganese, phosphorous, silicon, sulphur, chromium, nickel

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

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

  Effects of processing ceramics: e.g. water content of clay, sintering pressing force, firing temperature

Effects of processing composites: fibres e.g. 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 e.g. impact (piezoelectric), electric field (electro-rheostatic), magnetic field (magneto-rheostatic), temperature (shape memory alloys), colour change (temperature or viscosity)

- 3 **Be able to use information sources to select materials for engineering uses**

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

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

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

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

- 4 **Understand about the modes of failure of engineering materials**

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

Principles of fatigue: cyclic loading; effects of stress concentrations e.g. 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 e.g. tensile, hardness, impact, ductility, fatigue, creep; non-destructive e.g. dye penetrant, ultrasonic, radiographic (x-ray, gamma ray), magnetic powder, visual

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

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 describe the structure (including the atomic structure) associated with a given metal, polymer, ceramic, composite and smart material		
P2 classify given engineering materials as either metals or non-metals according to their properties		
P3 explain mechanical, physical, thermal and electrical and magnetic properties and state one practical application of each property in an engineering context		
P4 explain the effects on the properties and behaviour of processing metals, polymers, ceramics and composites and of post-production use of smart materials	M1 explain how the properties and structure of different given engineering materials affect their behaviour in given engineering applications	

P5 use information sources to select a different material for two given applications, using the criteria considered in the selection process	M2 explain the criteria considered in the selection process	D1 justify selection of an engineering material for one given application
P6 explain the principles of the modes of failure known as ductile/brittle fracture, fatigue and creep	M3 explain how two given degradation processes affect the behaviour of engineering materials	
P7 perform and record the results of one destructive and one non-destructive test method using one metal and one non-metallic material	M4 explain how one destructive and one non-destructive test procedure produces useful results.	D2 evaluate the results of one test procedure.
P8 explain a different process of degradation associated with each of metals, polymers and ceramics.		

Essential guidance for tutors

Assessment

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 and M1 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 e.g. 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 and understanding gained in meeting criteria P1 to P4. Written responses would satisfy these criteria.

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 P6 and P8, learners could be given the opportunity to research modes of failure and degradation processes reflected in local conditions e.g. a marine environment, or, for employed learners, failure and degradation pertinent to their companies' products.

To achieve the merit grade M1, 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. For M2 learners should consider design, cost and availability criteria in their explanation. To satisfy M3, 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. M4 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 criterion 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 M4. 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.

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 Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3	Structure and Classification of Engineering Materials	Questions relating to the structure and classification of the range of engineering materials	A written report containing reasoned answers to the set questions
P4, M1	Properties of Engineering Materials	Questions relating to the properties and behaviour of engineering materials	A written report containing reasoned answers to the set questions
P5, M2, D1	Selection of Engineering Materials	Selection of engineering materials for given applications	A written report listing selection criteria, information sources and justification for selected materials
P6, P8, M3	Failure and Degradation of Engineering Materials	Questions relating to the range of failure modes and degradation processes in engineering materials	A written report containing reasoned answers to the set questions
P7, M4, D2	Testing Engineering Materials	Carry out and report the results of destructive and non-destructive tests on engineering materials	A written report containing an explanation of test procedure and evaluation of test results

Essential resources

Centres will need a selection of exemplar materials and components for viewing, tactile inspection and discussion. Degraded and failed component specimens will also be of value. Centres will also require 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

Darbyshire A – *Mechanical Engineering BTEC National Specialist Units* (Routledge, 2010) ISBN 9780080965772

Higgins R – *Materials for Engineers and Technicians* (Routledge, 2014) ISBN 9781138778757

Timings R L – *Engineering Materials, Volume 1* (Longman, 1998) ISBN 9780582319288

Timings R L – *Engineering Materials, Volume 2* (Longman, 2000) ISBN 9780582404663

Tindell H –Engineering Materials, Crowood Metalworking Guides (The Crowood Press Ltd, 2014) 9781847976796