Unit 38: Industrial Alloys

Unit code: A/600/0303

QCF Level 3: BTEC Nationals

Credit value: 10

Guided learning hours: 60

Aim and purpose

This unit aims to provide a broad understanding of the different metallurgical alloys that are commonly used within the engineering and manufacturing industries.

Unit introduction

Alloys are a huge part of engineered materials and have a broad range of properties that find widespread application in today's technological society. A compound of two or more metals, an alloy is usually designed to have characteristics that are very different from its components. Mixing metals together can affect properties such as density, strength, fracture toughness, electrical conductivity and environmental degradation. For example, adding a small amount of iron to aluminium will make it stronger, or adding some chromium to steel will slow the rusting process but will make it more brittle. An understanding of alloys and their properties is vital when considering which alloy should be used for a specific purpose.

This unit aims to provide a broad understanding of the different metallurgical alloys that are commonly used within the engineering and manufacturing industries. The unit will introduce learners to a range of metals and alloy systems, the role of atomic structures and their effects on microstructures and metallurgical/mechanical properties of the materials.

Learners will be introduced to different industrial alloy systems. An integrative learning approach will enable them to select metals and alloys for a range of industrial applications. The unit also introduces learners to the importance of technical data, specifications, standards and their relationship to the microstructure and mechanical properties.

Learning outcomes

On completion of this unit a learner should:

1 Understand the metallurgical factors that affect the selection, use and classification of common ferrous metals and alloys

2 Understand the metallurgical factors that affect the use and selection of common non-ferrous metals and alloys

3 Understand how equilibrium and non-equilibrium thermal transformations affect microstructure and mechanical properties of ferrous and non-ferrous metals and alloys.

Unit content

1 Understand the metallurgical factors that affect the selection, use and classification of common ferrous metals and alloys

Chemical compositions: carbon steels and alloying elements eg silicon, manganese, sulphur, carbon range; alloy steels and alloying elements eg chromium, nickel, molybdenum, vanadium, tungsten; cast irons eg role of carbon, silicon, manganese, chromium, nickel, copper and other residual elements

Classification, selection and use: classification systems eg low, medium and high carbon steels – grey, white, spheroidal, malleable cast irons, ferritic, austenitic, martensitic stainless steels; the effect of different cooling rates eg formation of graphite, formation of pearlite; typical industrial selection and use eg low carbon steel wire (for bed springs) high carbon (for taps and dies) grey cast iron (for brake drums)

Technical data, specifications and standards: metallurgical, mechanical properties and other technical data for ferrous metals and alloys eg establish 'nominal' data, acceptable ranges and limits; relationship between the data, specifications and standards with the industrial and customer requirements

2 Understand the metallurgical factors that affect the use and selection of common non-ferrous metals and alloys

Chemical compositions: light alloys eg aluminium, magnesium, zinc alloys; high temperature alloys eg titanium, nickel/chromium alloys; copper-based alloys eg oxygen-free, arsenical, brasses, bronzes, aluminium bronze; the role of residual elements

Selection, use and classification: classification systems eg wrought and cast, heat-treatable and non-heat treatable alloys, single or duplex phase, solution/precipation hardening materials; industrial selection and use eg aluminium/silicon alloys for engine blocks, titanium, aluminium and vanadium alloy for turbine blades, copper/zinc alloy for cartridge cases

Single and duplex phases: effects of alloy additions eg role of interstitial and substitutional solid solutions formation, changes in atoms arrangement; effects of heating and cooling eg changes in alpha and alpha/beta alloys and the effects on transformed beta/Martensite in titanium alloys; industrial selection and use eg turbine blades and rings in aircraft engines

Technical data, specifications and standards: metallurgical, mechanical properties and other technical data for non-ferrous metals and alloys eg establish 'nominal' data and acceptable ranges/limits; relationship between the data, specifications and standards with the industrial and customer requirements

3 Understand how equilibrium and non-equilibrium thermal transformations affect microstructure and mechanical properties of ferrous and non-ferrous metals and alloys

Microstructure, matrix and mechanical properties: micro-examinations eg identification of matrix, martensite, alpha phase in copper system; range of associated data for different metal/alloy systems eg yield and tensile strength, hardness, impact, fatigue and creep resistance; variation in mechanical properties due to different methods of manufacture eg wrought, cast etc; changes in microstructure and matrix classification eg comparison of 'as cast' single phase magnesium aluminium alloy with a 'cold worked' single phase copper/zinc alloy, or quenched and tempered alloy steel

Equilibrium and non-equilibrium cooling: relationship between microstructure, grain size, cooling rate and matrix formation/classification due to rapid cooling eg making comparisons to annealing, normalising heat treatments and identifying the differences between solution treatment, precipitation hardening, quenching and tempering; changes and effects on metallurgical and mechanical properties due to different heat treatment eg hardness, ductility, toughness

Phase transformation: changes to the microstructure and variations in mechanical properties of non-equilibrium and equilibrium cooling; time temperature transformation (TTT), continuous cooling transformation (CCT) and thermal equilibrium diagrams (TED); effects of phase transformation eg formation of martensite or bainite on quenching plain carbon steels; role of ageing/tempering; role of solution treatment in the production of aluminium bronze alloys; solution treatment and precipitation hardening in nickel-based supper alloys

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 explain the importance of chemical composition and the effect on the classification, selection and use of ferrous metals and alloys	**M1** explain how differing carbon and alloying additions change the metallurgical and mechanical properties of ferrous material and how this will affect its industrial use	**D1** justify the choice of a ferrous and a non-ferrous material for given industrial applications based on metallurgical and mechanical properties
P2 use technical data, specifications and standards to determine the properties and applications of given ferrous metals and alloys [IE1, IE4]	**M2** explain how alloying changes the metallurgical and mechanical properties of a given non-ferrous metal, and how this may affect its industrial use	**D2** evaluate TTT, CCT and TED diagrams and explain how they can be used to identify the relationship between microstructure, properties and industrial requirements.
P3 explain the importance of chemical composition and the effect on classification, selection and use of non-ferrous alloys	**M3** use micro-examination to evaluate the changes in microstructure, matrix, metallurgical and mechanical properties due to the heat treatment of an alloy.	
P4 explain how alloying additions contribute to the formation of single and duplex phases and the effect on the industrial use of non-ferrous metals		
P5 use technical data, specifications and standards to determine the properties and applications of given ferrous and non-ferrous metals alloys [IE1, IE4]		
P6 carry out micro-examinations and identify the role that microstructure and matrix have on the metallurgical and mechanical properties of a given ferrous and non-ferrous alloy [SM2, SM3]		

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:**
P7 explain the relationship between equilibrium cooling, non-equilibrium cooling, and phase transformations.		

PLTS: This summary references where applicable, in the square brackets, the elements of the personal, learning and thinking skills applicable in the pass criteria. 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

Practical work and appropriate theory, coupled with demonstrations and research, will form an essential part of the teaching and learning process. This is likely to be through learners conducting a series of micro-examinations of metals and alloys, examining the grain structure/size and phases present and the changes in the metallurgical properties.

Case studies comparing microstructure and technical data will also provide learners with opportunities to match industrial standards and specifications to micro and mechanical properties. Use of international standards relevant to the learner's own industry, and the identification of how this metallurgical and technical data can be transferred to industrial alloys, will help bridge the gap between microstructure and properties.

Some of these activities will be undertaken in small groups and others individually. This approach will support both team working and individual accountability, which are professional requirements for an engineering technician at this level.

A mixture of formal tutor-led learning alongside practical experience and elements of self-study and research are essential for effective coverage of all the learning outcomes. Industrial visits will provide added value to learners' experiences and will allow centres to maximise the learning opportunities that exist in the workplace. Centres that have heat treatment facilities could provide further opportunities for learner-centred activities. Access to a range of mechanical testing equipment (eg hardness, tensile and impact testing etc) would also enrich the learning experience.

This unit will be best placed in the second year of a two-year programme of study. This will allow learners to use knowledge and prior learning from other units to maximise industry-based learning opportunities.

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.

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, scheme of work and methods of assessment • explain the chemical composition of carbon steels and alloying elements, alloy steels and alloying elements and cast irons • explain the systems used for classification of common ferrous metals and alloys • explain the effect of cooling rates. Describe the typical industrial selection and use of common ferrous metals • describe the use of mechanical properties and other technical data and how the data relates to specifications, standards and customer requirements.
Prepare for and carry out **Assignment 1: Ferrous Metals and Alloys** (P1 and M1)
Whole class teaching: • explain the chemical composition of light alloys, high temperature alloys and copper-based alloys. Explain the role of residual elements • explain the systems used for the classification of common non-ferrous metals and alloys. Describe the typical industrial selection and use of common non-ferrous metals • explain the effects of alloy additions, heating and cooling. Explain typical industrial selection and use • describe the use of metallurgical, mechanical properties and technical data for non-ferrous metals and alloys.
Prepare for and carry out **Assignment 2: Non-ferrous Metals and Alloys** (P2, P3 and M2)
Prepare for and carry out **Assignment 3: Use of Technical Data, Specifications and Standards** (P4)
Whole class teaching: • explain and demonstrate the use of micro-examinations. Describe the range of associated data for different metal systems. Explain the variation in mechanical properties due to different methods of manufacture and the changes in microstructure and matrix classification • explain the relationship between microstructure, grain size, cooling rate and matrix formation. Describe changes and effects on metallurgical properties due to heat treatment • explain the changes to microstructure and mechanical properties and effects of phase transformation. Describe the role of tempering and solution treatment. *Practical workshop activity:* • learners inspect a range of ferrous and non-ferrous metals and match industrial standards and specifications to micro and mechanical properties.
Prepare for and carry out **Assignment 4: Micro-examination and Microstructure** (P5, P6, M3, D2)
Prepare for and carry out **Assignment 5: Industrial Applications of Ferrous and Non-ferrous Metals** (D1)
Feedback on assessment, unit review and evaluation.

Assessment

Assessment of this unit could use a mixture of laboratory work, technical reports, project assignments, case studies and research. The use of practical assignments that are linked with appropriate theory, alongside the use of case studies and research, will enable learners to use and develop a range of different learning techniques. The development of this type of approach to tasks and activities will be useful when transferred into the workplace.

The pass criteria specify the minimum acceptable level for each learner. Achievement of a merit or distinction will require them to demonstrate a greater breath and range of understanding of the principle industrial alloys.

To achieve a pass learners should identify the importance of chemical compositions, the role of atomic structure, identify microstructures, phases, and the formation of metallic and non-metallic inclusions and compounds. They should be able to explain the relationship between microstructures and mechanical properties and be able to explain the changes that take place in these prior to and after heat treatment. Learners should also be able to use technical data and standards to determine if a metal or alloy is suitability for given industrial applications.

To achieve a merit learners must be able to explain the role that carbon and/or alloying elements have in changing the metallurgical and mechanical properties in ferrous and non-ferrous metals and therefore their industrial use. They must also apply micro-examination techniques to evaluate changes in microstructure, matrix, metallurgical and mechanical properties due to the heat treatment of an alloy.

To achieve a distinction learners must be able to demonstrate how the relationships between microstructure and mechanical properties work by using evaluative skills to make an appropriate selection of a ferrous and a non-ferrous material for given industrial applications. It is expected that at this level learners will make use of all the skills developed in the unit – understanding of microstructure, micro-examination and reference to technical data, specifications and standards. Learners should also be able to use their evaluative skills to examine TTT, CCT and TED diagrams and explain how they can be used to identify the relationship between microstructure, properties and industrial requirements.

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 and M1	Ferrous Metals and Alloys	Produce a leaflet for a conference for engineers.	Production of a technical leaflet.
P2, P3 and M2	Non-ferrous Metals and Alloys	Produce a leaflet for a conference for engineers.	Production of a technical leaflet.
P4	Use of Technical Data, Specifications and Standards	Produce a report for a metallurgist employer.	A report on given ferrous and non-ferrous metals and alloys.
P5, P6, M3 and D2	Micro-examination and Microstructure	Produce a report for management on the structure of different given ferrous and non-ferrous metals.	Case study and practical report.
D1	Industrial Applications of Ferrous and Non-ferrous Metals	Produce a report on the suitability of a ferrous and non-ferrous metal for a given industrial application.	Report on choice of non-ferrous and ferrous metals.

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 the following unit titles in the Engineering suite:

Level 1	Level 2	Level 3
		Mechanical and Thermal Treatment of Metals
		Structure and Properties of Metals
		Metallurgical Techniques
		Extraction and Refining of Metals
		Liquid Metal Casting Processes

Essential resources

Access to facilities and equipment for the metallurgical testing and examination of metals is essential for the delivery of this unit. Learners will benefit enormously from hands-on experience of micro preparation and use of an optical microscope. The range of ferrous and non-ferrous metallurgical samples/material should reflect the range of metals identified in the unit content.

Centres will also need to make technical and primary source information available, alongside current specifications and standards.

Employer engagement and vocational contexts

There are a range of organisations that may be able help centres engage and involve local employers in the delivery of this unit, for example:

- 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

Budinski K and Budinski M – *Engineering Materials* (Pearson Education, 2009) ISBN 0136109500

Timings R L – *Engineering Materials* (Longman, 1998) ISBN 0582319285

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 ...
Independent enquirers	identifying questions to answer, analysing and evaluating information when using technical data, specifications and standards
Creative thinkers	working towards goals, showing initiative and commitment and organising time and resources when carrying out micro-examinations.

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 ...
Creative thinkers	asking questions relating to industrial alloys in order to extend their thinking
Reflective learners	setting goals with success criteria for their development and work.

Functional Skills – Level 2

Skill	When learners are ...
English	
Speaking and listening – make a range of contributions to discussions and make effective presentations in a wide range of contexts	explaining the importance of chemical composition of ferrous and non-ferrous metals and alloys and the relationship between equilibrium cooling, non-equilibrium cooling, and phase transformations
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	investigating and researching the chemical and micro-structural composition of metals and alloys
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	explaining the importance of chemical composition of ferrous and non-ferrous metals and alloys and the relationship between equilibrium cooling, non-equilibrium cooling, and phase transformations.