Unit 27: Welding Principles

Unit code: M/600/0279
QCF Level 3: BTEC Nationals
Credit value: 10
Guided learning hours: 60

Aim and purpose

This unit will give learners an understanding of the principles of welding, the effect of heat on welded joints and the control measures required to produce quality joints.

Unit introduction

The industrial processes used to produce welded joints rely on the application of heat to melt and fuse the materials together. The amount of heat used varies according to the process, but one common factor is that the metallurgical structure of the metal will be changed to some extent by the welding operation.

This unit provides the learner with an understanding of the effect that the heat input has on a welded component. The unit is suited to welders and those responsible for the specification of the welding process and any post-weld heat treatments. The unit will develop learners' knowledge of the structure of pure metals and the effects of adding alloying elements. Learners will develop an understanding of the effect that heat has on metals and their alloys once they have been welded, and how this influences the performance of a welded component. Learners will also gain knowledge of the post weld heat treatment processes that are available to improve the performance of the structure and relieve stress. The testing of welds is also covered in the unit so that learners appreciates the need for a component to meet a quality standard.

Learners will perform a range of practical and investigative tasks to develop their understanding of different welding processes and the suitability of their application. Learners will prepare materials for welding and the post-welding treatments of welded materials. Identification of defects is vital in ensuring the quality of the finished product and learners will demonstrate their knowledge of the techniques employed in defect detection and the quality standards used in industry.

Learning outcomes

On completion of this unit a learner should:

1 Know the physical features of welding processes

2 Know the effects of welding and select post-weld heat treatments

3 Understand the weldability of metals

4 Be able to use and interpret quality standards and weld testing techniques.

Unit content

1 Know the physical features of welding processes

Welding processes: main processes eg manual metal arc (MMA), metal-arc gas shielded (MAGS), tungsten-arc gas shielded (TAGS), oxy-acetylene; additional processes eg resistance (such as spot, seam), friction, flash butt, laser, electron beam, explosive, exothermic (thermit), capacitor discharge stud welding, friction stir welding; choice of processes; working environment eg workshop, site work, suitability of machinery and plant

Electric arc: alternating current (AC); direct current (DC); heat distribution at the anode and cathode; effect of magnetic fields; applications of AC and DC; consumable and non-consumable electrodes; metal transfer and deposition; plasma-arc

Shielding gases: functions eg atmospheric protection, arc initiation; shielding gases eg inert gases, argon, helium; active gases used in mixtures eg carbon dioxide (CO2), nitrogen, oxygen; applications eg MAGS, TAGS, plasma-arc

Electrode coverings and fluxes: functions of coverings and fluxes eg atmospheric protection, slag, removal of impurities, alloying, arc initiation; composition eg basic, rutile, cellulosic, iron powder; fluxes eg fused, agglomerated; applications of coverings and fluxes eg MMA welding, submerged arc welding, braze welding

Oxy-acetylene combustion: chemical composition of the inner and outer envelope; heat distribution; applications of flame types, eg neutral, oxidising, carburising

2 Know the effects of welding and select post-weld heat treatments

Effects of welding heat input: distortion control eg pre-setting, pre- and post-heating, total heat input, weld deposition (skip and back step) techniques; effects eg distortion (expansion and contraction), expansivity, residual stress; effects of cooling rate eg hardening, grain growth, cracking; structure of the welded joint eg heat-affected zone (HAZ), crystal structure (such as equi-axed, columnar), grain growth; heat distribution during welding eg thermal gradients, heat flow, joint configuration (butt, tee, cruciform); use of chills; comparison of processes

Post-weld heat treatments: for ferrous metals eg annealing (full, process), normalising; for heat treatable aluminium alloys eg solution treatment, precipitation hardening

3 Understand the weldability of metals

Weldability: factors eg melting temperature, carbon equivalent, rate of heating and cooling (thermal shock), thermal conductivity, residual stress, degree of restraint (the rigidity of the construction), similar and dissimilar metals; dilution, hardenability, dissolved hydrogen, pre- and post-heat temperature; impurities eg phosphorous (cold shortness), sulphur (hot shortness); mechanical properties eg tensile strength, impact strength

4 Be able to use and interpret quality standards and weld testing techniques

Weld test techniques: non-destructive eg visual (weld gauges, dimensional), radiographic (such as x-ray, gamma ray), ultrasonic, dye penetrant, magnetic particle; destructive eg fracture, bend test, macro and microscopic examination, tensile, fatigue, hardness

Weld defects: visual (surface defects) eg undercut, overlap, excess weld metal, leg length of fillets, concavity, cracking (such as cold cracking, hot cracking, crater, transverse, longitudinal, centre-line, HAZ), blowholes, oxidation, restarts; internal eg porosity, inclusions (such as slag, metallic, gaseous), lack of inter-run fusion, cavities

Quality standards: in relation to relevant standards eg British Standard/European Standard BS EN 970, BS EN 1011, BS EN ISO 10042, BS EN ISO 15607, BS EN ISO 15609, BS EN ISO 15614, American Society of Mechanical Engineers (ASME) IX

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 select suitable welding processes for four given applications	**M1** explain the operation of two welding processes for given welding applications with respect to heat input and the fusion of welded materials	**D1** analyse the advantages and disadvantages of using post-weld heat treatments in a steel or aluminium welded component
P2 describe the physical features of an electric arc used in a welding process	**M2** explain how a post-weld heat treatment process will affect the grain structure and properties in two given materials	**D2** analyse the defects found in a component that has been weld tested and identify possible causes in relation to the heat input.
P3 describe the function of two given shielding gases, and two electrode coverings/fluxes used in welding processes	**M3** explain how impurities affect quality in terms of the weldability and material properties of a welded joint.	
P4 describe oxy-acetylene combustion and its application when using gas welding equipment		
P5 describe three methods of controlling the effects of heat input when using welding processes		
P6 describe the effect of heat input, heat distribution and cooling rate on the grain structures of two welded joints		
P7 identify suitable post-weld heat treatment processes for joints in steel and aluminium alloys that have been welded		
P8 analyse a given metal and determine the factors that will affect its weldability [IE1, IE4]		

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	use two weld testing techniques to detect surface defects and internal weld defects in accordance with quality standards [SM3]		
P10	produce a test procedure for a destructive or non-destructive weld test to detect weld defects in welded components [SM3].		

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

Delivery of this unit should use a combination of practical demonstrations and investigative assignments.

Ideally, learners will be given the opportunity to gain an appreciation of a range of welding processes. This could be through the observation of tutor-led demonstrations which would preferably lead to hands-on experience of at least one process. Industrial visits, videos and DVDs could be used to ensure that learners are exposed to a range of processes, this could include the use of internet resources.

Observation in a practical setting will ensure that learners are aware of the heat input required to fuse metals together. The effects of distortion could also be best illustrated in practical workshop sessions. Inspection of welds completed in the workshop will also have the advantage of providing specimens for use in the detection of weld defects. This may also be linked to other welding and fabrication units.

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

Where learners are employed, assignments could be designed to link to welding activities in their workplace, though these learners must be given an appreciation of the range of other processes available. Engaging with employers will also give learners who are not work-based an appreciation of the industry they are being prepared for. Employers may be used in the production of appropriate visual aids which enable centres to deliver parts of the unit content that they may not have access to in a practical context. They might also contribute towards the production of commercially produced weld specimens and components containing known defects. This can be used to help ensure uniformity in the recognition of defects.

Centres should have access to the necessary facilities and equipment to allow learners to observe at least one destructive and one non-destructive weld test. Mechanical properties such as hardness, ductility and tensile strength can be compared using simple equipment. Learners will require instruction in the safe operation of this equipment.

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 content and unit requirements • introduction to welding processes • range of welding processes covered in unit • features of electric arc – relate to processes • function of gas shields – relate to processes • function of electrodes coverings and fluxes • oxy-acetylene combustion and flame applications. *Workshop session*: • range of welding processes and the machinery involved – demonstrations and practice.
Preparation for and carrying out **Assignment 1: Welding Processes** (P1, P2, P3, P4, M1).
Whole-class teaching/workshop sessions with tutor led demonstrations: • effects of heat and process variables • precautions to minimise effects prior to welding – joint design, pre-setting, pre-heating • analysis of material behaviour during welding – materials structure, fusion, changes in structure etc • effects of heat during welding – expansion, contraction, distortion, stress etc • heat treatments for ferrous and non-ferrous materials • comparison of processes with regard to heat effects.
Preparation for and carrying out **Assignment 2: The Effects of Welding** (P5, P6, P7, M2, D1).
Whole-class teaching/workshop sessions with tutor led demonstrations: • weldability of materials – material properties, chemical composition • welding of similar and dissimilar metals • heating effect and dilution of fused materials • heating and cooling of materials – preheating and post heating • welding process rate of heating and cooling • restraint of materials during and after welding – rigid constructions and components.
Preparation for and carrying out **Assignment 3: Weldability of Metals** (P8, M3).
Whole-class teaching/workshop sessions with tutor led demonstrations: • weld testing techniques – visual, destructive and non-destructive • weld test theory and quality standards – variety of standards, tolerances, dimensions, weld quality • test procedures – visual, destructive and non-destructive.

Topic and suggested assignments/activities and/assessment
Laboratory and/or workshop practical: • safe practice for preparing joints and using equipment • preparation of joints for testing • testing of surface (visual) defects – undercut, cracking, craters, fillet leg length, excess weld, lack of fusion • testing of welded joints – destructive and non-destructive testing techniques • reporting results of weld tests.
Preparation for and carrying out **Assignment 4: Weld Testing and Quality Standards** (P9, P10, D2).
Feedback and unit evaluation.

Assessment

The learning outcomes of this unit may be linked with those of other units, in particular *Unit 23: Welding Technology*. Written assignments should be supported with appropriate photographs and diagrams.

Pass criteria P1, P2, P3 and P4 could be achieved by learners selecting and describing the functions and features of welding processes and their application in industry. Learners' responses could include both written and oral questioning. The four given applications should include processes across the range of those outlined in the unit content. A further written task to cover M1 should ensure that learners cover the range of processes and physical features identified in the unit content.

Achievement of P5 could be achieved by means of a written task. To enable learners to understand the effects of distortion it may be appropriate for them to participate in an associated practical task. This could, for example involve measuring the angle between two plates before and after the welding of a tee fillet joint. Evidence for P6 is also likely to come form a written task in which learners are asked to consider two joints that are subjected to extremes of heat input due to the process parameters. One joint could be in thin metal, welded by a process with a high deposition rate (for example MAGS or laser), compared with a thicker metal welded using a slower deposition process (for example MMA or oxy-acetylene welding). A further task covering P7 could require learners to investigate and recommend post-weld heat treatment processes appropriate to welded joints in steel and aluminium alloys. Another written task can then build on this to cover M2.

For P8, a written task could be used based on a range of factors and impurities known to affect the weldability and properties of metals. This could be extended to also cover M3, with learners providing an explanation of how impurities can affect welded joints.

A written task covering P9 should ask learners to produce a procedure for carrying out non-destructive and destructive tests as identified in the unit content. There is an opportunity to set different procedures for the range of learners or to concentrate on testing techniques that may be found in the learners' workplace, where applicable. P10 could be achieved using a combination of practical assessments and research. Learners could either use welds produced in the welding workshop or commercially produced weld specimens with known defects, to correctly detect surface and internal defects in welds relevant to a given quality standard. Learners should perform this on a range of materials, ferrous and non-ferrous. Whilst this criteria is suitable for assessing by a written report, the assignment may be assessed using an oral presentation where photographs, diagrams and samples should be used.

To achieve distinction criterion D1 learners need to analyse post-weld heat treatment processes and discuss the advantages and disadvantages. This will combine the knowledge gained in P1 to P7 as this will depend upon the materials, welding process and the heat input.

Assessment of D2 could be in the form of a written task though this may be better assessed as part of the oral presentation suggested for the assessment of P10. Learners would be expected to demonstrate their knowledge of not only the applications and operation of the weld testing technique, but also that of the quality standards and welding process used.

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	Welding Processes	An assessment based on learners' knowledge and investigations into the physical features of welding processes.	This assessment will use a written report and oral questions to assess learners' knowledge across a range of welding processes. Learners will need sufficient knowledge to select appropriate processes for given applications. They will also need to know the physical features of those processes. Learners will need to explain welding processes in terms of how the heat is input, and how the fusion of the material takes place to produce the weld.
P5, P6, P7, M2, D1	The Effects of Welding	This assessment requires the learner to investigate and report on the effects of welding in terms of controlling distortion, the grain structure and the heat treatment of materials.	A written assessment based on joints or components that the learner has investigated in the workshop, these may have been produced by the learner, or commercially produced. Those learners who are employed may benefit from applying procedures used in the workplace. The effects of welding should be considered in context with the welding process used. The learner may also explain the effects of welding and analyse these effects further.
P8, M3	Weldability of Metals	An assessment that focuses on the weldability of materials. Learners will report on their research and tutor-led activities.	This written assessment considers the factors that affect the weldability of a material and the effect of impurities on the welded material. An opportunity is given to explain the effect of impurities on a welded joint.

Criteria covered	Assignment title	Scenario	Assessment method
P9, P10, D2	Weld Testing and Quality Standards	This assessment reports on the findings of practical investigations when working to quality standards applicable to weld testing.	This may be assessed in the form of a written report, but would be better assessed by oral presentation (which may utilise ICT to produce a visual presentation). The learner should present a test procedure that has been produced to identify weld defects. Learners should also present information on their use of weld testing techniques and the defects found, comparing them to relevant quality standards.

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
	Application of Welding Processes	Fabrication Processes and Technology
		Applications of Welding Technology

Essential resources

Centres will require access to welding equipment to allow learners to observe at least one welding process. Weld testing facilities will be required for visual examination and at least one destructive and one non-destructive test. Centres will need samples which are commercially produced which use a range of welding processes.

Employer engagement and vocational contexts

The materials and processes used when delivering this unit should reflect the context of the learners' workplace, or may be based on case studies of local employers. Learners may benefit from industrial visits to provide an understanding of welding processes in an industrial context, and to appreciate the range of processes and materials used in industry.

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

Davies A – *Science and Practice of Welding, Volume 1* (Cambridge University Press, 1993) ISBN 9780521435659

Davies A – *Science and Practice of Welding, Volume 2* (Cambridge university Press, 1993) ISBN 9780521435659

Smith B – *Welding Practice* (Arnold, 1995) ISBN 9780340614068

Timings R – *Fabrication and Welding Engineering* (Newnes, 2008) ISBN 978075066916

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	analysing and evaluating information when determining defects in welded components
Self-managers	organising time and resources when using welding testing processes procedures for detecting weld defects.

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 ...
Independent enquirers	carrying out extended independent learning activities during the research of topics
Creative thinkers	planning investigative activities, both formative and summative, and when producing oral presentations.

Functional Skills – Level 2

Skill	When learners are ...
ICT – Find and select information	
Access, search for, select and use ICT-based information and evaluate its fitness for purpose	using computer-based information during investigative activities and researching information
ICT – Develop, present and communicate information	
Present information in ways that are fit for purpose and audience	when writing a test procedure and in the production of visual presentations
English	
Speaking and listening – make a range of contributions to discussions and make effective presentations in a wide range of contexts	speaking and listening to peers and tutors during investigative and research activities
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	selecting, reading and using research and standards during the production of assessments
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	note taking and preparing written information to describe and explain the effects of heat input during welding and producing a test procedure.