



Government of **Western Australia**  
Department of **Training**  
and **Workforce Development**

# BASIC MANUAL METAL ARC WELDING (MMAW)

Learning Resource

Metals and Engineering



**ENG722**

ENG722

Basic Manual Metal Arc Welding  
(MMAW)

Learning Resource

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# Chapter 1 – Arc welding safety

## Introduction

To achieve safe working conditions in the metal fabrication and welding industry, all personnel should be able to recognise the hazards which apply to their particular occupation. Welding operators must also know the correct operating procedures for the equipment.

An operator can be subjected to many safety hazards associated with the industry. As with any other industrial worker, they may be injured through incorrect lifting practices, falling or tripping, or incorrect use of hand tools and machines. The operator will also encounter particular hazards associated with welding.

A clean, tidy workplace, free from combustible materials, is an essential requirement for the safety of welding personnel.

Additionally, others working in the vicinity of welding operations are at risk from hazards such as electrocution, fumes, radiation, burns or flying slag and noise. They too must be protected if their health and safety is not to be put at risk.

In this chapter you will look at the following.

- Types of hazards
  - electric shock
  - fumes
  - radiation
  - fire and explosion
  - burns
- Personal protective equipment (ppe)
- The working environment
  - confined spaces/hazardous locations
  - cutting or welding in or near hazardous locations
  - working on tanks and containers
- First aid for operators
  - basic objectives
  - basic immediate first aid for some common operator injuries.



## Types of hazards

The major hazards associated with arc welding are:

- electric shock



Fig 1.1 – Electric shock

- fumes

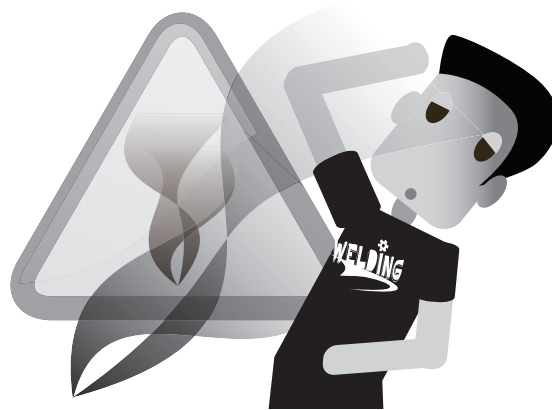
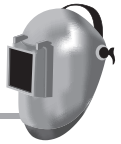


Fig 1.2 – Fumes





- radiation



Fig 1.3 – Radiation

- fire and explosion



Fig 1.4. – Fire and explosion

- burns.

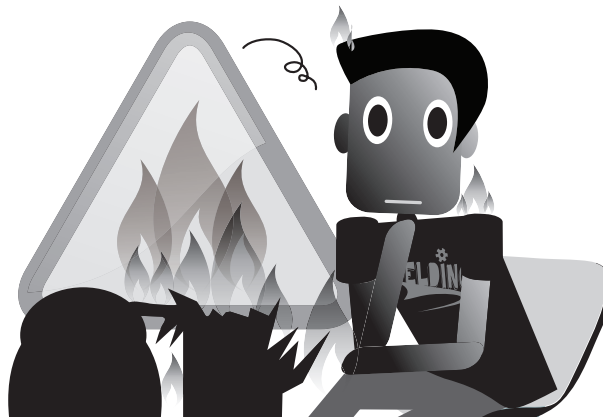


Fig 1.5. – Burns



## Electric shock

Electrical principles and requirements for arc welding machines will be discussed in depth in Chapter 2 – Electricity and welding machines, however at this stage it is necessary to clarify some basic electrical terms.



Term	Definition
voltage (V)	the force which makes current flow voltage is essentially electrical pressure
current (A)	the flow of electrons and is measured in amperes
open circuit voltage (OCV)	the voltage between welding terminals when the machine is switched on but welding is not in progress
resistance	the hindrance of a conductor to the passage of current, ie a force which opposes the flow of electricity
conductor	a material that permits the easy flow of electricity
insulator	a material that will not convey an electric current

Electric shock may only cause a minor tingling sensation or it may cause muscle spasms, or paralysis and this may cause an operator to grip onto the source of electricity. In the worst case scenario this may contribute to the welding operator's death.

In arc welding processes a number of potential electrocution sources can be identified.

The primary input lead is either 415 V or 240 V and should never be tampered with, altered, or repaired except by a licensed electrician. The output circuit of an arc welder is controlled at a 'safe voltage' but this safe voltage can also kill if given ideal conditions. The ancillary circuits of most welders are also at a safe voltage of either 32 V or 24 V, although some machine manufacturers also use 110 V on older control circuits.





The prevention of electrical shock from welding equipment relies on three major principles.

<p>1. That the OCV of welding machines is low enough to prevent easy passage of current through the body.</p>	<p>Although arc welding machines are capable of supplying a wide range of current, they generally operate within the following voltage range: Arc voltage: 16–36 V To maximise safety for the welding operator, OCV is restricted to: Maximum OCV for AC machines is 80 V Maximum OCV for DC machines is 110 V</p>
<p>2. That electrical resistance in the welding circuit is low. The current will take the path of least resistance.</p>	<p>Maintain insulation on leads and handpiece Avoid moisture and use insulating gloves</p>
<p>3. That the current path is confined to the welding circuit.</p>	<p>Don't touch live parts Don't put body in current path</p>

However, even with these limitations severe electric shock is still possible. The following factors will influence the severity of electrical shock.

<p><b>The amount of current passing through the body</b> Increased voltage will result in greater current flow. Even quite low voltages can be dangerous where resistance is low.</p>
<p><b>The direction of the current flow</b> If the current path is via vital organs then the risk of serious injury is much greater.</p>
<p><b>The body resistance</b> The body is a semi-conductor and dry skin acts as an insulator that naturally resists the flow of current. Moist skin in contact areas, and contact over large areas increases the chance of electric shock.</p>
<p><b>The duration of the current flow</b> A longer exposure to electric current means a greater risk of consequence.</p>
<p><b>The state of health of the person receiving the shock</b> A healthy person will better resist the effects of electric shock. The phase of the heart cycle at the instant the shock occurs will also influence the severity of electric shock.</p>



To avoid electric shock, the following practices are highly recommended.



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**Fig 1.5.1**

Dry gloves in good repair should be worn when handling equipment, particularly when changing electrodes.



BOC Limited © 2006

**Fig 1.5.2**

Footwear should be insulating, dry, and in good condition.

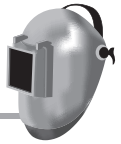


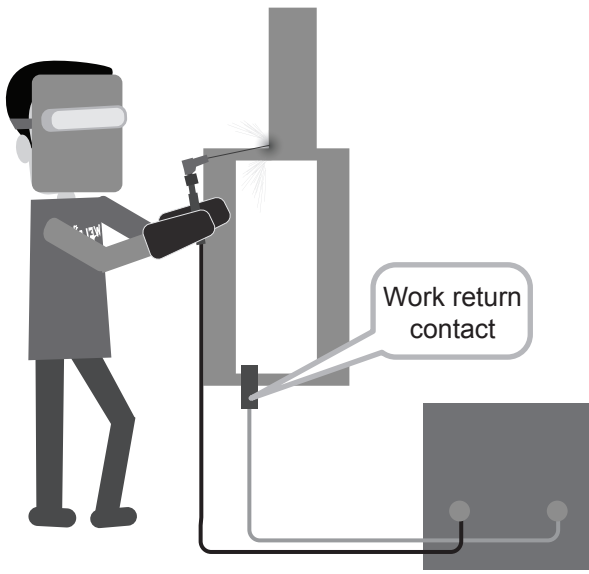

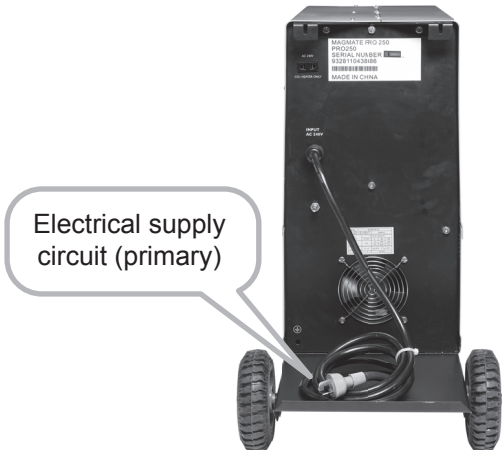
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**Fig 1.5.3**

Welding equipment should be in good repair and fully insulated.





 <p>Work return contact</p> <p>Current flow through the shortest pathway</p> <p><b>Fig 1.5.4</b></p>	<p>Work return contact points should be close to the site of welding and be carefully selected.</p>
 <p>BOC Limited © 2006</p> <p><b>Fig 1.5.5</b></p>	<p>All connections should be clean and tight.</p>
 <p>Electrical supply circuit (primary)</p> <p>BOC Limited © 2006</p> <p><b>Fig 1.5.6</b></p>	<p>Electrical supply circuits (primary) should be kept as short as possible and be serviced only by electrical tradespersons.</p>

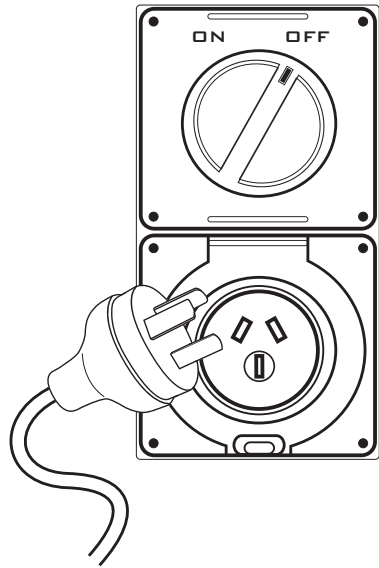


Fig 1.5.7

Machines should be switched OFF and unplugged when changing leads or carrying out maintenance.

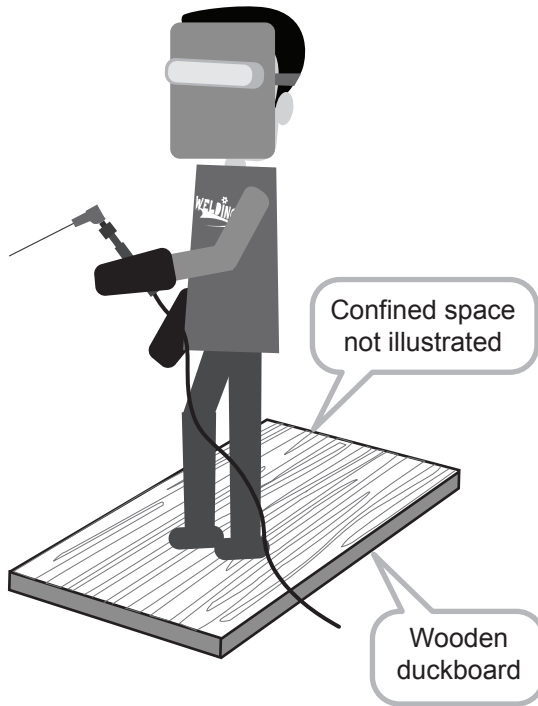
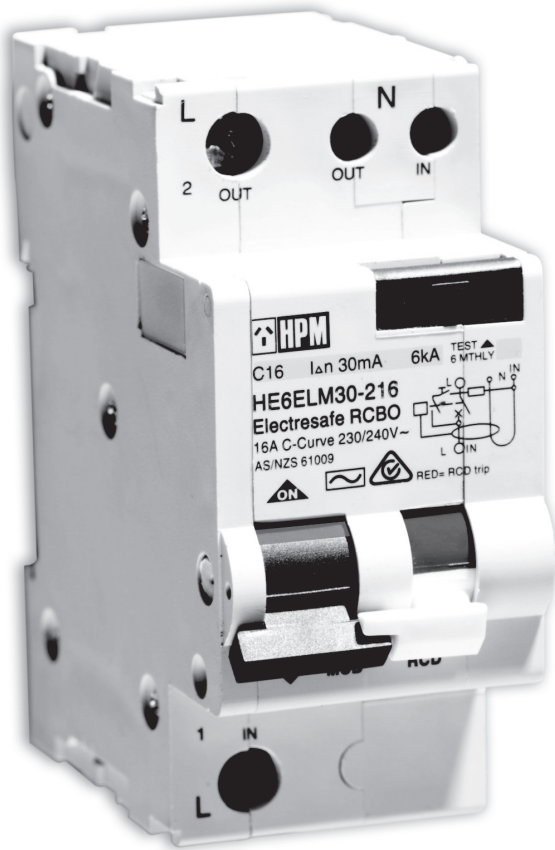
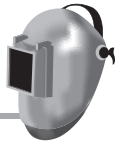


Fig 1.5.8

Dry insulating material should be used in confined spaces; wooden boards or rubber mats are ideal.





Photograph courtesy of HPM Industries Pty Ltd

**Fig 1.5.9**

When working in a confined space or in wet or moist conditions, electrodes should not be left in the holder and the power should be isolated when electrodes are being changed.



**Fig 1.5.10**

Remember, sweating decreases body resistance. Therefore, be extra careful when welding under hot conditions.

**Fig 1.5 – To avoid electric shock (1–10)**



## Fumes

Fumes are produced in all welding and cutting operations. They are a mixture of:

- atmospheric gases
- arc shielding gases
- vaporised elements from the parent metal, metal coatings, or flux coated welding consumables
- airborne particles small enough to be inhaled.

Welding fumes are normally at levels low enough to pose no great health risk. However, when fume concentration is excessive the operator will be deprived of the oxygen needed to maintain good health. Fumes of highly toxic metals, even in low concentrations, may also cause health problems with respect to the upper respiratory tract, lungs, blood, liver, kidneys and central nervous system.

Certain substances found in welding fumes are recognised as being particularly dangerous, even in very low concentrations. Welding operators should be aware of the dangers associated with metals such as beryllium, cadmium, zinc and lead.

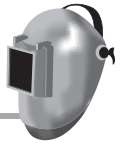
Table 1.1 gives an indication of the toxicity of some of the metals more commonly encountered by welding operators.

<b>Metal</b>	<b>Effect</b>	<b>Typical fume source</b>	<b>Ventilation</b>
beryllium	A highly toxic, quick acting poison. A carcinogen	copper based bearing alloys casting alloys	glove box, fresh air supply
cadmium	A highly toxic carcinogen. Causes heart, lung, kidney damage	silver brazing alloys surface coatings	glove box, fresh air supply
chromium	A carcinogen. Causes lung and skin disease, nasal irritation	chromium alloys stainless steel electroplating	local exhaust
lead	Causes fatigue, nerve and kidney damage and high blood pressure	copper base castings lead based paints free machining steels	local exhaust
copper	An irritant to nose and throat. Causes metal fume fever	copper alloys and castings	local exhaust
nickel	Causes skin and respiratory irritation and kidney damage. A carcinogen	nickel alloys stainless steel	local exhaust
zinc	Causes metal fume fever	surface coatings bronze and brass	local exhaust
aluminium	Causes irritation to nose and throat and chronic bronchitis	plates, castings extrusions	local exhaust

Table 1.1 – Toxicity of some common metals







Any toxic material that is used in a workshop must be accompanied by a material safety data sheet (MSDS) and these should be held in a secure but accessible location. A sample MSDS for chromium, which is a common alloying material, is shown on the next page.



**Material safety data sheet (MSDS) for CHROMIUM**

**1 PRODUCT IDENTIFICATION**

PRODUCT NAME: CHROMIUM  
FORMULA: CR  
FORMULA WT: 52.00  
CAS NO.: 7440-47-3  
NIOSH/RTECS NO.: CB4200000  
PRODUCT CODES: 4961  
EFFECTIVE: 09/10/86  
REVISION #03  
  
PRECAUTIONARY LABELLING: BAKER SAF-T-DATA™ SYSTEM

HEALTH - 0 NONE  
FLAMMABILITY - 0 NONE  
REACTIVITY - 0 NONE  
CONTACT - 0 NONE

HAZARD RATINGS ARE 0 TO 4 (0 = NO HAZARD; 4 = EXTREME HAZARD).

**LABORATORY PROTECTIVE EQUIPMENT**

SAFETY GLASSES; LAB COAT

**PRECAUTIONARY LABEL STATEMENTS**

DURING USE AVOID CONTACT WITH EYES, SKIN, CLOTHING. WASH THOROUGHLY AFTERHANDLING. WHEN NOT IN USE KEEP IN TIGHTLY CLOSED CONTAINER.

SAF-T-DATA™ STORAGE COLOR CODE: ORANGE (GENERAL STORAGE)

**2 HAZARDOUS COMPONENTS**

COMPONENT	%	CAS NO.
CHROMIUM	90-100	7440-47-3





### 3 PHYSICAL DATA

BOILING POINT: 2200 °C (3992 °F)	VAPOUR PRESSURE (MM HG):	N/A
MELTING POINT: 1900 °C (3452 °F)	VAPOUR DENSITY (AIR=1):	N/A
SPECIFIC GRAVITY: 7.14 (H <sub>2</sub> O=1)	EVAPORATION RATE: (BUTYL ACETATE=1)	N/A
SOLUBILITY (H <sub>2</sub> O):	NEGLIGIBLE (LESS THAN 0.1%)	
% VOLATILES BY VOLUME:	0	
APPEARANCE & ODOUR:	STEEL GREY TO SILVER PELLETS.	

### 4 FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (CLOSED CUP) N/A

FLAMMABLE LIMITS: UPPER - N/A % LOWER - N/A %

FIRE EXTINGUISHING MEDIA

USE WATER SPRAY, ALCOHOL FOAM, DRY CHEMICAL OR CARBON DIOXIDE.

SPECIAL FIRE-FIGHTING PROCEDURES

FIREFIGHTERS SHOULD WEAR PROPER PROTECTIVE EQUIPMENT AND SELF-CONTAINED BREATHING APPARATUS WITH FULL FACEPIECE OPERATED IN POSITIVE PRESSURE MODE. MOVE CONTAINERS FROM FIRE AREA IF IT CAN BE DONE WITHOUT RISK. USE WATER TO KEEP FIRE-EXPOSED CONTAINERS COOL.

UNUSUAL FIRE & EXPLOSION HAZARDS

CAN BE AN EXPLOSION HAZARD, ESPECIALLY WHEN HEATED.

### 5 HEALTH HAZARD DATA

NOTE: WHILE THE SPECIFIC COMPOUNDS CANNOT BE IDENTIFIED, THERE IS EVIDENCE THAT CERTAIN CHROMIUM COMPOUNDS CAUSE CANCER IN HUMANS AND EXPERIMENTAL ANIMALS. CHROMIUM IS WIDELY DISTRIBUTED IN AIR, WATER, SOIL AND FOOD. TRIVALENT CHROMIUM MAY BE AN ESSENTIAL TRACE INGREDIENT IN THE HUMAN DIET. ALL CHROMIUM COMPOUNDS ARE REGULATED BY THE EPA, BUT NO SPECIFIC DATA IS AVAILABLE TO LINK TRIVALENT CHROMIUM TO CANCER. PRUDENT JUDGEMENT DICTATES THAT EXPOSURE SHOULD BE MINIMISED AS MUCH AS POSSIBLE.

(SEE IARC MONOGRAPH ON EVALUATION OF CARCINOGENIC RISK OF CHEMICALS TO HUMANS, VOLUME 23 LYON, FRANCE IARC, 1980, PP. 205-323).

THRESHOLD LIMIT VALUE (TLV/TWA): 0.5 MG/M3 (PPM)

PERMISSIBLE EXPOSURE LIMIT (PEL): 1 MG/M3 (PPM)

CARCINOGENICITY: NTP: YES IARC: YES Z LIST: NO OSHA REG: NO



EFFECTS OF OVER EXPOSURE

CONTACT WITH SKIN OR EYES MAY CAUSE SEVERE IRRITATION OR BURNS.

DUST MAY ULCERATE MUCOUS MEMBRANES. EXCESSIVE INHALATION OF DUST IS IRRITATING AND MAY BE SEVERELY DAMAGING TO RESPIRATORY PASSAGES AND/OR LUNGS. INGESTION MAY RESULT IN SEVERE INTESTINAL IRRITATION WITH BURNS TO MOUTH.

**NOTE:** PRODUCT IS A SOLID MASS; HOWEVER, WARNINGS ARE BASED ON INHALATION DUST, MIST OR FUME EMISSIONS THAT ARE POSSIBLE DURING MANUFACTURING OR CHEMICAL REACTIONS.

TARGET ORGANS

RESPIRATORY SYSTEM

MEDICAL CONDITIONS GENERALLY AGGRAVATED BY EXPOSURE NONE IDENTIFIED

ROUTES OF ENTRY

INGESTION, INHALATION

**EMERGENCY AND FIRST AID PROCEDURES**

INGESTION: IF SWALLOWED AND THE PERSON IS CONSCIOUS, IMMEDIATELY GIVE LARGE AMOUNTS OF WATER. GET MEDICAL ATTENTION.

INHALATION: IF A PERSON BREATHE IN LARGE AMOUNTS, MOVE THE EXPOSED PERSON TO FRESH AIR. GET MEDICAL ATTENTION.

EYE CONTACT: IMMEDIATELY FLUSH WITH PLENTY OF WATER FOR AT LEAST 15 MINUTES. GET MEDICAL ATTENTION.

SKIN CONTACT: IMMEDIATELY WASH WITH PLENTY OF SOAP AND WATER FOR AT LEAST 15 MINUTES.

**6 REACTIVITY DATA**

STABILITY: STABLE

HAZARDOUS POLYMERISATION: WILL NOT OCCUR

CONDITIONS TO AVOID: FLAME

INCOMPATIBLES: CARBONATES, STRONG BASES,  
MINERAL ACIDS

**7 SPILL AND DISPOSAL PROCEDURES**

STEPS TO BE TAKEN IN THE EVENT OF A SPILL OR DISCHARGE

WEAR SUITABLE PROTECTIVE CLOTHING. CAREFULLY SWEEP UP AND REMOVE.

DISPOSAL PROCEDURE

DISPOSE IN ACCORDANCE WITH ALL APPLICABLE FEDERAL, STATE, AND LOCAL ENVIRONMENTAL REGULATIONS.

EPA HAZARDOUS WASTE NUMBER: D007 (EP TOXIC WASTE)





### 8 PROTECTIVE EQUIPMENT

VENTILATION: USE ADEQUATE GENERAL OR LOCAL EXHAUST VENTILATION TO KEEP FUME OR DUST LEVELS AS LOW AS POSSIBLE.

RESPIRATORY PROTECTION: A RESPIRATOR WITH DUST/MIST FILTER IS RECOMMENDED. IF AIRBORNE CONCENTRATION EXCEEDS TLV, A SELF-CONTAINED BREATHING APPARATUS IS ADVISED.

EYE/SKIN PROTECTION: SAFETY GLASSES WITH SIDE SHIELDS, PROPER GLOVES ARE RECOMMENDED.

### 9 STORAGE AND HANDLING PRECAUTIONS

SAF-T-DATA™ STORAGE COLOR CODE: ORANGE (GENERAL STORAGE)

SPECIAL PRECAUTIONS

KEEP CONTAINER TIGHTLY CLOSED. SUITABLE FOR ANY GENERAL CHEMICAL STORAGE AREA.

### 10 TRANSPORTATION DATA AND ADDITIONAL INFORMATION

DOMESTIC (DOT)

PROPER SHIPPING NAME            CHROMIUM

HAZARD CLASS                    ORM-E

LABELS                            NONE

REPORTABLE QUANTITY            1 LBS

INTERNATIONAL (IMO)

PROPER SHIPPING NAME            CHEMICALS, NOS (NON-REGULATED)

Reference: West Virginia Toxics Release Inventory Database Search //gis.wvdep.org/tri/cheminfo/msds452.txt



### Control of fumes

To ensure that the concentration of fumes and exposure to fumes is within safe limits, various controls can be applied.

Substitution	Where practicable, a less dangerous material, consumable, process or procedure can be substituted.
Limiting the period of exposure	Limiting the time any one operator is exposed to excessive fume concentration is not the most desirable method, but in some cases may be the only practical solution.
Work methods	Good housekeeping and work practices can avoid the unnecessary generation and exposure to fumes. For example, removing surface contaminants from parent material prior to welding or cutting. It should be noted that certain degreasing agents decompose under heat and ultraviolet radiation to give off toxic fumes.
Ventilation	This is the most common method of control and can be achieved by various means.

### Types of ventilation

- Natural ventilation – in the greater majority of workshops and open sites, the natural flow of air through open plan layouts and natural breeze is sufficient to disperse fume concentrations.
- General exhaust ventilation – this method is often used where the workshop does not have adequate natural ventilation. Fumes rise and are dispersed into the atmosphere, generally through ceiling exhaust fans.
- Local exhaust ventilation – this method collects fumes at its source and directs them away from the work area. The suction inlet should be as close as possible to the source. There are various types of local exhaust systems, each offering certain advantages and suited to certain applications.
- Local dispersion ventilation – in some cases, suitable ventilation can be obtained locally by fans which deflect and disperse the fumes away from the operator.

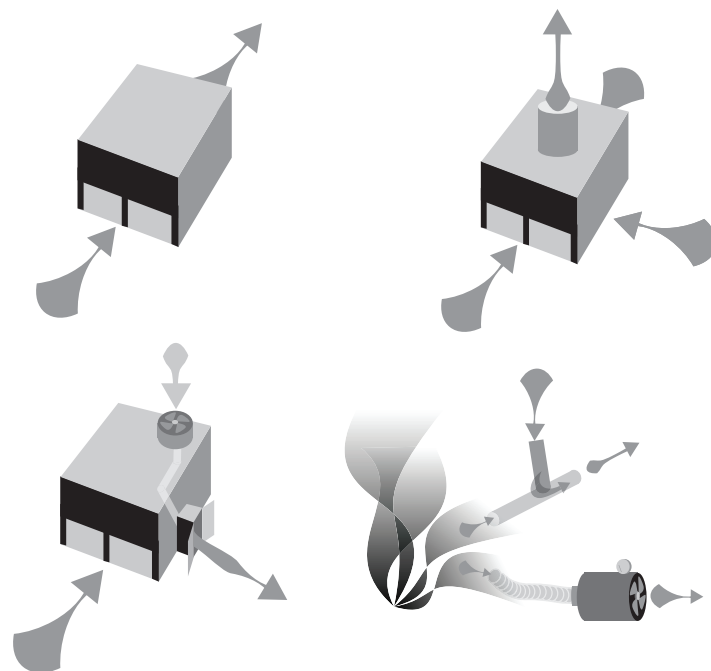


Fig 1.6 – Ventilation types for welding



## Personal respiratory protection

In special situations where general or local ventilation systems are not effective or convenient in reducing fume levels, you may use personal respiratory protection by one of the following methods. These comply with Australian Standards® AS/NZS 1716 Respiratory protective devices.

- Hose mask respiration method, which is a full-face piece fitted with a length of relatively large bore air hose drawing from a clean source by the normal breathing action of the wearer.
- Airline respiration which may comprise a full-face piece, half-face piece, hood or helmet type. Clean air is supplied at a suitable pressure from a remote source.
- Self-contained breathing apparatus using a cylinder of compressed air. This equipment is not dependant on an air compressor which may be subject to failure and is recommended for use in confined spaces.
- Dust respirator which may consist of a full-face, or half-face mask fitted with the correct filter cartridge.



These provide protection only against fume particles and not against gases.

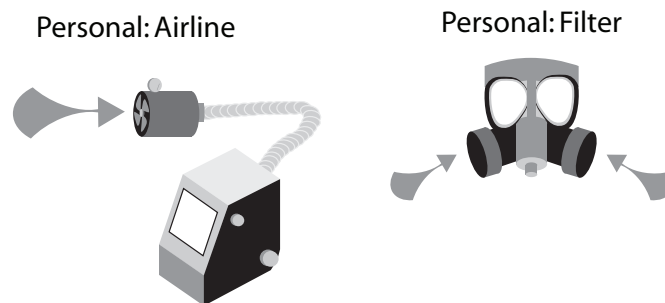


Fig 1.7 – Local dispersion ventilation

## Radiation

### Types of radiation

Three types of radiation are emitted by arc welding processes: visible, infra-red and ultraviolet. The first two types are also emitted from flames in gas welding and cutting.

- Visible radiation – exposure to high intensity visible radiation may result in ‘dazzle’ with temporary loss of vision. There is no long-term or permanent damage to the eyes.
- Infra-red radiation – this radiation acts in the same manner as exposure to heat, producing burns. Permanent damage is unlikely, but the heat adds to discomfort. Infra-red radiation can damage the unprotected internal structure of the eye, such as the iris, the lens and the retina. In severe cases of repeated exposure to luminous infra-red, eye cataracts can be produced.
- Ultraviolet radiation – ultraviolet is the most common and powerful radiation hazard in welding. This radiation attacks the eyes and exposed skin.



Brief exposure can produce an inflammation of the cornea of the eye resulting in a condition known as 'arc eye' or 'welding flash'. The symptoms of arc eye do not appear until several hours after the exposure (similar to sunburn). Pain, watering of eyes, and photophobia (intolerance to light) occur. These symptoms may last several days in severe cases, but generally subside leaving no permanent or residual damage.

Prolonged exposure to ultraviolet light can cause permanent damage to eyes and skin in the form of impaired vision, cataracts and skin cancer.

The amount of ultraviolet radiation emitted from the arc depends on several factors (the welding process, the type of electrode, the amperage, and the arc length).

High current density welding processes such as the tungsten inert gas and gas metal arc processes, in particular, emit powerful ultraviolet radiation.

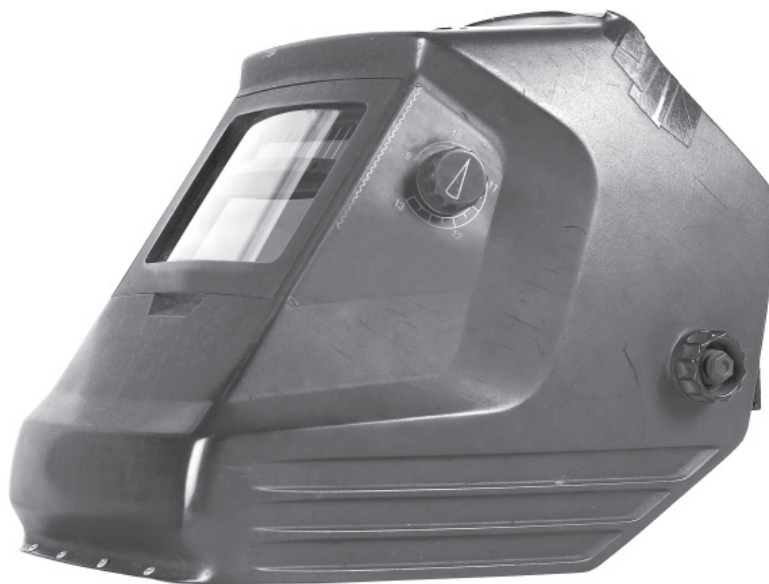


It is most important to realise that all three radiation types can be reflected from shiny surfaces – such as the underside of galvanised roofs, plates, or painted screens.

## Protection from radiation

### Personal protection

Protection is needed for both the eyes and skin. For arc welding, a suitable welding helmet or face shield, fitted with the recommended filter for the job in hand, is necessary.



Photograph © 2007 JupiterImages Corporation

**Fig 1.8 – Welding helmet**







Recommended filters for manual metal arc welding (MMAW) are given in table 1.2.

Recommended filters for MMAW	
Amperage	Shade No.
Up to 100	8
100–200	10
200–300	11
400–500	12
Over 400	13

Based on AS/NZS 1338.1: 1992 – Table A2 ([www.saiglobal.com](http://www.saiglobal.com))

**Table 1.2 – Recommended filters for MMAW**

For more detailed and current information refer to AS/NZS 1338.1:1992 for electric welding.



Higher current density/open arc processes such as GTAW or GMAW require darker shade lenses for the same current.

For gas welding and cutting, the use of protective goggles fitted with the recommended shade 5 filter, is essential. Clear safety spectacles give only limited protection from stray radiation, however spectacles fitted with lenses not less than 2 mm thick incorporating a shade filter of up to 2.5 are highly desirable to give protection from stray arc welding flashes. In order to protect the skin from radiation it is essential that suitable clothing is worn to cover all areas which could be exposed. Woollen materials have much greater resistance to ultraviolet radiation than synthetic and plain cotton materials which can rapidly deteriorate or rot when exposed to strong ultraviolet radiation. Leather aprons, sleeves, jackets and gloves are usually required in welding processes where strong radiation is emitted.

Where reflection is likely, for example in welding on highly reflective metals such as aluminium or stainless steel, protection for the eyes and skin against indirect radiation is required.

### Protection of others from radiation

Adequate protection should be provided for all personnel within 12 metres of an open arc or gas flame. Suitable screens (either fixed or portable) are desirable. These screens and surrounding walls or partitions should have a matt finish and dull colours in order to reduce reflection.

Personnel working near welders should wear safety spectacles complying with the requirements of Australian Standards® AS/NZS 1336:1997 Recommended practices for occupational eye protection.



## Fire and explosion

Oxy-acetylene flame cutting and welding operations are a major cause of industrial explosions and fires. Each year losses amounting to several million dollars and loss of life or severe injury result from fire caused by welding and cutting operations. The safety requirements depend largely upon the processes being used and the location of the work being carried out. Protection against fire and explosion should comply with statutory regulations covering prevention and comply with the requirements of Australian Standards® AS 1674.1 Safety in welding and allied processes – Fire precautions.

### Sources of fire

The temperature of the arc (or flame) of welding and cutting is sufficient to cause the combustion of many materials. Solid materials such as wood, wood-based products, paper, synthetic materials, liquid materials such as paint and oil, and grease-soaked materials, have a low ignition temperature and will readily ignite through direct contact with the arc or flame. Ignition will also occur by contact with metal offcuts, electrode stubs and spatter. Such materials should be cleared away from any welding or cutting areas, as hot particles lodged amongst them may initially produce smouldering and then fire.

When considering the area affected by cutting and welding sparks, account should be taken of the process and the job situation. Cutting and gouging can produce high speed particles travelling long distances (up to 10 metres in the flat), and hot particles falling from a high workstation will travel further than normal, as illustrated in Fig 1.9.

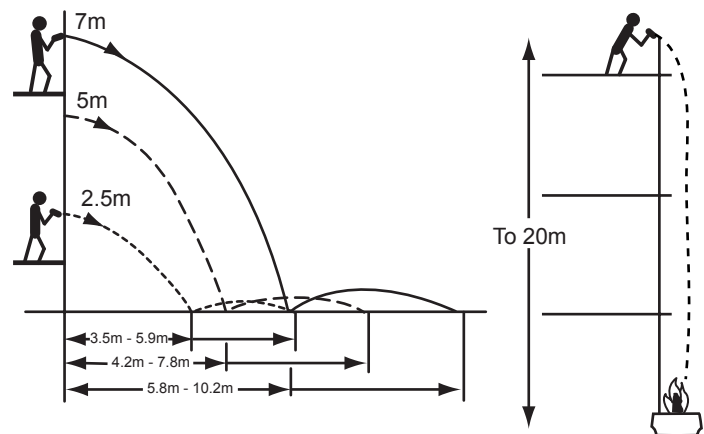


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**Fig 1.9 – Typical travel distances for hot or molten metal particles in cutting or welding**

### Causes of explosion

The risk of explosion is always present when welding or cutting. These processes may project hot sparks into an atmosphere containing flammable gases, liquids or solids. Non-volatile oils or solids which do not produce flammable gases at atmospheric temperatures may produce flammable or explosive gases when exposed to heat from welding or cutting. Drums, fuel tanks and other containers pose a particular hazard to the safety of the welding operator, and no cutting or welding should be carried out until all precautions have been carried out and the job has been made safe.



Fire and explosions become greater hazards in situations where flammable gases and liquids are present. In the ordinary workshop, operators should be aware of normal fire precautions.

### Prevention of fire and explosion

- Maintain clean and tidy work areas, free from accumulations of combustible materials.
- Check that work introduced for cutting or welding does not constitute a fire or explosion hazard.
- Ensure that screens, aids, and building fittings are not constructed from flammable materials.
- Ensure that personal clothing is sound and made from suitable materials.
- Store flammable substances and gases in a safe area or separate building.
- Be aware of fire extinguisher locations and how to operate each type.
- Avoid oxygen enrichment of clothing or work space, which may be caused by leaking oxygen valves.

### Burns

Because welding and cutting is associated with intense heat, the operator is always in danger of receiving painful burns.

Burns are classified in terms of their extent and depth. The extent of a burn is described by calculating the burned area as a percentage of total skin area. The depth of a burn is described by degree:

- superficial burn – produces reddening of the skin (first degree)
- intermediate burn – produces blistering (second degree)
- severe burn – extends below the surface of the skin and causes injury to underlying tissues (third degree).

In welding and cutting operations, burns can result from:

- ultraviolet and infra-red radiation
- contact with slag, sparks and hot particles
- contact with hot work or heat radiated from work
- electrical leakage, in particular, leakage from high-frequency devices
- fire and explosions.

### Protection from burns

- Use tongs to handle hot metal.
- Make provision for disposal of hot metal and electrode stubs.
- Wear all the necessary protective clothing.
- Protective clothing must be non-flammable, and free from oil, grease, tears, and fraying.



## Personal protective equipment (PPE)

Arc welding, like most welding processes, requires operators to protect themselves from the radiated heat and rays associated with the process.

Perhaps the most efficient way of doing this is by the wearing of protective clothing. The use of all protective clothing is dictated by the nature of the work and the comfort of the operator.

Ideally, clothing for the operator should consist of:

- long-sleeved cotton shirt
- sleeves rolled down and buttoned
- strong trousers without cuffs
- strong leather shoes or work boots
- aprons
- gloves
- spats (leather)
- caps
- leather capes or jackets.



Fig 1.10 – Dressed for safety





Always take care to check clothing for frayed edges, torn areas and open pockets where sparks can lodge and start burning. Work clothes should also be free of oil or grease. This may be difficult in some workshops, but a spare pair of clean overalls could be left at work specifically for welding operations.

## The working environment

There are work situations which present increased hazards to the health and safety of the welding operator. These are:

- confined spaces
- hazardous locations
- working on tanks and containers.

### Confined spaces/hazardous locations

Working in confined spaces usually entails difficult access and cramped conditions. The workplace is often poorly ventilated, and the welder is often completely surrounded by a conductor which forms part of the welding circuit. Under these circumstances the welding operator is at increased risk from:

- a build-up of fumes
- electric shock.

The possibility of a build-up of dangerous fumes whilst welding in a confined space must be allowed for and adequate ventilation be provided through:

- exhaust fans
- an additional supplementary air supply.

The possibility of an electric shock is greater because the operator can easily make contact with the job, and awkward and enclosed workplaces often lead to higher levels of perspiration.

The operator should keep themselves as dry as possible and use the necessary protective clothing to prevent electrocution. Additionally:

- an all-insulated electrode holder should be used
- high-frequency attachments should not be used
- portable electric lamps exceeding 32 V supply should not be used. Electronic leakage breakers (ELB) devices are acceptable.

Provision must be made, close to the work area, for the power to be switched off by an assistant when:

- the welder is not prepared for welding
- the electrode is being changed
- the operator leaves the job.



### Confined space regulations

The following regulations are specified as mandatory when working in a confined space.

- Adequate ventilation must be provided.
- A lifeline must be attached.
- A semi-skilled operator who is trained in rescue and resuscitation must be stationed at the manhole to monitor the work space at all times; to adjust oxy-acetylene gear and the welding machine, whilst continually observing the operator.
- All leads and hoses are to be kept clear of the floor, dampness and falling metal sparks. Circular vessels must be prevented from rolling.
- General tidiness and care is essential, equipment should not be allowed to contact hot work or sharp objects.
- Oxy-flame cutting equipment should not be left inside the confined space when not in use, and it should always be lit by the assistant outside and then passed to the operator inside.
- Oxygen should never be used for dusting down or any purpose other than for the oxy-flame.

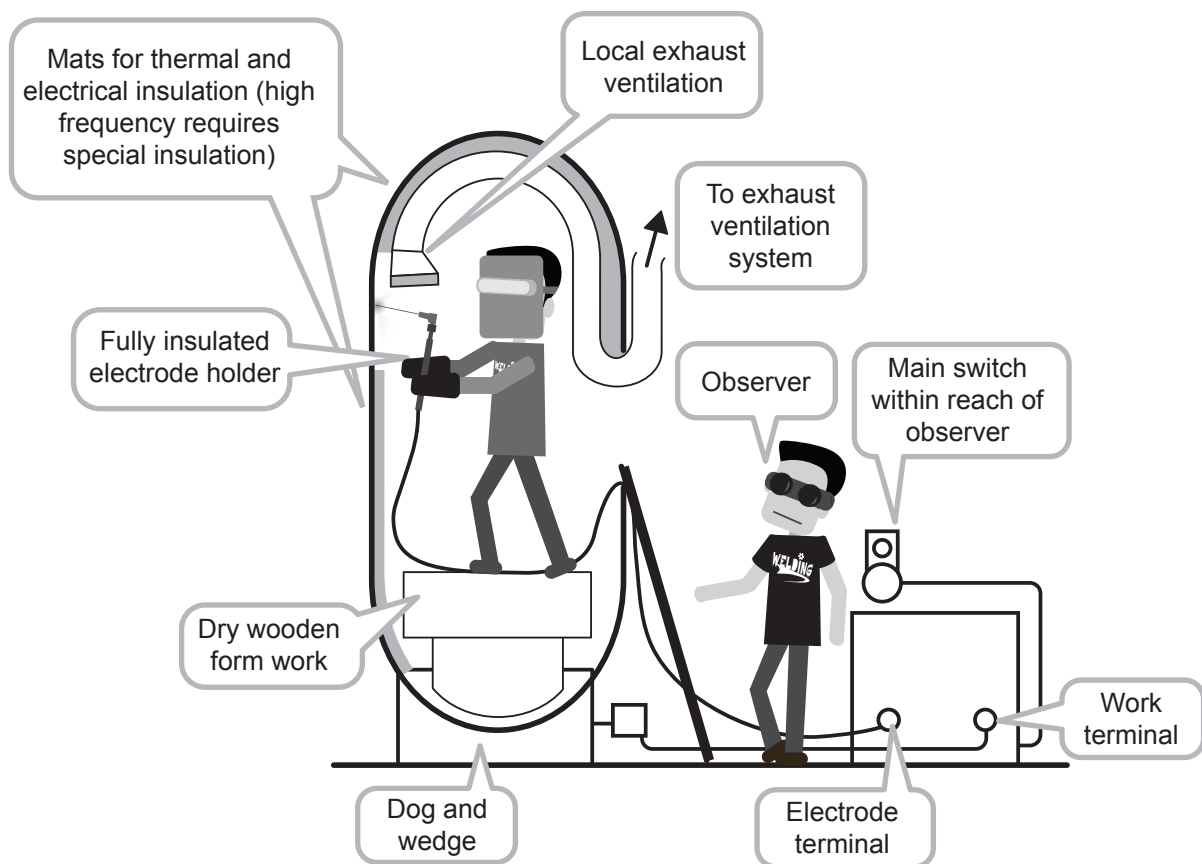


Fig 1.11 – Precautions for welding in confined spaces



### Hazardous locations

Although many workplaces may be described as hazardous, a **hazardous location** is defined as: 'An area where flammable dust, fibres or gases may be present so as to pose a fire or explosion hazard'.

Hazardous locations may be classified into **four main groups** typically, as follows.

1. In locations where flammable liquids are manufactured, used, handled or stored, or where vapours may be present.  
eg refineries, fuel stores  
dry cleaning plants  
spray painting premises  
varnish and paint manufacturing plants.
2. In locations where combustible dust is thrown into suspension in the air and quantities may be sufficient to produce explosive mixtures.  
eg sections of flour mills  
grain elevators  
cocoa and coal pulverising plants  
iron ore or aluminium plants  
metal grinding plants  
charcoal grinding plants.
3. In locations where easily ignitable fibres are produced, handled, used or stored.  
eg cotton or cotton seed mills  
wood working plants  
sections of clothing factories.
4. In any location or part of a ship.

### Cutting or welding in or near hazardous locations

If at all possible, work should be removed from the hazardous locations and carried out to a safe location.

Cutting or welding in or adjacent to hazardous locations should not take place until the following conditions have been established.

- A hot work permit has been obtained.
- Authorisation has been obtained from the responsible officer.
- It is impractical to move the work to a safe area.
- The production of any hazardous or explosive substance has ceased or been excluded from the work area.
- The location has been tested and found to be free from flammable substances.



In general terms the operator's responsibility with respect to hazardous locations can be expressed as follows.

- Always examine work areas for possible hazards.
- Seek authorisation before proceeding with cutting or welding whenever any doubt exists.
- Work must be carried out in accordance with the provisions of the hot work permit.
- Always examine the possibility of removing the work to a safe area.
- Be vigilant in the provision and maintenance of any safety screens, doors or barriers required to ensure safety.
- Be vigilant in the possible entrapment or catching of any sparks, offcuts or electrode butts as provided for in the safety arrangements.
- Always check behind walls, partitions, bulkheads etc, to ensure safety in adjoining areas.
- Take precautions when working in the vicinity of storage batteries as they are liable to explosion, particularly whilst charging.



A fire watch must be maintained for a minimum of one hour after any cutting and welding operations have ceased.

## Working on tanks and containers

### Responsibility for work

When working on tanks or containers the operator should display the same caution as when working in hazardous locations. If there is any possibility that the container may have held petrol, oil or any volatile liquid, special precautions are necessary. Sight and smell are not reliable indicators of the presence of flammable gases as some substances may release them when heated. Doubtful cases should be referred to a qualified person for testing, and subsequent work carried out by an experienced operator under supervision.

### Recommended practice

Where steam is available, this may be used to remove materials which are easily volatile. Washing with strong soda solution or detergents will remove heavier oils.



Chlorinated hydrocarbon solvents must not be used for cleaning prior to welding.

Even after thorough cleansing, the container should, whenever possible, be filled with water before any cutting or welding operation is performed. In most cases it should be possible to place the container in such a position that it can be filled with water to within a short distance from the point where cutting or welding is to be done.







In doing this, however, care should be taken to make sure that there is a vent or opening to provide for the release of heated air from the container. Where it is not possible to fill the container with water, carbon dioxide or nitrogen may be used for added protection. If possible, periodic examination of the air contents of the vessel should be made by means of a detector of combustible gases, where such an instrument is available.

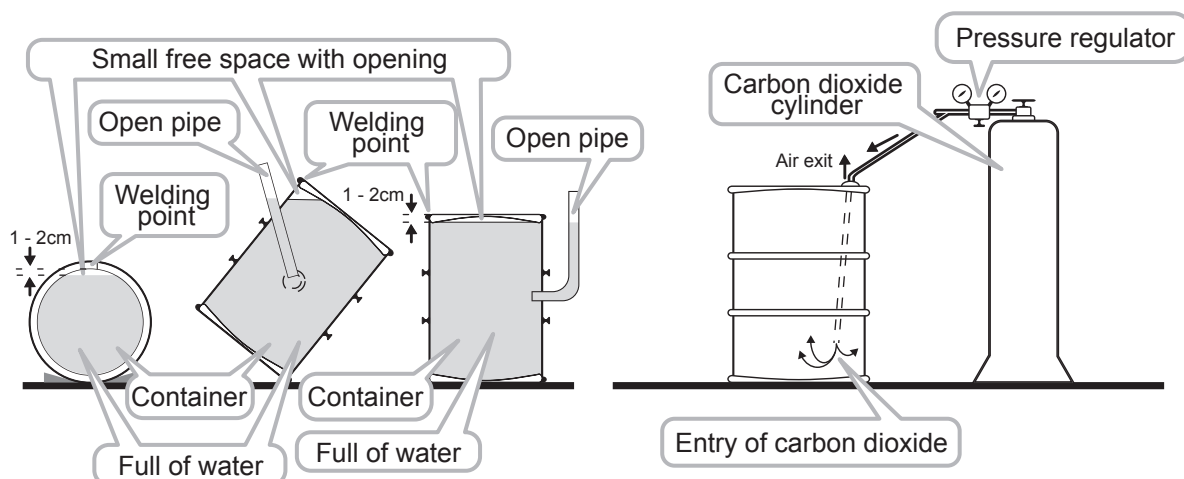


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**Fig 1.12 – Preparation of tanks for welding**

## First aid for operators

### Basic objectives

In the event that a person is injured or suddenly becomes ill, efficient first aid should be carried out as quickly as possible, preferably by trained first aiders. Taken before medical help is available and often at a critical stage, this action can save lives, reduce the severity or worsening of the injury and limit discomfort.

### Essential emergency action

This involves:

- ensuring that there is no danger to the patient or rescuer
- getting the casualty out of any danger zone, without endangering anyone
- giving first aid to the casualty.

For all but minor injury, arrange for medical assistance. If there is little risk in moving the casualty, arrange for transport and for care during transport to a doctor, hospital or nurse. If there is any risk of further injury posed by moving the patient, he/she should not be moved, and qualified medical help should be sought.



## Basic immediate first aid for some common operator injuries

### Welding flash (arc eye)

This is an eye injury caused by exposure to ultraviolet rays.

- In mild cases, add eye-drops and shade the eyes.
- In severe cases, loosely pad both eyes (cold may help) and get the casualty quickly to a doctor.

### Hot particles in the eyes

- Cover BOTH eyes of the victim and take the patient as quickly as possible to a doctor.
- In the case of chemical burns (eg from acids, alkalis or similar liquids) remove the chemicals from the eyes by washing at once with large amounts of running water and flush continuously for up to 20 minutes.
- Urgently seek medical advice.

### Burns (to hand/s and body)

#### Minor burns

Minor burns should be immediately cooled under cold running water, then covered with sterile dressing material. Avoid the use of ointment or powder as these may interfere with any subsequent medical treatment.

#### Major burns

Since urgent action is essential, cool the area with running water quickly and over a long period to remove any residual heat, and get the casualty to hospital as quickly as possible. Keep the casualty covered with a light blanket or other suitable material. Care must be taken to ensure that dressings, blankets, etc will not stick to the wound.

### Electric shocks

Electric shock usually does not kill at once, but may stun the victim and stop his or her breathing. Delay in rescue and resuscitation may be fatal.

In the event of electric shock, immediately switch off the electricity where practicable, and then pull or push the patient clear. If the electricity cannot be switched off immediately, remember that the patient is electrified until released and take precautions against receiving a shock yourself. The patient must be pulled or pushed away from the conductor using any type of **DRY** insulating material, such as wood, rope, clothing, rubber or plastic. **DO NOT USE METAL OR ANYTHING MOIST**. In some cases it may be easier to remove the conductor from the patient. Where necessary take care that the patient does not sustain injury by falling.





### Resuscitation

After rescue, if the patient is not breathing, commence artificial respiration immediately and **CONTINUE WITHOUT INTERRUPTION, FOR HOURS IF NECESSARY**. When assistance is available, send for a doctor and an ambulance.

### Artificial respiration and cardiac massage

The need for artificial respiration is evident if the patient is not breathing, and it must begin immediately. At the same time a check on the patient's **carotid** pulse will establish the need for cardiac massage. If no pulse can be felt, cardiac massage should proceed together with artificial respiration. The techniques employed are described in detail in Australian Standards® AS 1674.2 Safety in welding and allied processes – electrical, and also in the Trust publication module – 'Resuscitation' and other first aid manuals.

### Severe bleeding

Apply direct pressure to the wound by placing a large dressing over the wound and holding it in position with a firm bandage. If the dressing becomes saturated with blood, do not remove it but apply another. This will aid clotting. In an emergency, if a dressing is not readily available, firmly press the sides of the wound together with the fingers or hand. Elevate the injured part to decrease the blood flow to the wound. Seek medical attention immediately.

### Fractures

Do not move the patient, but immobilise the person and the fractured limb by use of pillows, blankets or other suitable materials. Bleeding should be controlled if present, and the patient kept warm until qualified medical help arrives.

### Inhalation of toxic or intensively irritating gas or fumes

Remove the patient out of the danger zone at once and into fresh air. Place them in a warm comfortable position. The patient should be taken to, or seen by, a doctor as quickly as possible. Where possible, the gas or fumes involved should be identified to assist the doctor with treatment.

### Commonly referred to safety standards

Australian Standard®

- AS 1674.1 Safety in welding and allied processes – Fire precautions.
- AS 1674.2 Safety in welding and allied processes – Electrical.
- AS/NZS 1716 Respiratory protective devices.
- AS/NZS 1336 Recommended practices for occupational eye protection.
- AS/NZS 1337 Eye protectors for industrial applications.
- AS/NZS 1338.1 Filters for eye protectors against radiation generated in welding and allied operations.
- AS/NZS 1338.2 Filters for eye protectors – Filters for protection against ultraviolet radiation.
- AS/NZS 1338.3 Filters for eye protectors – Filters for protection against infra-red radiation.





## Chapter 2 – Electricity and welding machines

### Introduction

All arc welding processes have a few basic requirements for their operation. They must have a safe voltage available that is sufficient for the operator to get the arc started and be maintained. They also require sufficient amperage to provide the heat for melting of the parent metal and filler material.

Arc welding processes have been a popular and widely applied method of welding for many years. They offer sound and reliable weld, simple operation and low capital cost.

In this chapter you will look at the following.

- Arc welding process overview
  - manual metal arc welding (MMAW)
  - gas metal arc welding (GMAW)
  - flux cored arc welding (FCAW)
  - submerged arc welding (SAW)
  - gas tungsten arc welding (GTAW)
- Electricity and welding machines
  - welding current
  - current types
  - welding machines
  - amperage control
  - machine characteristics
  - selecting a welding power source.

At the end of this chapter, you will complete an activity.

### Arc welding process overview

There are a lot of arc welding processes used in the metal fabrication and welding industries. Some of these are commonly used and others are used in specialist applications. This section introduces some of the most commonly used arc welding processes; which are:

- manual metal arc welding (MMAW)
- gas metal arc welding (GMAW)
- flux cored arc welding (FCAW)
- submerged arc welding (SAW)
- gas tungsten arc welding (GTAW).



### Manual metal arc welding (MMAW)

MMAW is a welding process that creates an electric arc between a hand held, flux-coated, consumable filler wire and the work piece. The arc heat melts the parent metal and filler wire. The flux coating breaks down in the arc to produce a gaseous shield that excludes atmospheric gases from the weld zone. The flux coating also provides a de-oxidising action and forms a slag on the cooling weld.

The MMAW welding process needs a suitable and constant current power source (AC or DC), a handpiece, a work clamp, leads and flux-covered consumable electrodes.

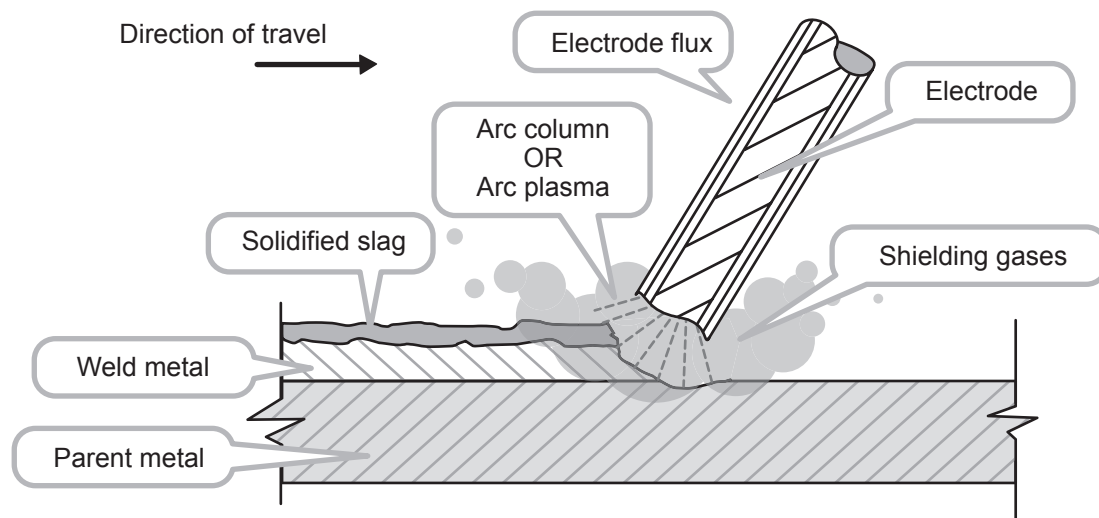


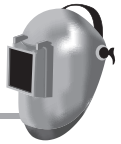
Fig 2.1 – MMAW process

MMAW equipment is cheap and simple to use and people with very little training and practice are able to use the MMAW process to make reliable welds. A skilled operator can use the MMAW process to weld practically any material in virtually any situation.

Typical uses for the MMAW process include:

- light/heavy/fabrication
- general engineering
- site work
- repairs.

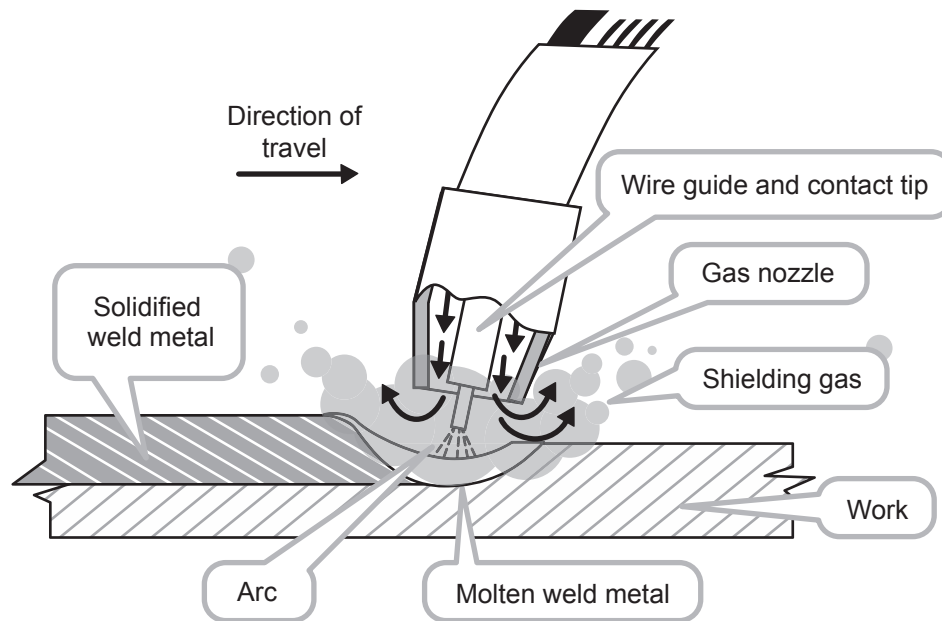




### Gas metal arc welding (GMAW)

GMAW is a welding process that creates an electric arc between an automatically fed wire electrode and the work piece. The arc heat melts the parent metal and filler wire. A supply of shielding gas that excludes atmospheric gases from the weld zone is introduced around the arc.

The GMAW welding process needs a suitable and constant voltage power source (DC), a wire feed unit, consumable wire electrodes, a shielding gas supply, a welding gun, a work clamp and leads.



**Fig 2.2 – GMAW process**

GMAW equipment is not as cheap as MMAW and requires some skill to set up properly. A good operator can use the GMAW process to weld most materials in most welding positions.

Typical uses for the GMAW process include:

- light/heavy fabrication
- general engineering
- most materials and thicknesses.



## Flux-cored arc welding (FCAW)

FCAW is a welding process that creates an electric arc between an automatically fed, hollow wire filled with flux and the work piece. The arc heat melts the parent metal, filler wire and flux. The flux may also add additional material or elements and breaks down in the arc to produce a gaseous shield that excludes atmospheric gases from the weld zone. An optional supply of shielding gas may be introduced around the arc.

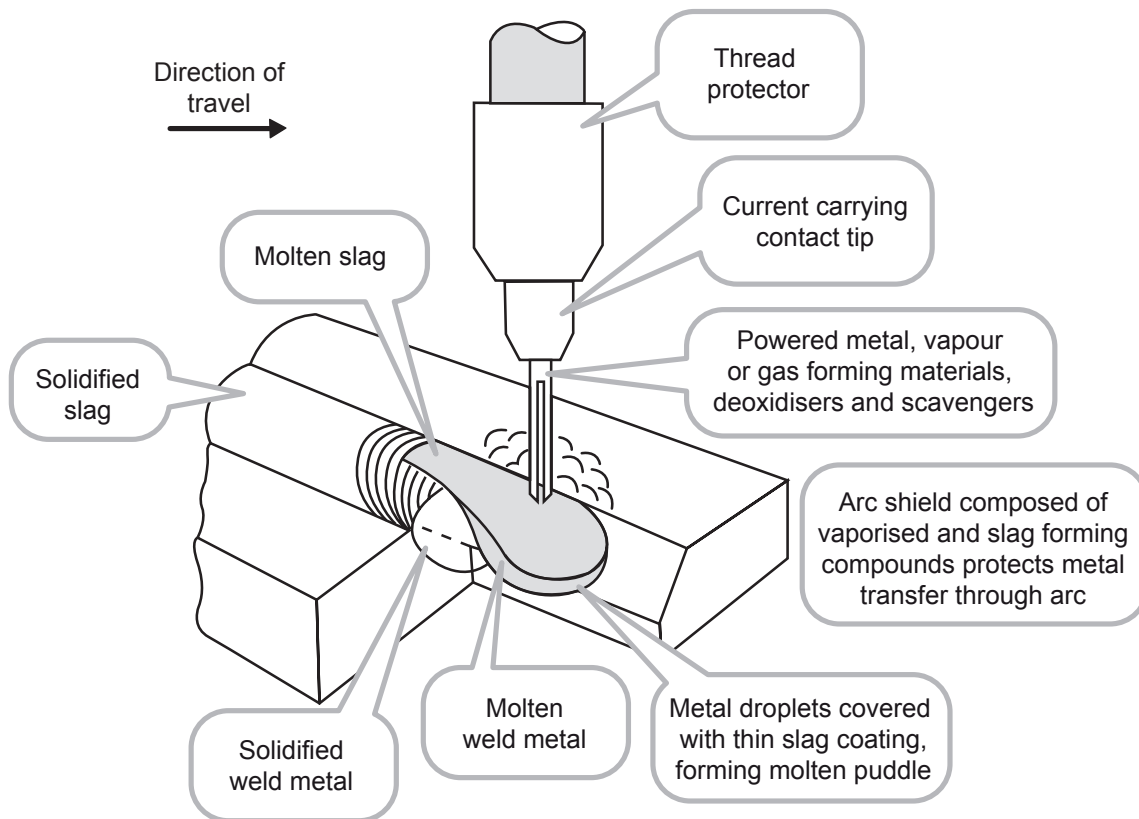


Fig 2.3 – FCAW process

The FCAW welding process needs a suitable and constant voltage power source (DC), wire feed unit, consumable flux-filled electrodes, an optional shielding gas supply, a welding gun, a work clamp and leads.

FCAW equipment is generally more robust than GMAW plant and requires some skill to set up properly. The process may be self shielding or gas shielded.

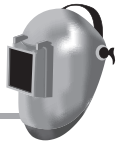
Typical uses for the FCAW process include:

- heavy fabrication
- general engineering.

FCAW has a better deposition rate and fusion than GMAW.



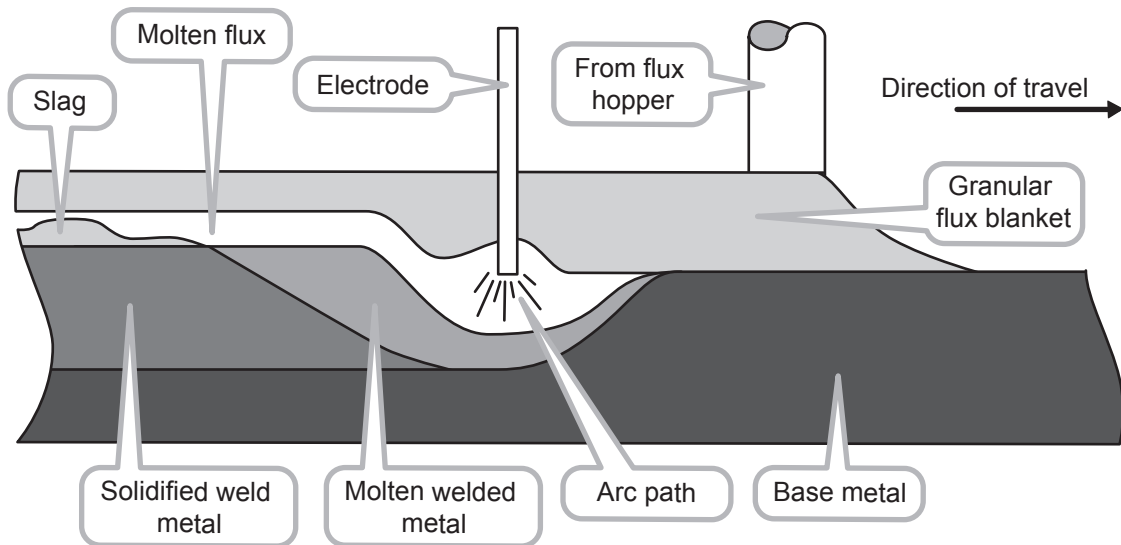




### Submerged arc welding (SAW)

SAW is a welding process that creates an electric arc between an automatically fed wire electrode and the work piece. The arc heat melts the parent metal and filler wire. A supply of flux material is introduced around the arc to contribute to the welding operation, exclude atmospheric gases from the weld zone and form a slag over the cooling weld.

The SAW welding process needs a heavy duty power source (DC), a wire feed unit, wire electrodes, flux and a flux delivery system, a power head unit, a welding gun, a work clamp and leads.



**Fig 2.4 – SAW process**

SAW equipment is heavy and specialised and generally produces high quality welds on steel products.

Typical uses for the SAW process include:

- heavy/fabrication
- flat butt and fillet welds only.



## Gas tungsten arc welding (GTAW)

GTAW is a welding process that creates an electric arc between a non-consumable tungsten electrode and the work piece. The arc heat melts the parent metal. A supply of inert shielding that excludes atmospheric gases from the weld zone gas is introduced around the arc. Filler wire may be introduced into the weld area.

The GTAW welding process needs a suitable and constant current power source (AC or DC), tungsten electrodes, an inert shielding gas supply, a welding torch, a work clamp and leads.

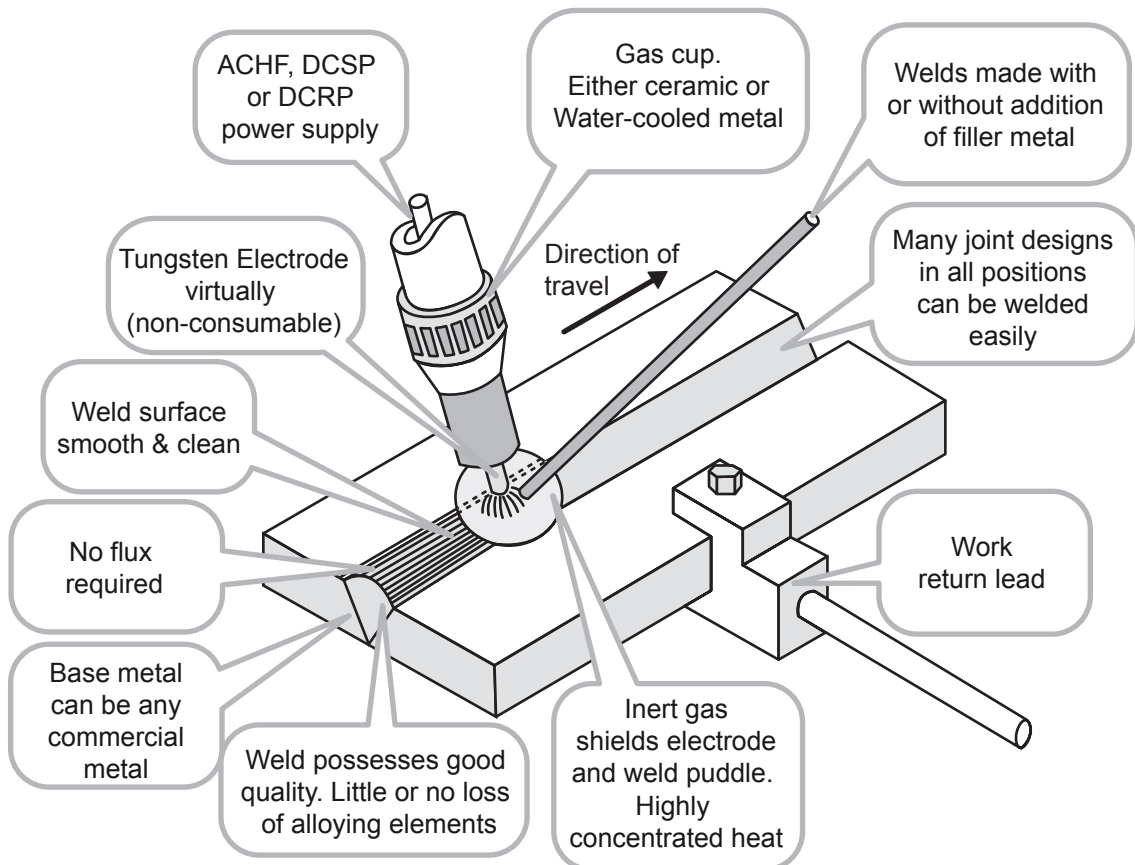


Fig 2.5 – GTAW process

The GTAW equipment process requires some skill to set up properly and a good operator can produce high quality welds on nearly all materials.

Typical uses for the GTAW process include:

- light fabrication
- general engineering
- root runs, pipe work.

GTAW welds most materials and thicknesses (carbon steel, aluminium, stainless steel etc).





There are other welding processes used in the metal fabrication industry that are not covered in this text. These are:

- electric resistance welding (ERW)
- electroslag welding (ESW)
- laser welding (LW)
- fuel gas welding (FGW).

Fuel gas welding is covered in greater depth in gas welding theory.

## Electricity and welding machines

All welding processes depend on three main requirements for their operation.

1. A heat or energy source – needed for fusion.
2. Atmospheric shielding – to prevent oxygen and nitrogen in the atmosphere from contaminating the weld.
3. Filler metal – to provide the required weld build-up.

These factors are looked at more closely in later chapters dealing with the various arc welding processes.

## Welding current

To be suitable for welding, the current used must meet the following requirements.

- There must be sufficient amperage to provide the heat for fusion.
- The voltage must be high enough to initiate the arc, but low enough to ensure the safety of the welding operator.
- There must be a suitable means of current control.

Mains supply is unsuitable for use as the welding current as the voltage is too high and the amperage too low. Mains supply must be ‘transformed’ to make it suitable for use in welding. Alternatively, the welding current can be produced from a dedicated welding generator or alternator.

## Current types

Electric current may be either:

- alternating current (AC)
- direct current (DC).



Term	Definition
alternating current (AC)	an electric current that reverses direction in a circuit at regular intervals
direct current (DC)	an electric current flowing in one direction only



**Alternating current (AC)**

Alternating current is produced by an alternator – AC is usually taken from the mains supply which operates at 50 cycles/sec.

- There is a period of current flow from positive to negative followed by a period of current flow from negative to positive.
- The flow changes direction 50 times every second.
- The voltage falls to zero 100 times/sec (therefore the arc is broken and re-established 100 times every second).

Due to the even periods of current flow with AC:

- the heat is distributed evenly at the electrode and work piece
- there is no choice of polarity.



Term	Definition
polarity	(positive or negative) polarity in this instance refers to the welding terminals being positive (+ve) or negative (-ve)

**Direct current (DC)**

DC may be produced in the following ways:

- by chemical reaction as produced in a storage battery
- by a generator driven by a rotational shaft
- by converting AC by means of a rectifier or inverter.

Direct current exhibits the following characteristics:

- DC flows continuously in one direction at the preset voltage
- in DC the current always flows from negative to positive
- with DC the flow of electrons striking the positive pole (+ve) generates two thirds of the heat from the arc at the positive pole.

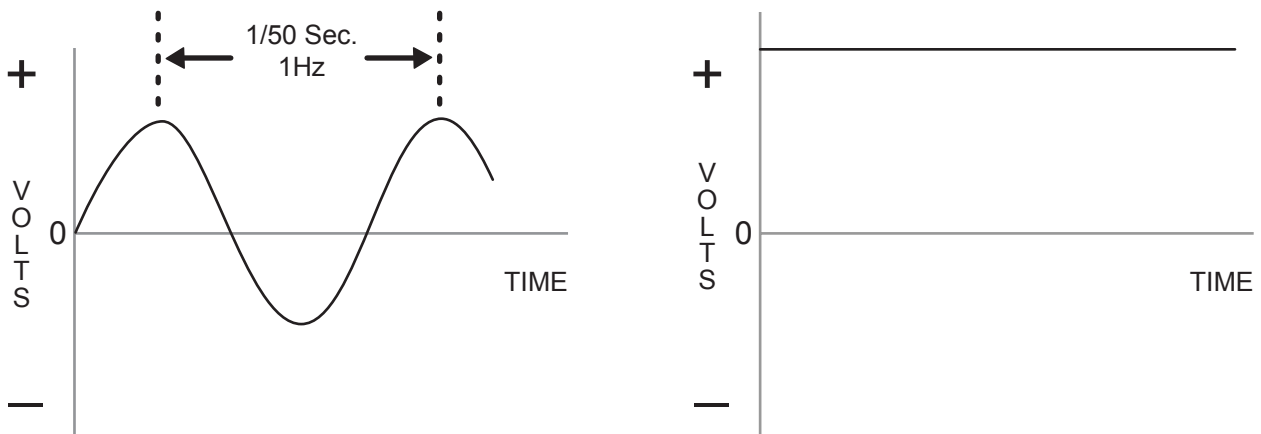


Fig 2.6 – Typical AC and DC output curves as seen in an oscilloscope





## Polarity

Polarity refers to the way in which the electrode lead is connected to the DC welding power source. When welding with positive polarity the electrode lead is connected to the positive terminal of the welding machine. When welding with negative polarity the electrode lead is connected to the negative terminal.

Changing polarity with DC does not change the direction of current flow. Current still flows from the negative to the positive pole. Changing polarity, however, alters the point at which the greater portion of heat is generated in the welding circuit. For example:

- most of the heat is generated at the electrode with +ve polarity (electrode connected to positive)
- most of the heat is generated at the work piece with –ve polarity (electrode connected to negative).



There is no polarity with AC welding circuits. As current flow is equal between both the positive and negative poles, the heat is distributed between both the positive and negative poles, and between the electrode and the work piece.

## Arc blow

Arc blow is a problem peculiar to DC circuits. Arc blow is the effect of electromagnetic forces within the circuit which deflect the metal droplets as they flow across the arc gap. As the current within the circuit increases, the magnetising effect increases accordingly. Consequently, arc blow is more severe at higher amperages, particularly above 300 A.



Term	Definition
arc blow	a deflection of the arc by electromagnetic forces in the welding circuit caused by the flow of the welding current arc blow occurs in DC circuits only

Some of the methods used to control or minimise the effects of arc blow are:

- change to AC
- change polarity
- change the position of the work return lead
- use two work return connections
- change the direction of welding
- wrap the work return lead around the job
- reduce the amperage.



### AC versus DC

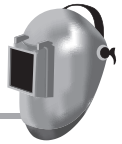
AC and DC welding circuits each have their own advantages and disadvantages. AC welding machines are cheap, and though they lack portability they are simple and trouble-free in their design and operation.

DC generator machines are generally portable and offer better control of welding conditions, but are more expensive to buy and maintain.

	<b>Alternating current (AC)</b>	<b>Direct current (DC)</b>
portability	these machines generally consist of static step-down transformers and are considered as stationary	most modern types have features that allow portability (especially the self-contained types)
power supply	the use of these machines is restricted to the location of the nearest alternating current power point	petrol or diesel engine driven machines can be used in any location
efficiency	70–90 per cent electrically efficient	40–60 per cent efficient but some modern types compare with alternating current efficiency
polarity	no polarity	choice of polarity
arc blow	unaffected	arc blow occurs even in normal currents and is difficult to control above 300 amperes
maintenance	as there are no moving parts to be considered, maintenance costs are low	revolving and wearing parts add to maintenance
initial costs	cheaper plant as less construction is involved	more costly due to generator and motor construction
electrodes	restricted to use of electrodes that are suitable for alternating current only	suitable for all types of electrodes
running cost	cheaper running costs due to the use of an installed power supply	added costs due to the use of electric motors or internal combustion engines
voltage control	constant open circuit voltage	the open-circuit voltage can be varied by the operator
arc length	limited arc length	greater tolerance in arc length due to the characteristics of the machine

**Table 2.1 – Comparison of AC and DC machines**





## Welding machines

There are various types of welding machines available to accommodate the wide range of welding processes and applications that comprise 'welding'.

Welding machines range from small 'hobby type' machines putting out as little as 100 amps to large industrial types with outputs in the thousands of amps.

To ensure the safety of the welding operator, the open circuit voltage (OCV) of welding machines is restricted by regulations to:

- AC – maximum OCV 80 volts
- DC – maximum OCV 110 volts.



Term	Definition
open circuit voltage (OCV)	the voltage between welding terminals on the machine when it is switched on but welding is not in progress

## AC machines

When an AC mains supply is available, it is possible to use a step-down transformer to reduce the supply voltage of 415 V to a safe OCV of around 70–80 volts. At the same time current is increased so as to provide sufficient heat for welding.

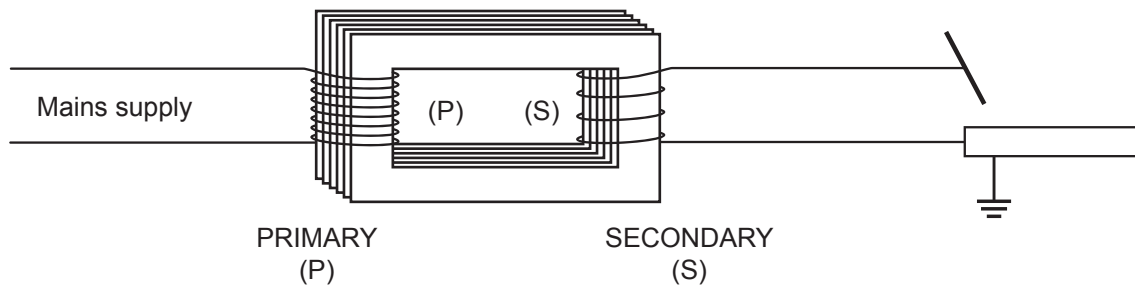


Fig 2.7 – Step-down transformer

The step-down welding transformer consists of a laminated, soft iron core carrying two coils which are not electrically connected. The first is connected to the supply (primary). Voltage applied across the first coil will produce, by induction, a voltage in the second coil. The value of this secondary (induced) voltage will be proportional to the ratio between the turns in the two coils. If each coil has an equal number of turns, equal voltage will appear at the secondary connections. If, however, a transformer has 400 turns in the primary coil, and 50 turns in the secondary coil, then a primary voltage of 400 V will induce 50 V to appear at the secondary connections.



The power into the welding machine is calculated by multiplying the volts by the amps and is expressed as volt-amps (VA). This figure is generally quite large and is usually divided by 1000 and expressed as kilovolt amperes (kVA).

**Power IN = volts x amps**

$$400 \text{ V} \times 50 \text{ A} = 20\,000 \text{ VA}$$

Since transformers have very low losses, we can consider here that the total power put into the machine must equal the power output. Therefore, in this machine which is theoretically 100% efficient:

**Power OUT = 20 000 VA**

The output voltage is determined by the ratio of the windings of the transformer. Therefore in this case the output voltage will be equal to 50 volts.

If power = amps x volts, it can be seen that:

$$\text{amps} = \frac{\text{power}}{\text{volts}}$$

Therefore, in our welding machine the output current is equal to:

$$\frac{20\,000}{50} = 400 \text{ amps}$$

The output current of 400 amps at 50 volts would now be suitable for welding, particularly if some form of current control were added.

We considered a transformer that was theoretically 100% efficient, however in practice this would not be the case. Let us say that our transformer was only 90% efficient. This means that we would have a power loss of 10 per cent.

Since the voltage is determined by the ratio of the windings of the machine and is therefore fixed, the power loss would be in the form of reduced output amperage. Therefore our output amperage would be:

$$400 \text{ A} \times 90\% = 360 \text{ A}$$

### DC machines

Direct current for welding may be obtained from a generator set, a transformer rectifier unit, or from an inverter.

### Generators

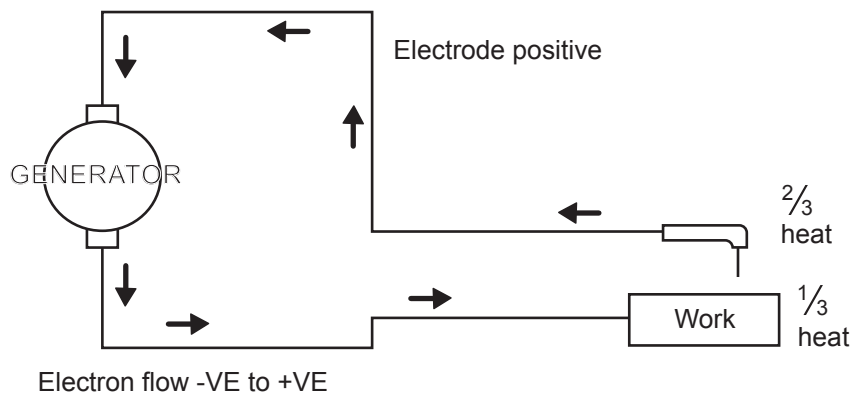
A welding generator basically consists of an armature carrying a number of windings, which rotate in a magnetic field produced by electromagnets (field coils). The passage of the armature through this field induces a voltage through the windings. The current is collected by carbon brushes running on a copper commutator at one end of the rotating armature, and current will flow when the circuit is made. The armature is rotated by an electric motor connected to an AC supply or by a diesel or petrol engine.







Term	Definition
armature	a coil in which voltage is induced by motion through a magnetic field
commutator	a device used to enable a rotating coil to produce DC current



**Fig 2.8 – Direct current circuit with electrode positive**

Welding generators are constructed to produce high current flow at comparatively low voltages, which are suitable for welding. The current produced by the generator should be steady and the voltage must not fluctuate during welding. A steady current is maintained by compensation coils or reactors to absorb current fluctuations and produce a more stable arc.

Generators can be driven using either petrol or diesel engines. These machines offer the advantage of being portable and are popular for site work where line power is unavailable. Some generators also provide auxiliary power which is useful for power tools and lighting.

Most modern portable power supplies utilise a highly efficient, high frequency alternator and electronics to provide both AC and/or DC current at constant voltage or constant current type outputs, suitable for use in a wide range of welding operations.

### Rectifiers

A rectifier is a device which permits current flow in one direction only and can therefore be used to convert AC to DC. They can be supplied as an individual unit, but most often are incorporated into the welding power source. The rectifier consists of metal plates coated with a selenium compound, or of silicon diodes – each having the special property of allowing the current to flow in one direction only. This means that when an alternating voltage is applied, only the positive half-cycles are effective. This 'half wave rectification' is undesirable and uneconomical, so the rectifier units are arranged in the form of a bridge to achieve 'full wave rectification'.



### Transformer/rectifiers

Where both AC and/or DC welding current is desirable, eg for gas tungsten arc welding (GTAW) or when DC is required from mains supply, eg for gas metal arc welding, (GMAW) a transformer/rectifier is commonly selected. GMAW machines usually provide DC output. Molten metal arc welding (MMAW) and GTAW machines usually provide both AC and DC output. By means of a switch or by changing leads, the welder can select either positive or negative polarity on the DC output.

Most GTAW machines are equipped with a high-frequency oscillator which provides a high-frequency spark to enable the arc to be started without the electrode making contact with the work. The high-frequency spark may be used simply to start the arc when using DC or may be continuous to re-establish and maintain a steady arc with AC.

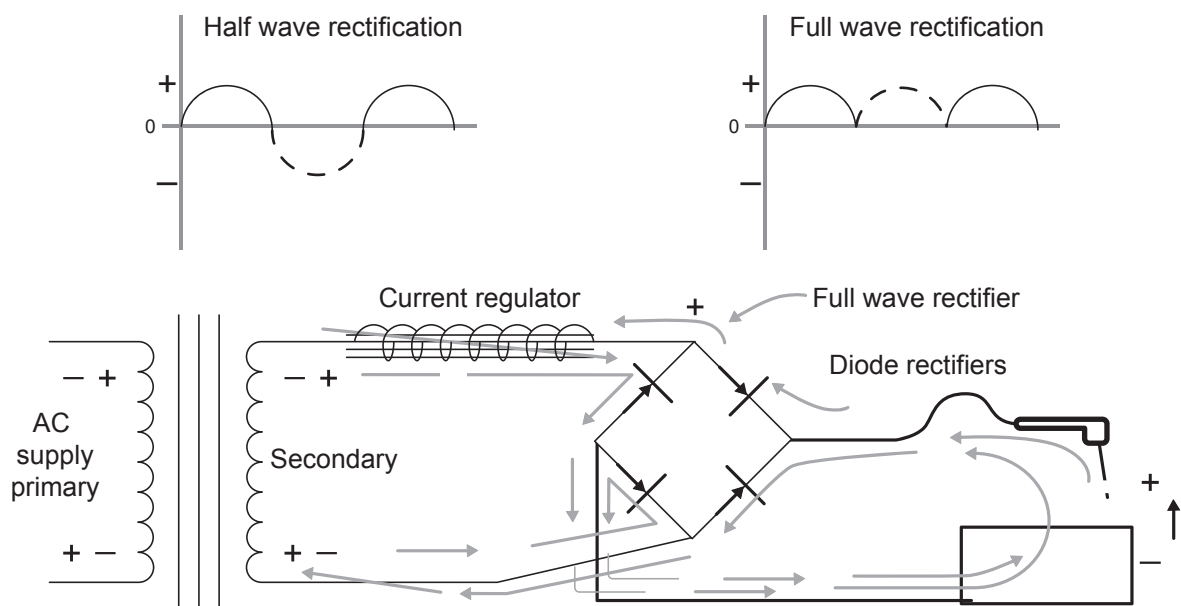


Fig 2.9 – Single phase transformer with bridge (full wave) rectifier

### Inverters

Inverters are fast taking over from other types of welding machines. These machines are able to provide AC and smooth stable DC output at high-efficiency levels, and feature lightweight construction.

The machines operate on either 240 V or 415 V AC input current and immediately rectify this to DC using a series of high temperature diodes. This DC current is stored in filter capacitors and then converted to an oscillated AC output in an oscillator stage at a much higher frequency than the input supply. This high-voltage/high-frequency signal is then fed into a high-efficiency transformer primary coil and high-frequency AC current is produced in the secondary coil. The frequency can be anything from 5 kHz upward, depending on the design and type of output required.

Due to the high-frequency AC generated by the oscillator, the weight of transformers can be reduced dramatically because there is no magnetic loss or heat loss through the windings, and much greater transformer efficiencies can be achieved.



Now that a high-frequency, low voltage, but high current power supply has been created it can be used as high-frequency AC welding power for MMAW or GTAW of aluminium. Alternatively the AC can then be rectified into DC current again and passed through a second filtering system to produce a very smooth current flow. Welding machines with an output frequency of around 5 kHz demonstrate a characteristic whistling sound during welding.

Inverter welding machines have very good electronic controls that can regulate the voltage and current. They are also very efficient and highly portable due to their reduced weight.

### The inverter cycle

1. Mains current rectified to DC and stored.
2. DC is oscillated to a high frequency.
3. High-frequency/high voltage AC is transformed to low voltage AC.
4. AC rectified to produce DC.
5. DC filtered to a smooth current.

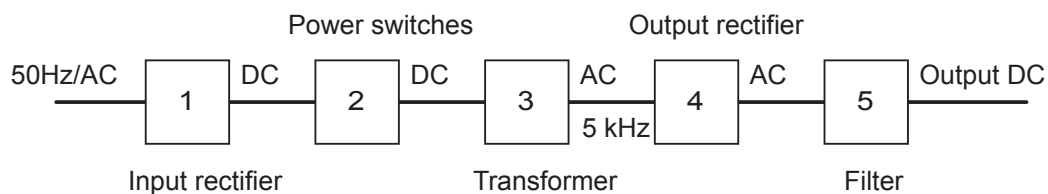


Fig 2.10 – Inverter cycle

### Amperage control

If a welding operator draws current directly from a transformer, with no form of current control, the welding current is fixed and will only be limited by the resistance of the arc, the welding leads and the transformer's characteristics. The current may be excessive and there would be no means for the operator to select the correct setting for the job. Some method of current control is required if a machine is to be practical to use. Five common types of current control devices are described below.



Term	Definition
resistance	a resistance inhibits the flow of electrons along a conductor. The greater the resistance the greater the voltage drop. Electrical resistance always causes heat to be produced.
voltage drop	the difference in electrical pressure (volts) between two points in a circuit, caused by resistance opposing the flow of current, ie excessively long welding cables, loose connections, damaged cables, arc length too long



### Movable coil

This consists of a special arrangement in the transformer that allows the distance between the primary and secondary windings to be varied, enabling the amount of current induced in the secondary coil to be altered.

Amperage is usually selected by winding a hand wheel or shifting a lever. This action moves the primary coil in the machine either closer to or away from the secondary coil, which is usually mounted on the machine base. The closer the two coils are together, the greater the magnetic force between them, and consequently the higher the amperage. As the coils are moved further apart, efficiency is lowered resulting in reduced current output.

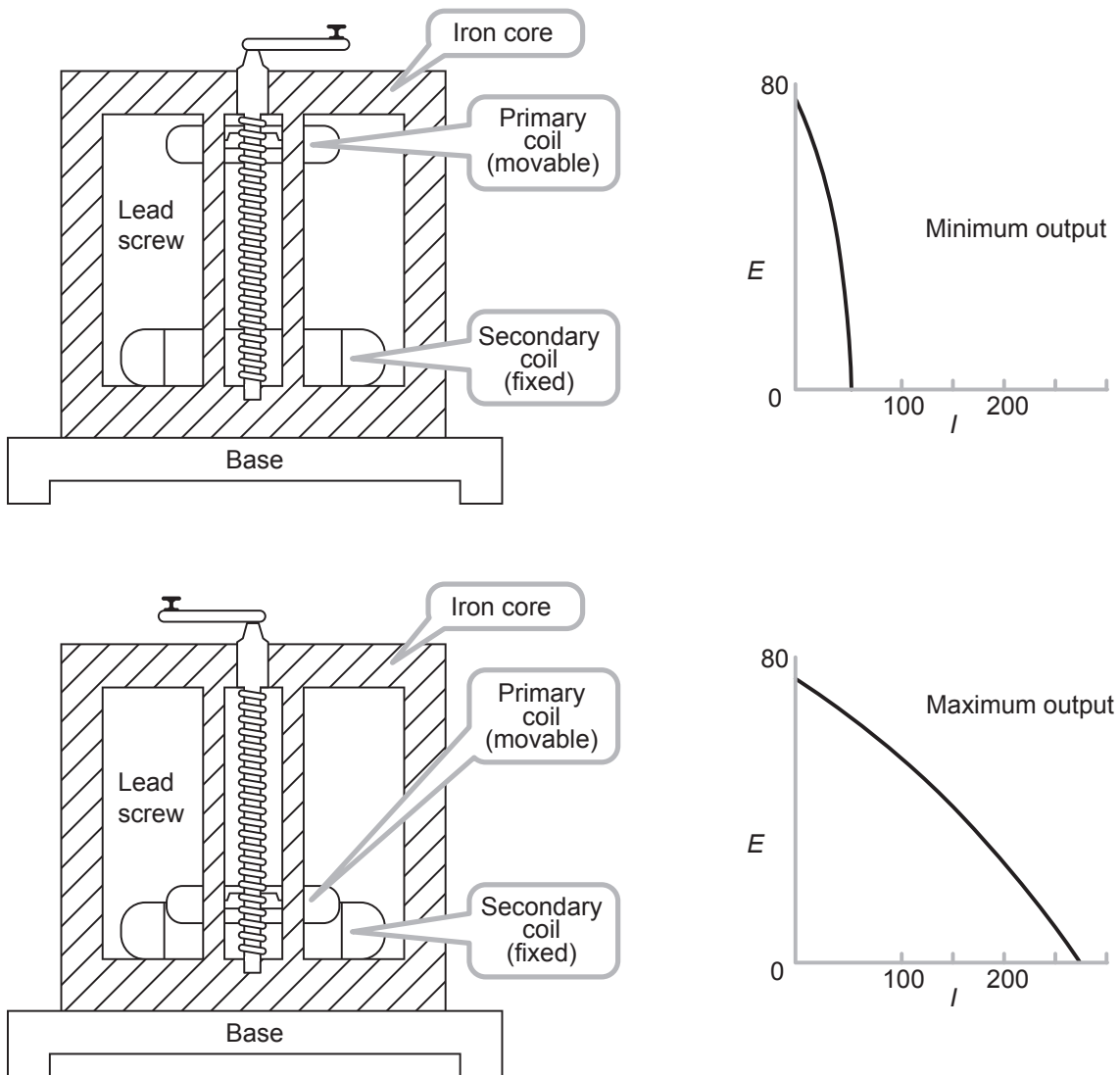
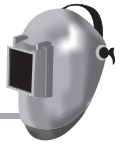


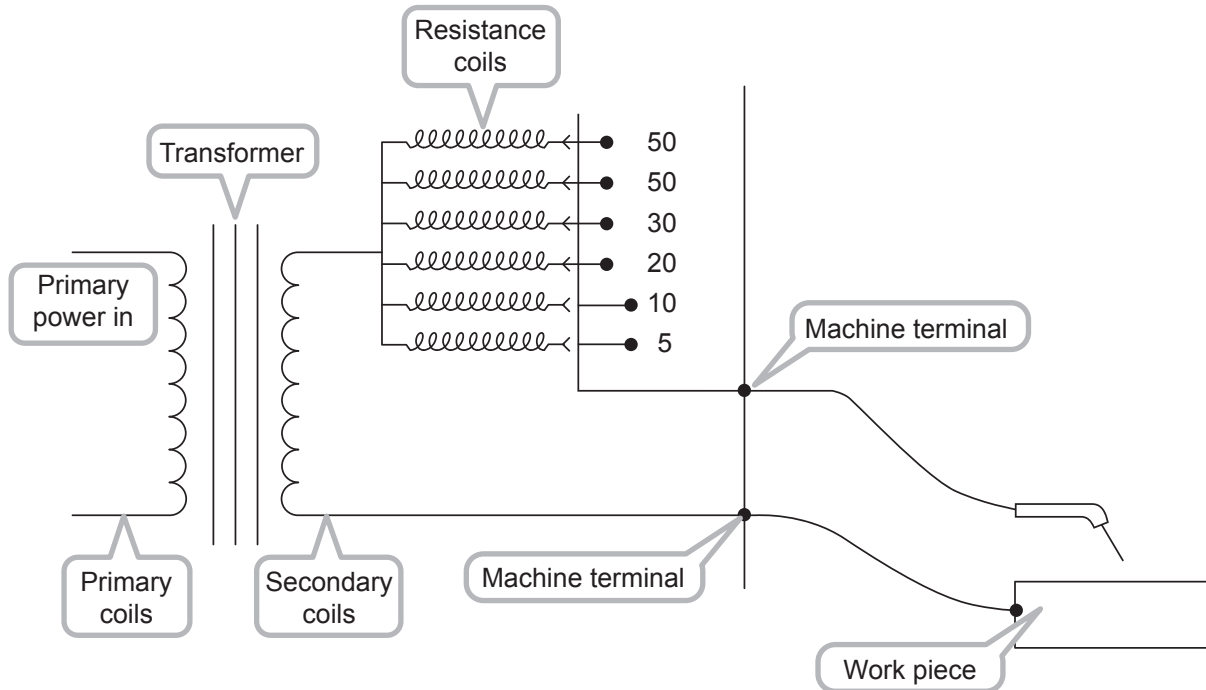
Fig 2.11 – Movable coil AC transformer





### Resistance

Electrical resistance in a circuit opposes the flow of current. By varying the resistance in the welding circuit the amperage can be controlled. This is usually done by passing the current through one variable resistance coil, or a series of coils with fixed resistance. Resistance is inefficient where high currents are used, as large amounts of heat are generated.



**Fig 2.12 – Fixed resistance coils**

With machines as in Fig 2.12 above, amperage is selected by pushing in buttons to make contact with the appropriate resistance coil. Each coil allows only a certain amperage to flow through it. The more coils selected, the greater the amperage.



### Moving core choke

This consists of a coil of wire or copper strip heavy enough to carry the welding current, which is wound around an iron core. This induces a counter-voltage which chokes back on the current flow. By adjusting the amount of iron within the coil, the flow of current can be controlled. The further the core is pushed into the coil, the greater the choking effect and consequently less amperage flow.

A strong magnetic field is also generated and this will tend to draw the core into the coil, so a locking device is necessary.

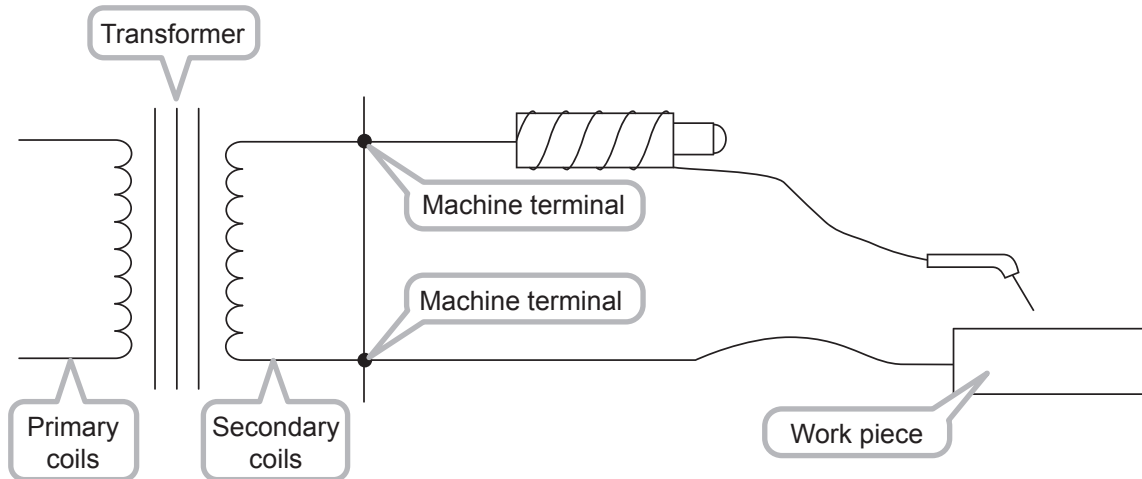


Fig 2.13 – Moving core choke transformer

### Reactors

Various forms of reactor are used to control welding current. By saturating the laminated iron core of the reactor with the magnetic flux of direct current, the available output alternating current is reduced. In DC circuits the current passes through the reactor prior to being converted to DC in the rectifier section of the power source.

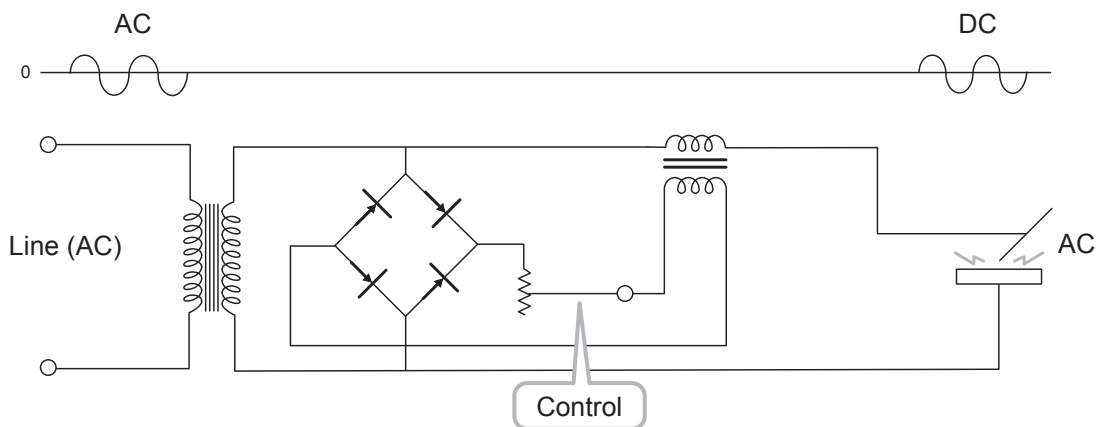


Fig 2.14 – Saturable reactor





### Silicon controlled rectifier (SCR)

Modern welding machines use silicon controlled rectifier (SCR) devices to provide a 'one knob' output control system. The SCR circuit is fitted into the transformer output circuit and is an electronic device that can be switched on and off at various points in the AC cycle. When this is coupled with a feedback circuit the output voltage and current can be easily controlled. These machines can provide AC and/or DC current choice and may also offer constant current or constant voltage type output from the same machine.

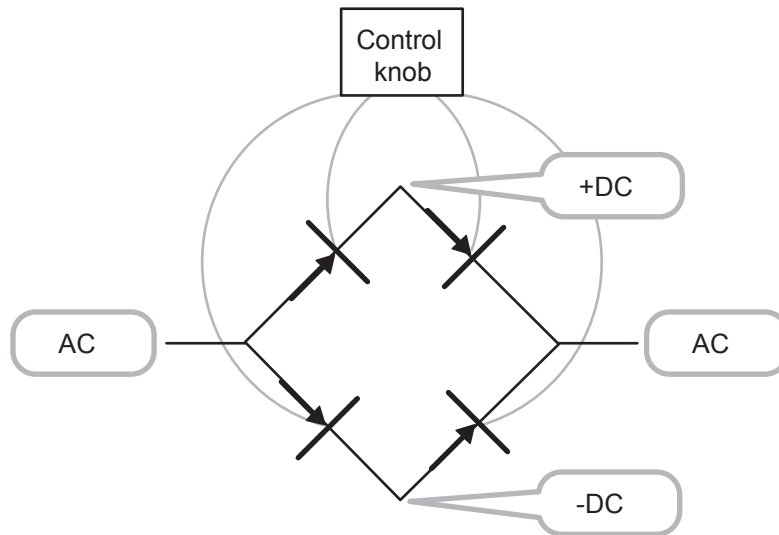


Fig 2.15 – Silicon control rectifier (SCR)



### Machine characteristics

Further to classifying welding machines as AC or DC, welding machines are also classified according to their characteristic output curve. Machines are classified as either:

- constant current (CC) – also known as drooping characteristic
- constant voltage (CV) – also known as constant potential or flat characteristic.

The machine characteristic is often referred to as the slope of the machine, as it can be seen that the output curve slopes downward.

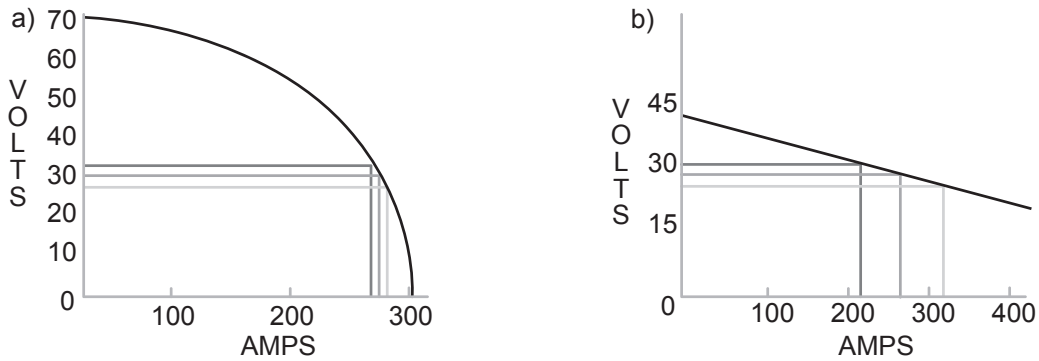


Fig 2.16 – Volt/amp curves (a) constant current machines (CC) and (b) constant voltage machines (CV)

The curves on the above graphs represent the power output of each type of machine. They show voltage output at a given load amperage. It can be seen from the output curves that a change in arc voltage produces a change in the output amperage of the power source.



Term	Definition
arc voltage	the voltage across the arc between the electrode and parent metal. This will vary depending on the length of the arc, type of electrode, etc

Some welding processes (such as GMAW) are intolerant of changes in arc voltage. Others (such as MMAW or GTAW) are intolerant of fluctuations in amperage. The arc length (electrical stick-out with GMAW) varies by natural movement of the operator’s hand during welding, causing resistance across the arc to vary. An increase of arc length would cause an increase in arc voltage and a decrease in amperage. Shortening the arc length would have the opposite effect. These fluctuations in amperage and voltage are controlled by manufacturing machines which have the desired characteristic curve.







## Constant current machines

Constant current machines translate fluctuations in arc length to changes in arc voltage and permit little change in the output amperage. This is desirable in hand held welding processes such as MMAW or GTAW, where changes in arc voltage have little effect on welding, but fluctuations in amperage would make it difficult for the welding operator to control the welding process.

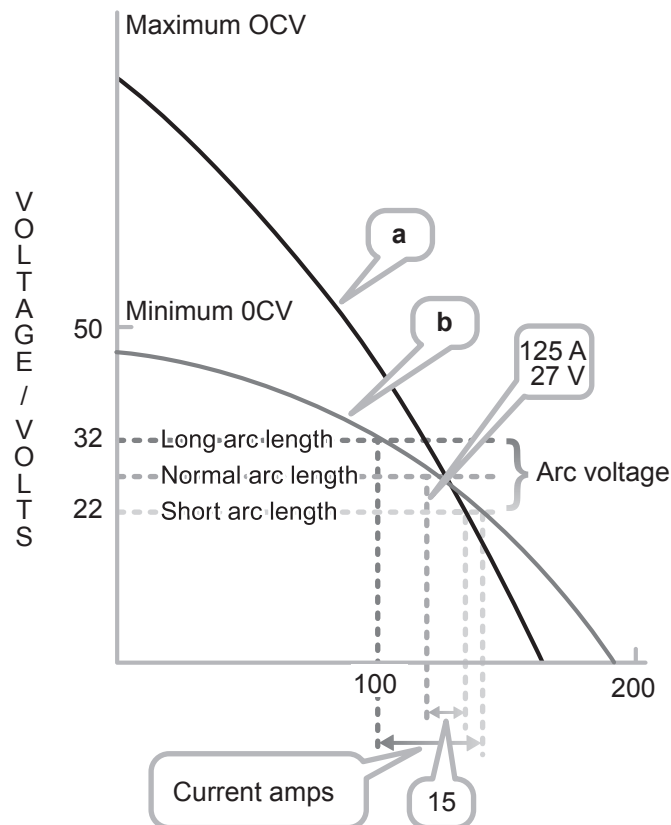
## Constant voltage machines

Constant voltage machines are designed to hold the arc voltage steady, and allow the amperage to fluctuate with minor variations in arc or stick-out length. In power feed processes such as GMAW, arc conditions are greatly affected by even small changes in arc voltage. Therefore changes which would naturally occur in stick-out length (with the movement of the operator's hand) are translated to fluctuations in amperage whilst holding the arc voltage constant. It should be noted that small variations in stick-out length will produce relatively large changes in amperage.

## Variable slope machines

Some machines allow adjustment of the open circuit voltage, however not only does the OCV change, but the slope (current response) of the machine changes also.

It can be seen in Fig 2.17 that when the maximum OCV is selected, the machine has an output curve associated with a constant current machine. When the minimum OCV is selected, a different output curve results. This slope is infinitely variable between the maximum and the minimum OCV. This type of machine is ideal for applications such as pipe welding as it gives the operator the ability to control amperage by means of adjusting the arc length.



**Fig 2.17 – Typical volt-ampere curves possible with a variable voltage power source**  
**The steep curve (a) allows minimum current change**  
**The flatter curve (b) permits the welder to control current by changing the length of the arc**



### Duty cycle

An essential factor in the performance of any welding machine is the machine duty cycle.

The duty cycle is the percentage over a five-minute period that the machine can operate at the rated output amperage.

It is important to realise that:

- the duty cycle rating may not be at the maximum current output of the machine
- semi-automatic and fully automatic processes may require that the machine be rated at or near 100%
- if the current required is higher than the amperage at which the machine is rated, the operating time will have to be reduced
- welding at an amperage lower than the amperage at which the machine is rated will enable the operating time to be increased
- simply reading the maximum output current on the dial of a welding machine is not a reliable indicator of the machine's performance capability.

Example: A welding machine is rated at 60% duty cycle at 300 A on the front label.

The maximum amperage output of this machine is 350 A.

At 100% duty cycle the allowable amperage would be 232 A.

### Selecting a welding power source

The choice of machine depends on three major factors:

- the type of work the machine is required to do
- the operating conditions – field or site work, shop work, available power
- the type of welding required, with regard to specific operating conditions, for the least cost.

There are six basic machine types commonly available:

- AC transformers
- transformer rectifiers
- inverters
- motor generators
- independently driven generators
- engine driven generators.





## AC transformers



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**Fig 2.18 – AC transformer**

These stationary machines require mains current to operate. They are cheap to buy and maintain and electrically efficient, but offer limited control of the welding current and restricted electrode choice.

## Transformer rectifiers



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**Fig 2.19 – Transformer rectifier**

These stationary machines provide AC/DC welding current from an AC main by means of a rectifier. They offer quiet, efficient operation with virtually no moving parts. These machines are commonly used for GTAW and GMAW.



### Inverters

#### Operating Controls

1	Negative (-) dinse connection
2	Positive (+) dinse connection
3	Overload protection indicator
4	Welding curent regulator
5	Main power switch and signal light
6	Carry strap
7	Selector switch for welding process
8	Machine body
9	Work clamp and cable
10	Electrode holder and cable

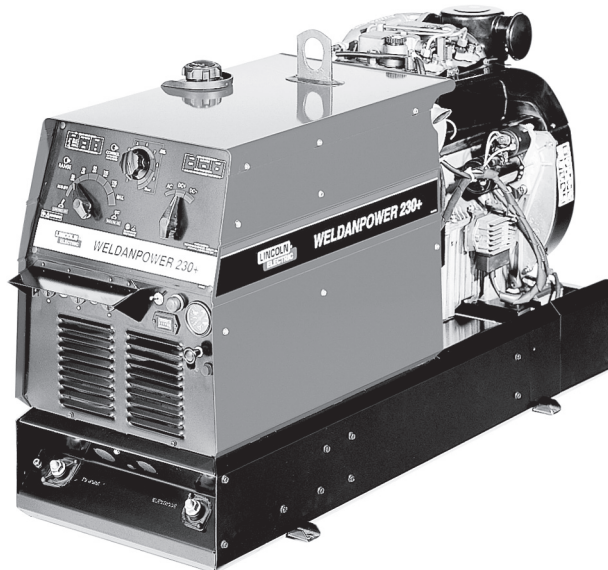


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**Fig 2.20 – Inverter**

Inverters also require mains primary current. Compared to other machines of similar current capacity they are compact, lightweight and provide a smooth DC output. They are commonly used as MMAW, GMAW and GTAW machines.

### AC motor generators

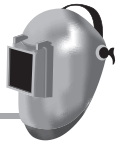


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**Fig 2.21 – AC motor generator**

An AC electric motor and a DC generator are built on a common shaft. The AC motor turns the shaft and direct current is produced in the generator section, and output to the welding terminals. These machines offer smooth current with a choice of polarity and OCV. Small machines (typically to 300 A) are commonly used for MMAW and larger machines are commonly used to provide current for SAW.





### Independently driven generator

These machines are normally purchased where a power take off (PTO) is available, such as those on a truck, tractor or 4WD. A welding current is then available wherever the host vehicle can go. Often this type of machine has a power pack built in to provide power for other devices such as lights, drills and grinders.

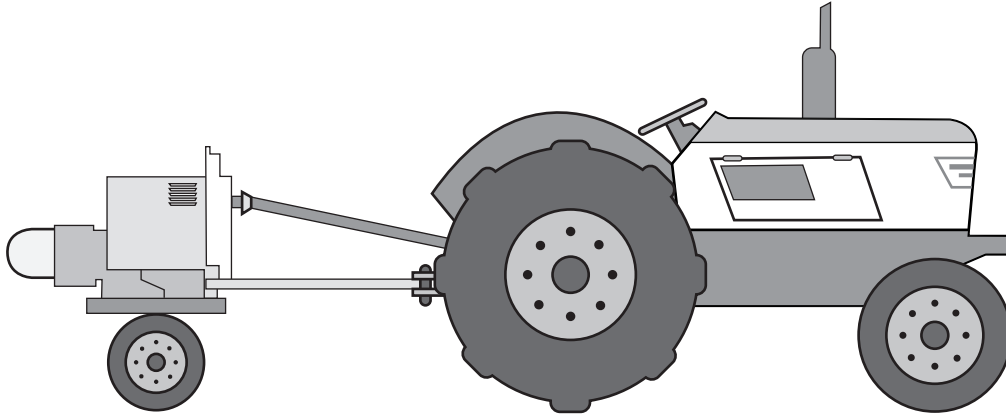


Fig 2.22 – Independent driven generator

### Engine-driven generator

These machines are DC generators or AC alternators with electronic control coupled to a diesel or petrol internal combustion engine. They are extremely portable, and are commonly used for site construction work. These machines are equipped with governors to maintain constant engine speed and idling devices to reduce engine speed when welding is not in progress. Most machines are water-cooled, but machines with air-cooled engines are available for light duty use. Initial maintenance costs of these machines is high. Diesel engines cost more than petrol engines, but are more economical to run and maintain.



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Fig 2.23 – Engine-driven alternator

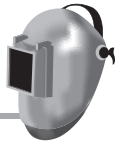


### Activity

In the workshop:

- note the various types of welding machines
- identify the type of current they produce, the OCV and the machine duty cycle from the front label
- identify the current control method used by each machine
- detail the different applications for each welding machine.

Your lecturer can assist you with this activity.



## Chapter 3 – Weld preparation and workmanship

### Introduction

There are many types of joints and preparations used in welding, with the correct selection based on a wide range of factors. Some of these are:

- welding process being used
- thickness of the material
- required strength of the weld
- accessibility – from each side
- positioning of the parts.

In this chapter you will look at the following.

- Selection of joint type
  - fillet welds
  - butt welds
- Points to remember
  - welding terms and positions.

At the end of the chapter, you will complete an activity.

### Selection of joint type

The type of joint depends on three factors:

- intensity of loading – butt welds are better able to transfer stress, however, when forces are essentially static, as in buildings for example, fillet welds are usually the preferred type
- ease of welding – fillet welds are generally easier to make and require less operator skill
- cost – fillet welds are generally cheaper to produce as the cost of weld preparation for butt welds is often considerable.

Welds may be one of four basic types:

- fillet weld
- butt weld
- pad weld (surfacing)
- plug and slot weld.

These welds may also be combined to produce compound welds.

Pad and plug welds and slot welds are not commonly used in general fabrication and will not be considered in this text.



## Fillet welds

A fillet weld is a weld approximately triangular in cross-section, lying external to the planes of the parts being joined.

Parts	Description
1. parent metal	the parts to be joined
2. root	where the parts to be joined are in the closest proximity
3. face	the exposed surface of the weld
4. toe	where the weld face meets the parent metal
5. depth of fusion	the degree to which the weld penetrates the parent metal
6. leg length	the distance from the root to the toe
7. actual throat thickness	the distance from the root to the weld face measured through the centre of the weld
8. design throat thickness	the distance from the root to the hypotenuse of a triangle lying wholly within the weld (used for design calculations)
9. reinforcement	the distance between the design throat thickness and the actual throat thickness

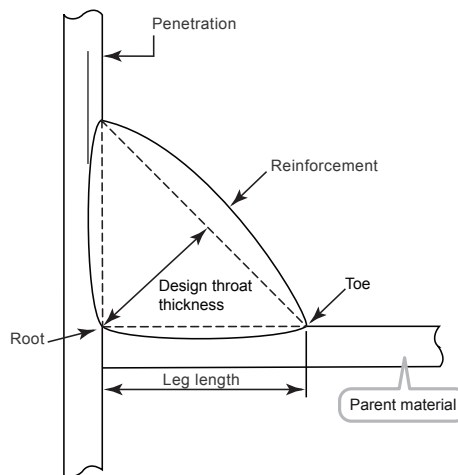


Fig 3.2 (a) – Parts of a fillet weld

### Fillet weld configuration

The weld configuration relates to the relationship of the plates to be joined. The joint types may be tee fillet, outside corner or lap and these may be made in various positions, eg flat, vertical.

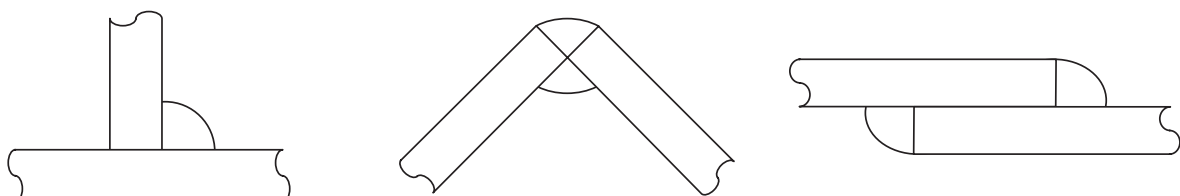
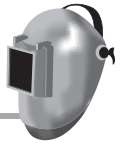


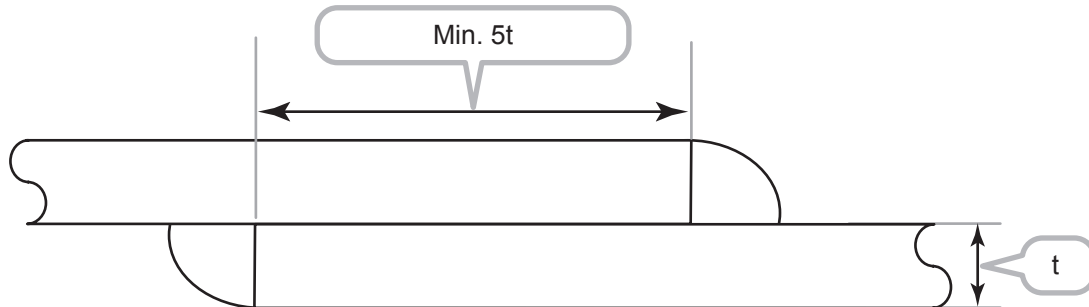
Fig 3.2 (b) – Fillet weld configurations





### Lap joints

The minimum overlap for parts carrying stress is five times the thickness of the thinner part joined. Both ends of the lap require welding.

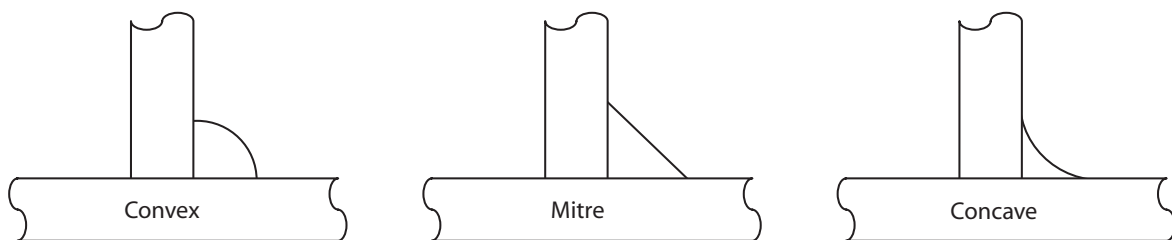


**Fig 3.3 – Lap joint overlap**

eg	Minimum lap of 2 x 6 mm plates	5 x 6 mm = 30 mm
	Minimum lap of 5 mm plate lapped onto 8 mm plate	5 x 5 mm = 25 mm

### Fillet weld profile

Three fillet profiles are possible. A perfect fillet weld would be the right size and equal leg, have an even front face and described as mitre-shaped. An over-welded fillet weld or a weld that has excess reinforcement and abrupt transition at the toes that may cause stress concentration, is described as convex. A weld that has a reduced throat distance compared to a leg size is described as concave (this may cause centerline cracking or weld failure).



**Fig 3.4 – Fillet weld profile**

Ideally, fillet welds should be slightly convex. It should be noted that concave fillet welds require longer leg lengths to meet the requirements of nominal size.



### Fillet weld size

The amount of fillet weld required to obtain the necessary strength may be specified in one of two ways.

1. Nominal size – the length of the leg of a triangle which can be inscribed wholly within the cross-section of the weld and the throat thickness, which must be 0.7 of the leg length. Where a gap exists in the root of the joint, a reduction in the nominal size may be made.

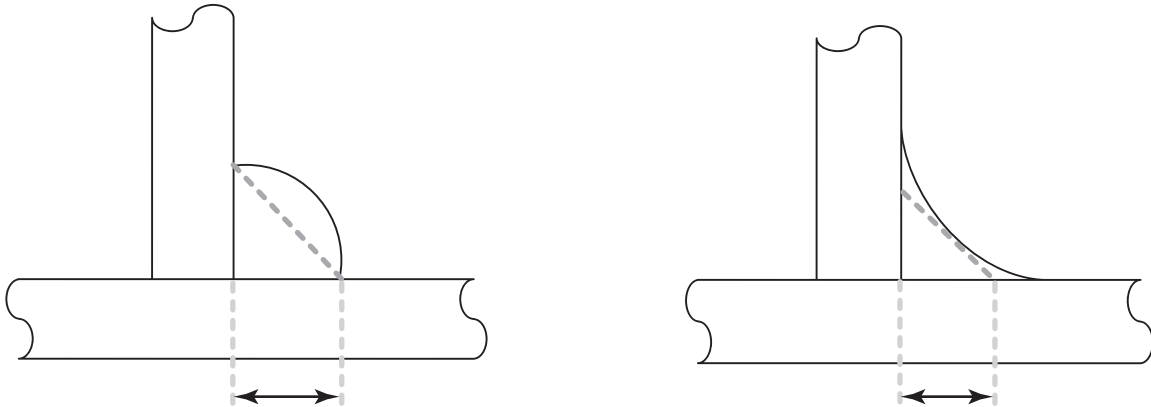


Fig 3.5 – Nominal size

Where the amount of weld required is specified on an engineering drawing by nominal size, the length of weld of the required size will be stated.

eg 200 mm of 6 mm fillet

2. Effective area – the amount of weld required may also be expressed in terms of effective area. The effective area of a weld is the effective length multiplied by the design throat thickness (DTT). The effective length (EL) is the length of the weld which is on the specified size.

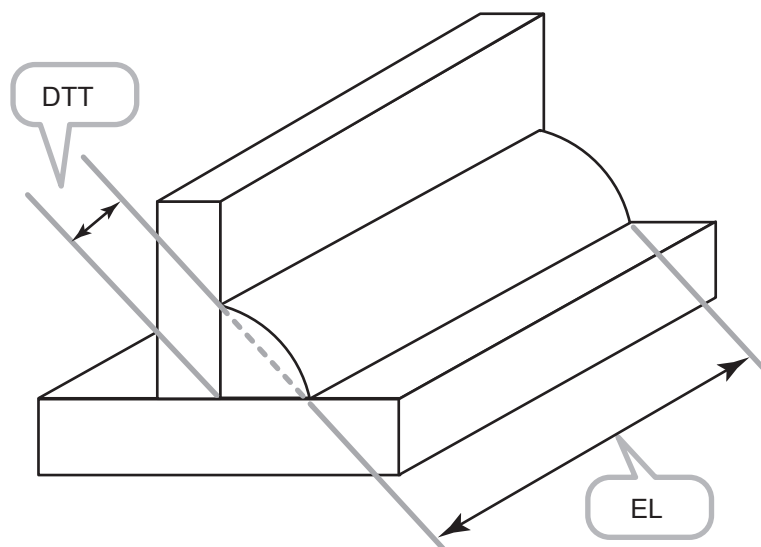


Fig 3.6 – Weld effective area



### Example 1

What is the effective area of 400 mm of 8 mm fillet weld?

$$\begin{aligned}
 \text{DTT} &= 0.7 \times \text{nominal size} \\
 &= 0.7 \times 8 \text{ mm} \\
 &= 5.6 \text{ mm} \\
 \text{effective area} &= \text{effective length} \times \text{DTT} \\
 &= 400 \times 5.6 \\
 &= 2240 \text{ x mm}^2
 \end{aligned}$$

### Example 2

A lifting lug requires 1600 mm<sup>2</sup> of fillet weld to provide the necessary strength. What length of 10 mm<sup>2</sup> fillet weld is required?

$$\begin{aligned}
 \text{DTT} &= 0.7 \times \text{nominal size} \\
 &= 0.7 \times 10 \text{ mm} \\
 &= 7.0 \text{ mm} \\
 \text{effective area} &= \text{effective length} \times \text{DTT} \\
 \text{effective length} &= \text{effective area} \div \text{DTT} \\
 &= 1600 \div 7.0 \\
 &= 228 \text{ mm}
 \end{aligned}$$

Therefore, the required length of 10 mm fillet is 228 mm.

Use of the effective area method allows the fabricator flexibility in the welding process, for example:

If an effective area of 2000 mm<sup>2</sup> were specified:

$$\begin{aligned}
 200 \text{ mm of } 10 \text{ mm DTT fillet} &= 2000 \text{ mm}^2 \\
 400 \text{ mm of } 5 \text{ mm DTT fillet} &= 2000 \text{ mm}^2
 \end{aligned}$$

### End returns

Welds terminating at the ends or sides of parts of members should, where possible, be returned around the corners for a distance of not less than twice the nominal size of the weld, to help prevent cracking. The weld carried around the corner is not taken into account for purposes of strength calculations. This weld part is counted as the allowance for start and finish of the weld.

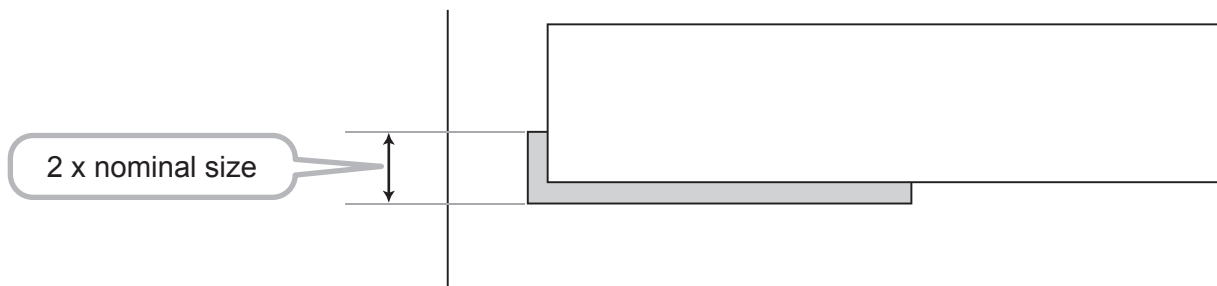
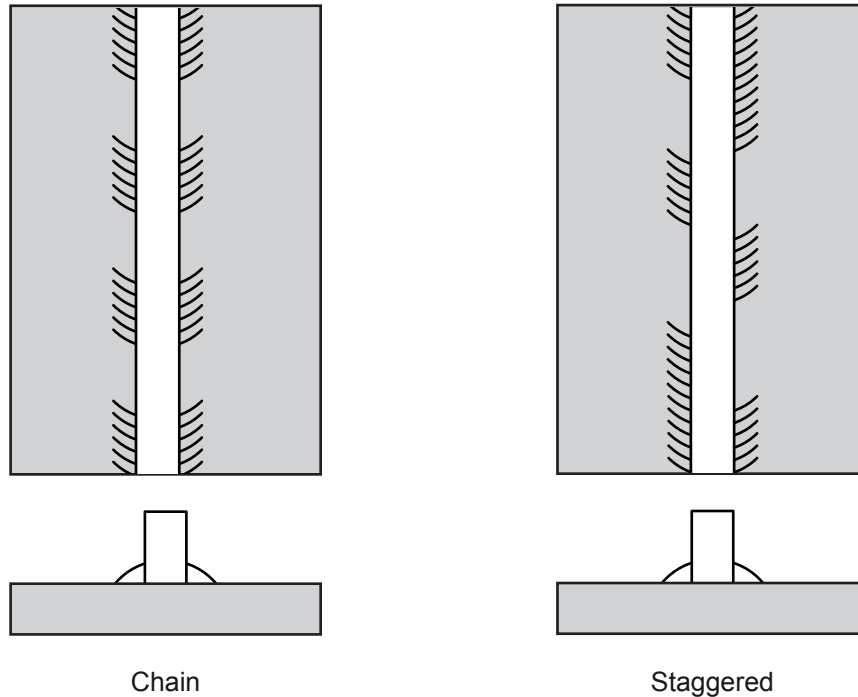


Fig 3.7 – End returns



### Intermittent fillet welds

There are many applications where the required strength can be achieved without the need for a continuously welded joint. Where this is the case it is common to use intermittent fillet welds. There are two types of intermittent fillet welds: chain or staggered.



**Fig 3.8 – Intermittent fillet welds**

Any section of intermittent fillet welding shall have an effective length of not less than four times the weld size with a minimum length of 40 mm.

The clear spacing between the effective lengths of each weld carrying stress shall not exceed the following number of times the thickness of the thinner part joined.

- 16 times for compression.
- 24 times for tension, and in no case be more than 300 mm.

Chain intermittent welding is preferred to staggered intermittent welding.

Where staggered intermittent welding is used, the welds on each side of the parts joined shall be continued to the end of the part.

### Butt welds

Butt welds are used to join metal products such as sheet, plate, rolled and pressed sections. This type of joint has the advantage of having high strength without changing the profile of the structure. Butt welds are better able to transfer stress than fillet welds and are preferred for live or cyclic loading.

Industrial uses for butt welds include:

- boiler and pressure vessel construction
- ship building
- earth moving equipment
- aircraft and submarines.



### Butt weld terminology

The terminology that applies to the parts of a fillet weld applies equally to butt welds, with the major difference being design throat thickness, which in a full penetration butt weld is equal to the plate thickness.

The terms concerned with the preparation for butt welds require explanation at this stage.

Graphic	Terminology	Description
	weld root	the portion of the weld where the parts to be joined are in the closest proximity to each other
	root face	that portion of the prepared edge of a part to be joined by a butt weld that has not been bevelled. This unbevelled section will support the first run of weld metal deposited in the groove
	root gap	the separation between parts to be joined by a butt weld. The gap is for the purpose of ensuring, as far as possible, complete fusion or penetration through the full thickness of metal
	angle of bevel	the angle of the prepared edge of a component bevelled for welding
	included angle	the angle between the fusion faces of components prepared for welding



	throat thickness	the distance from the root to the weld face measured through the centre of the weld
	design throat thickness	in a full penetration butt weld the design throat thickness is equal to the thickness of the thinner part joined
	reinforcement	reinforcement in a butt weld is the term given to the metal lying outside of the planes of the parts being joined

Fig 3.9 – Butt welds

### Preparation of plate edges for butt welds

In most cases, especially when joining metal of considerable thickness, it is difficult to produce satisfactory butt welds unless the edges to be joined are adequately prepared. Sheet metal and thin plate may be welded without preparation (up to 5 mm thick), but for metal over 6 mm in thickness the edges must be prepared in such a way as to provide a 'V' or 'U' shaped groove in which the weld metal is deposited, so allowing complete fusion or penetration through the full thickness of the metal.

Failure to properly prepare the edges may lead to the production of faulty welds, as the correct manipulation of the electrode may be impeded and/or the desired degree of penetration may not be achieved.

Plates which have been cut by shearing should have all burrs and irregularities removed before welding.

Plates prepared for welding by oxy-flame cutting techniques should have an even surface, free from notches or grooves. For this reason machine flame-cut surfaces are preferred to hand flame-cut surfaces. Imperfections on bevelled edges may be removed by filing or grinding. Preheating may be required when oxy-flame cutting weld preparation on hardened steel, particularly if thick.

'U' and 'J' preparations may be carried out by means of oxy-flame gouging, but usually such forms of bevelling are prepared by machining the parts.



Weld preparation is commonly applied by:

- shearing
- grinding
- machining
- oxy-flame or plasma cutting
- arc or oxy-flame gouging.

Butt welds can be either a **complete penetration butt weld** where fusion exists through the full thickness of the joint, or an **incomplete penetration butt weld** where the depth of the weld is less than the thickness of the plates joined.

At this stage it is only intended to discuss complete penetration butt welds, and even here the types of butt welds referred to will be the more common types. Additional information can be gained by referring to Australian Standard® AS/NZS 1554 Structural steel welding.

### Types of butt welds

Butt welds are made between the edges of abutting plates and are generally described according to the way these edges are prepared. The edge preparation chosen for a particular type of joint must generally ensure that complete penetration can be achieved with minimum weld metal and effort, while bearing in mind other relevant factors such as:

- the accessibility of the joint to be welded – whether it can be welded from both sides of the joint or only one
- the position of the joint to be welded, ie vertical, horizontal, flat.

The type of butt weld selected for a particular job is usually the one which is easiest and cheapest to make when all other factors have been considered.

### Edge preparation and specification

The various types of edge preparation in common use for the welding of steels are as follows.

- Closed square butt joint – The edges are not prepared and are fitted together without a gap. This preparation is suitable for steel up to 3 mm thick and is welded from both sides.

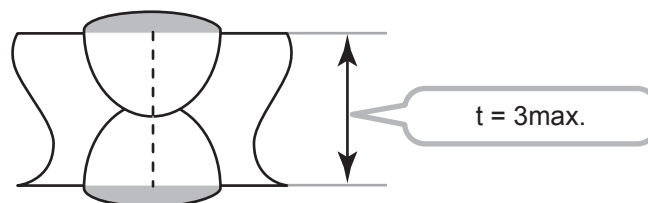


Fig 3.10 – Closed square butt



- Open square butt joint – The edges are not prepared but are separated slightly to allow fusion through the full thickness of the plate. The gap is equal to half the plate thickness, to within 1.5 mm. Suitable for steel up to 6 mm in thickness, but must be welded from both sides.

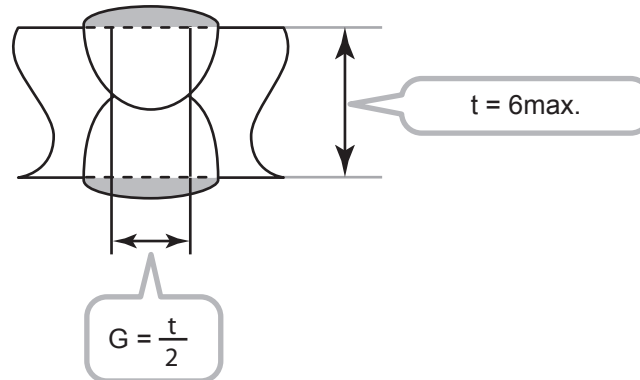


Fig 3.11 – Open square butt

- Open square butt joint with permanent backing material – This type of joint is used when welding plates up to 6 mm thick, where welding is possible from one side only. The gap is equal to the plate thickness. Complete fusion of the weld into the backing material must be obtained.

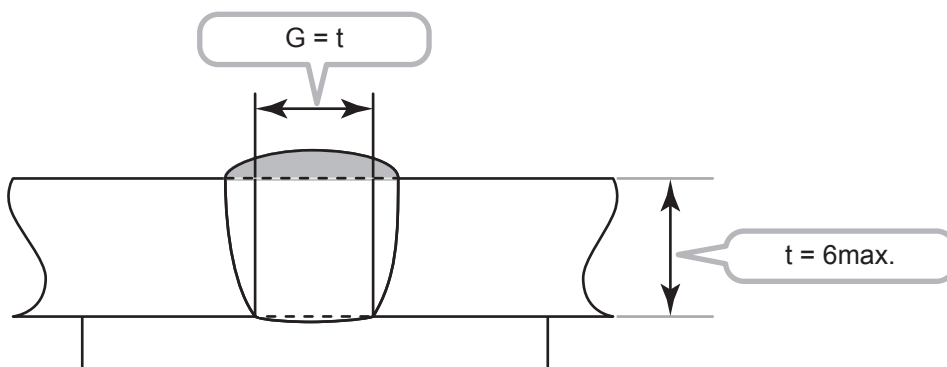
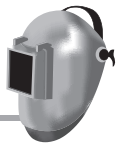
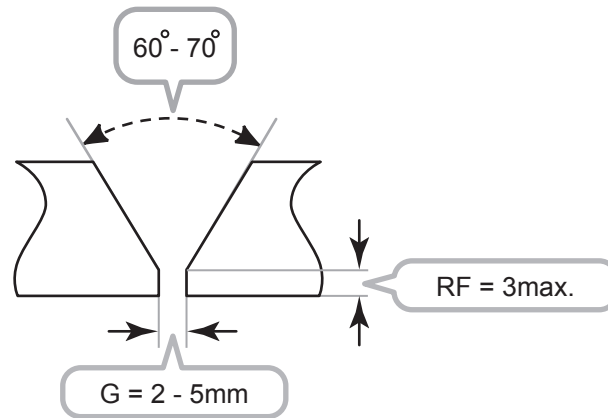


Fig 3.12 – Open square butt with backing material



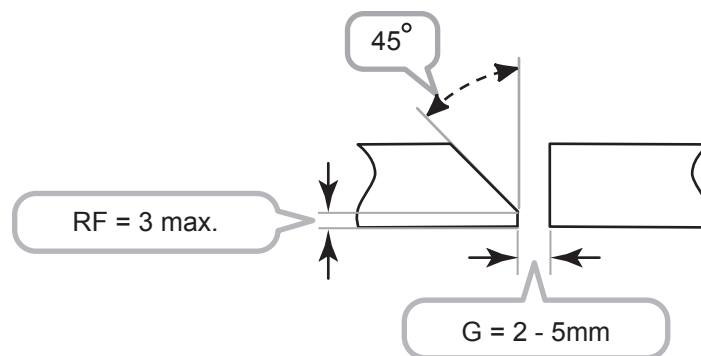


- Single vee butt joint – Used on steel up to 12 mm thick and on metal of greater thickness, where access from both sides is difficult. Where possible the back of the first run must be cleaned out and the job completed by deposition of a backing run.



**Fig 3.13 – Single vee butt**

- Single bevel butt joint – Applications for single bevel butt joints are as for single 'V' joints described previously.



**Fig 3.14 – Single bevel butt**



- Double vee butt joint – Used on plate 12 mm and over when welding can be applied from both sides. It allows a reduction in weld metal compared to a single 'V' preparation on the same thickness of steel. This type of preparation also tends to minimise distortion as the weld contraction is equal on each side of the joint. Not economical on steel over 50 mm thick.

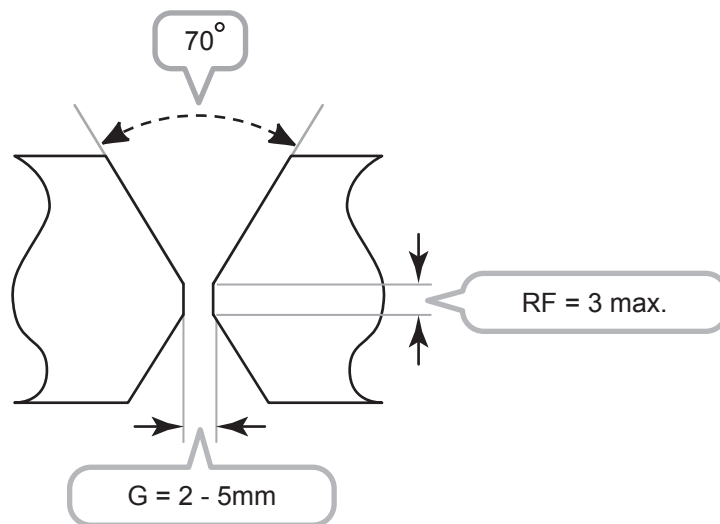


Fig 3.15 – Double vee butt

- Double bevel butt joint – Applications for double bevel butt joints are as for double 'V' joints described previously.

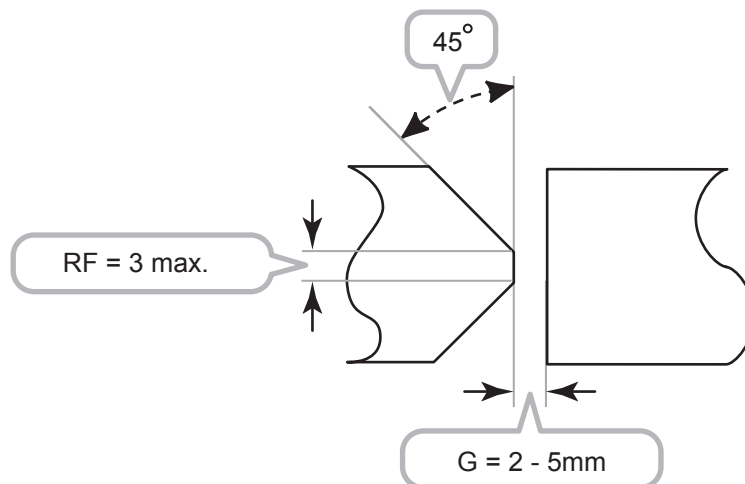


Fig 3.16 – Double bevel butt



### Backing runs

Backing material is used to support the root run of a butt weld, or to provide a sound weld through the full plate thickness, when access is possible from one side only.

To help reduce weld deposition rates complete penetration butt welds are often welded from both sides. The back of the first root run should be gouged and/or ground to clean metal to ensure complete penetration of the other side run.

### Backing material

Permanent backing material is known as a backing strip. Temporary backing material is known as a backing bar.

Backing strips are fused into the weld and should:

- be no less than 3 mm thick and be of sufficient size to ensure they do not burn through
- have weldability not less than that of the parent metal
- fit as close as possible with a maximum gap between the parent metal and the backing strip of 1.5 mm.

### Points to remember

- Test welds should be carried out to ensure the suitability of amperage/root face/gap combinations. Frequent tacks and a consistent gap should be used.
- For economy, an electrode of the largest possible size should be employed and where possible welding carried out in the downhand position.
- Small variations in gap or root face dimensions can significantly effect penetration and fusion in the root of a joint. Accuracy and consistency of weld preparation and fit-up is essential.



## Welding terms and positions

Abbreviation	Weld type
a	pad weld
b	lap weld
c	corner weld
d	plug weld slot weld
e	single vee butt weld
f	double vee butt weld
g	intermittent fillet welds
h	fillet weld

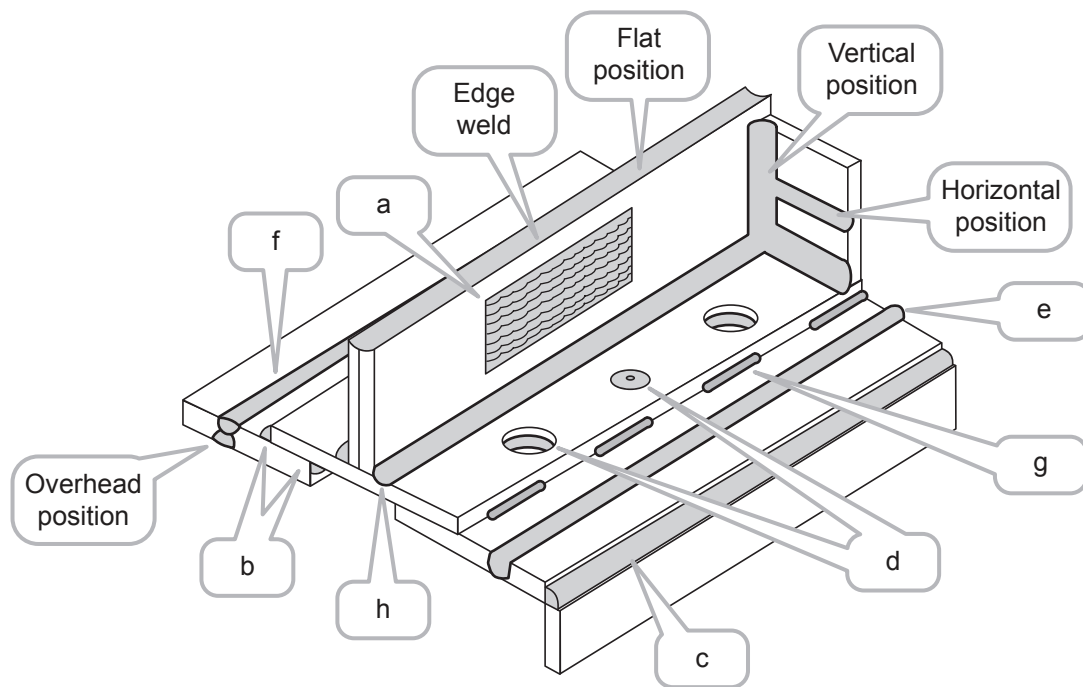


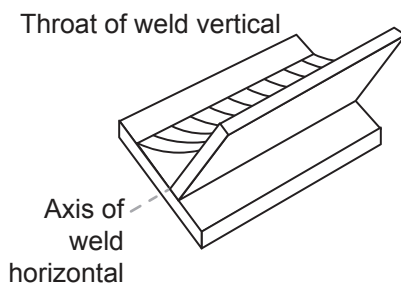
Fig 3.17 – Weld types



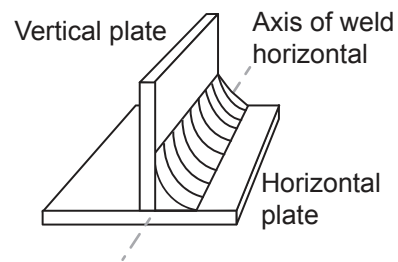


Terms	Weld description
1.F	flat fillet
2.F	horizontal fillet
3.F	vertical fillet
4.F	overhead fillet

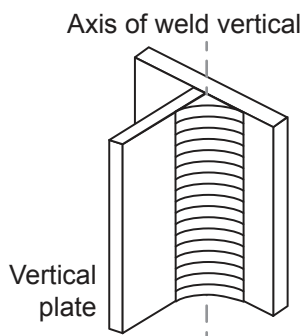
1.F



2.F



3.F



4.F

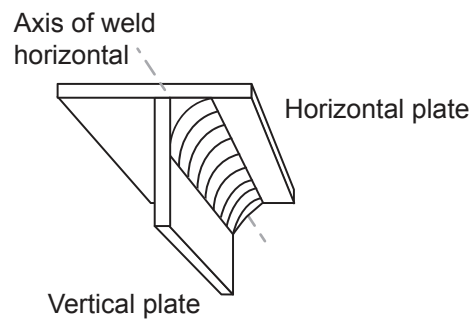


Fig 3.18 (a) – Fillet weld terms



Terms	Weld description
1.G	flat butt weld
2.G	horizontal butt
3.G	vertical butt
4.G	overhead butt
5.G	fixed pipe axis horizontal
6.G	fixed pipe axis 45 degrees

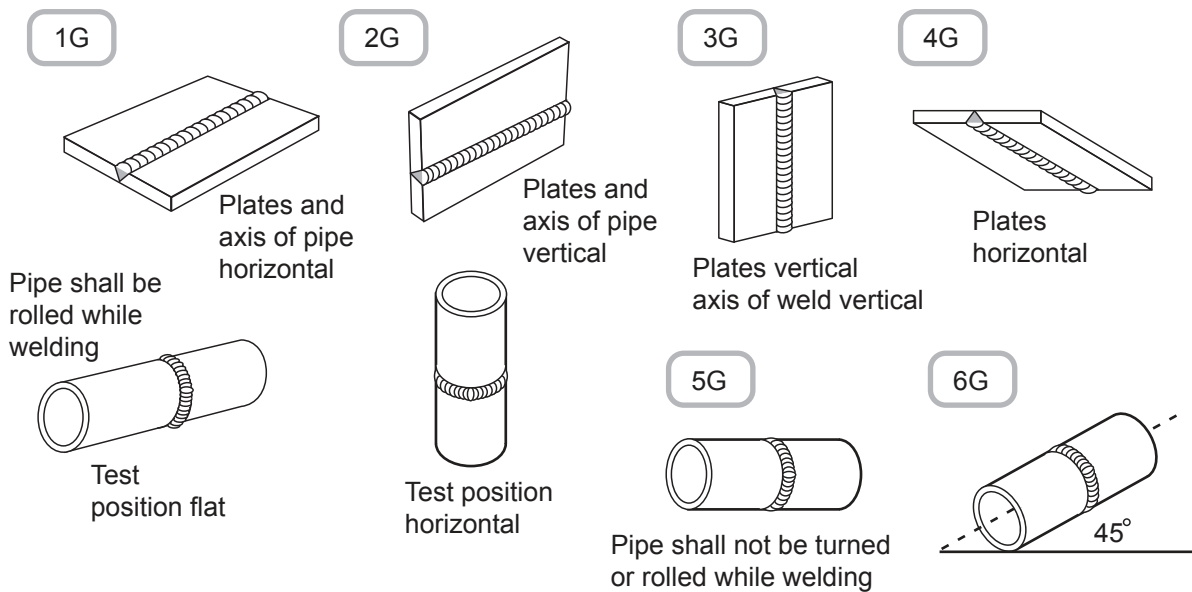


Fig 3.18 (b) – Butt weld terms



- The flat position is also referred to as the downhand position.
- The welding position 'VERTICAL' can be 'VERTICAL UP' and 'VERTICAL DOWN' and hence application codes make no distinction between the two.
- A fillet weld where one plate is in the flat position and one plate is in the vertical position, is commonly referred to as an H/V (horizontal/vertical) fillet.

## Activity

Refer to Australian Standard® AS/NZS 1554 Structural steel welding to further research the various weld preparations that are available for use by the code. Note how the specifications required for the weld preparations are altered to suit the various welding processes and for various positions.



# Chapter 4 – Manual metal arc welding (MMAW)

## Introduction

Manual Metal Arc Welding (MMAW) is one of the earliest of the arc welding processes, but has remained popular despite the introduction of newer and more sophisticated processes. Indeed, this lack of sophistication is one of the major attractions of the process.

In this chapter you will look at the following.

- The process
  - applications
  - advantages
  - limitations
- Equipment
- MMAW variables
  - amperage
  - angle of approach
  - angle of travel
- MMAW faults
- MMAW electrodes
  - functions of flux coating
  - types of coating
  - care of electrodes
  - electrode deterioration
  - storage of electrodes
  - redrying of electrodes
  - electrode classification.

At the end of the chapter, you will complete an activity.



## The process

The MMAW process operates as follows.

A low voltage, high amperage current flows to create an arc between the tip of the electrode and the work piece. This generates the heat for welding and causes the work piece and the tip of the electrode to melt.



Term	Definition
amperage	a measurement of the amount of electrical current

The flux coating on the electrode decomposes (burns) due to the intense heat of the arc and generates a gaseous shield, which protects the weld pool and surrounding hot metal from the atmosphere.

The electrode melts off and is transferred across the arc in the form of droplets. The molten metal provided by the electrode adds to the molten parent metal and they become the weld metal when solidified.

Molten electrode flux which is transferred across the arc acts as a scavenger, picking up impurities from the surface of the parent metal. The slag which forms covers the weld pool, solidifies, and protects the hot weld metal as it cools.

The flux ingredients provide arc ionisation (the air gap between the tip of the electrode becomes electrically conductive), enabling the use of alternating current.

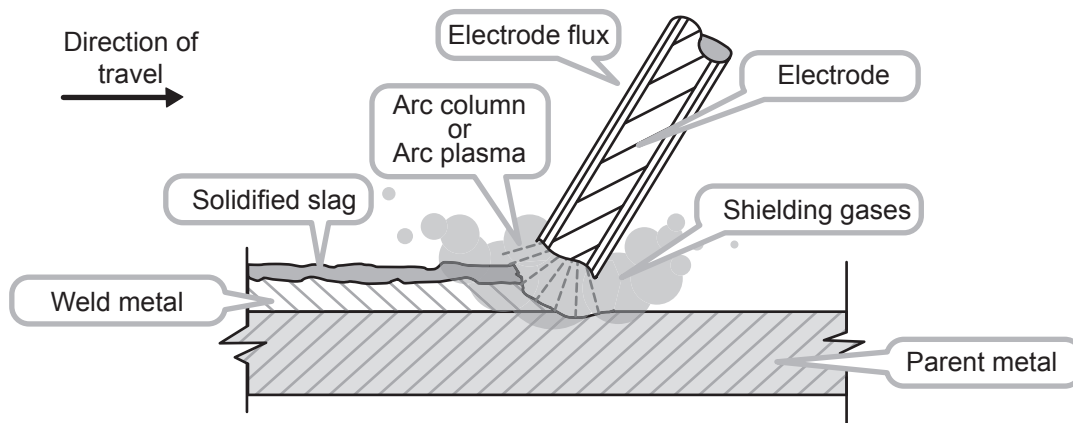


Fig 4.1 – Arc welding







### Applications of the process

Many welding operators have grown up using the MMAW process. This familiarity and the fact that it is simple to set up and use, makes it first choice for selection in many instances. The low cost of equipment makes the process accessible to most people, and MMAW has no special requirements such as external gas shielding or high-frequency arc initiation. Sound welds are easily produced and the process doesn't tend to result in weld defects such as lack of fusion which is common in GMAW.

MMAW is widely used for:

- structural work
- pressure vessels
- piping
- maintenance welding
- site construction
- general fabrication.

### Advantages of the process

The advantages of the MMAW is its versatility and the availability of a wide range of consumables. Set-up time is short, making the process ideal for small jobs, short production runs, and where the welding is carried out on site.

MMAW offers the following advantages over other welding processes:

- low capital cost for equipment
- versatility across a wide range of applications
- simple, reliable equipment
- low maintenance of equipment
- ideal for site work
- wide operator appeal
- sound, reliable welds.

### Limitations of the process

Although faster than some welding processes, MMAW has lower deposition rates than many of the newer welding processes that use a higher current. The process has a low operator duty cycle, with the operator spending a lot of time changing electrodes and chipping slag. These two factors combine to limit the application of this process, especially if high production rates are required.



## Equipment

Equipment for manual metal arc welding consists of the following.

- Power source – usually a constant-current type output transformer or transformer rectifier is used, although various other types of power sources, such as generators or inverters can also be used. The function of the power source is to supply welding current with sufficient amperage to provide the necessary heat, at a voltage which is safe to use.
- Electrode handpiece and lead – to carry current to the arc via the electrode.
- Work return lead – connects the work piece to the power source thereby completing the welding circuit. (A closed circuit is necessary for current flow).

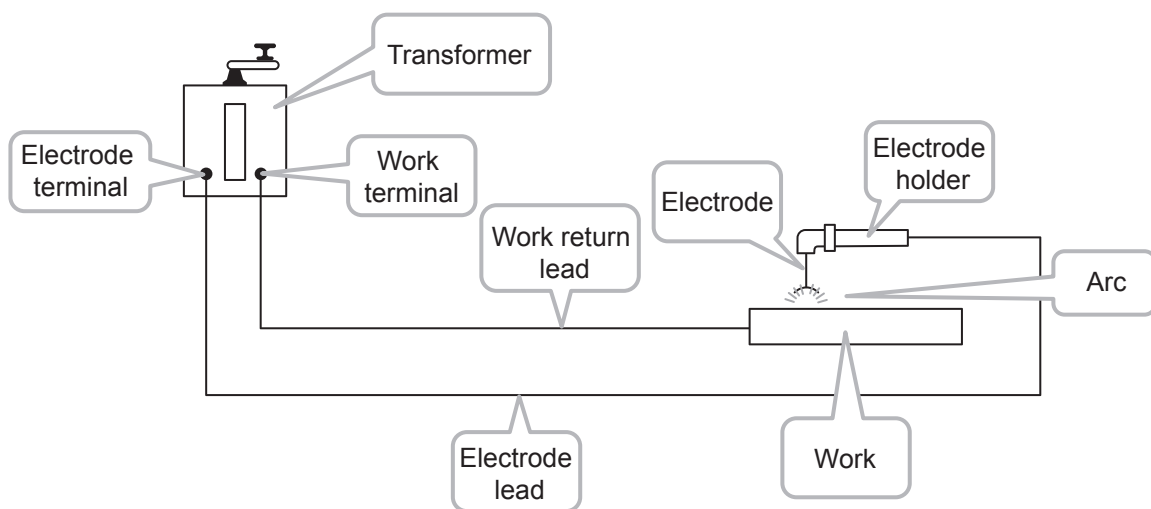


Fig 4.2 – Manual metal arc welding equipment

## MMAW variables

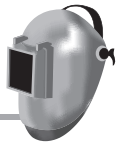
The major variables of the MMAW process are:

- amperage
- arc length
- travel speed
- angle of approach
- angle of travel.



Arc voltage is not considered to be a variable in the MMAW process as this is essentially dependent on the electrode flux type and only varies from around 21–25 volts.



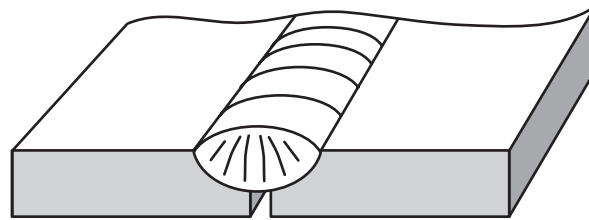


### Amperage

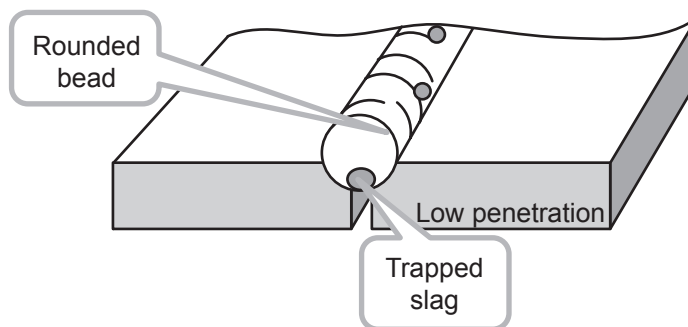
An increase in amperage will:

- increase the heat of the welding arc
- increase fusion and penetration
- give a higher deposition rate
- increase arc force
- enable easier arc starting
- give a more fluid weld pool
- increase spatter
- increase emission of ultra violet radiation.

Correct current



Current too low



Current too high

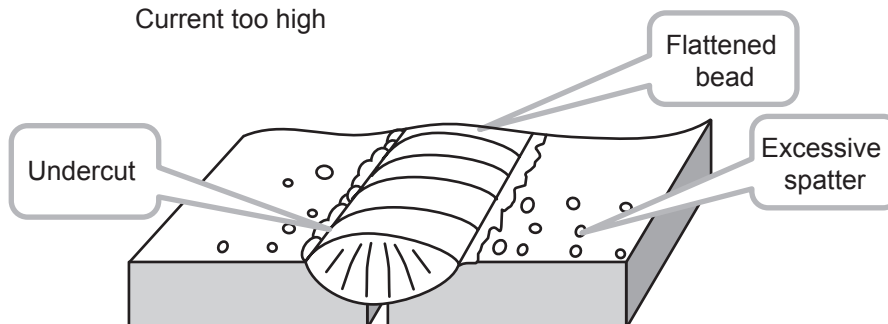


Fig 4.3 – Effects of amperage



A decrease in amperage will have the opposite effect.

As the size and thickness of the metal to be welded increases, so the heat required for fusion increases, necessitating higher amperages. Also the higher the heat input, the slower the cooling rate of the weld zone. Slow cooling rates are generally desirable when welding most metals.

A simple equation is: **VOLTAGE x AMPERAGE = HEAT**

### Angle of approach

Another simple rule for welders is that the metal goes where you point the electrode. Following that rule, it can be seen in the fillet weld example below that to get an even weld build up, the electrode must be pointed evenly at both plates, ie 45° and the welding arc is 'directional', that is metal transfer is essentially along the line of the electrode.

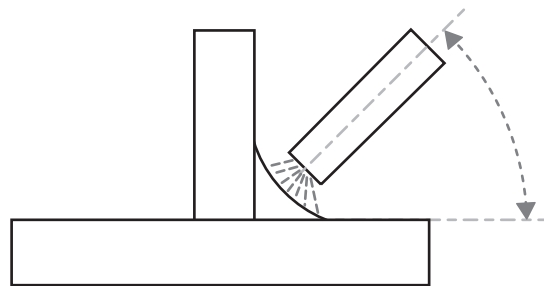


Fig 4.4 – Angle of approach

Unless attention is given to the angle of approach, defects such as slag inclusions, lack of fusion and penetration, and unacceptable weld contours may result.

### Angle of travel

The angle of travel is established essentially as a means of keeping the molten weld pool behind the arc, and preventing the slag from catching up to the electrode and causing slag inclusions. Although the angle of travel is commonly set at 60–70° many factors such as amperage, electrode type, and travel speed will determine the actual angle used. It should be noted however that the angle of travel used should be the minimum required for slag control, as laying the electrode too flat causes problems such as poor appearance, excessive spatter, reduced penetration, and a narrow, convex bead shape.

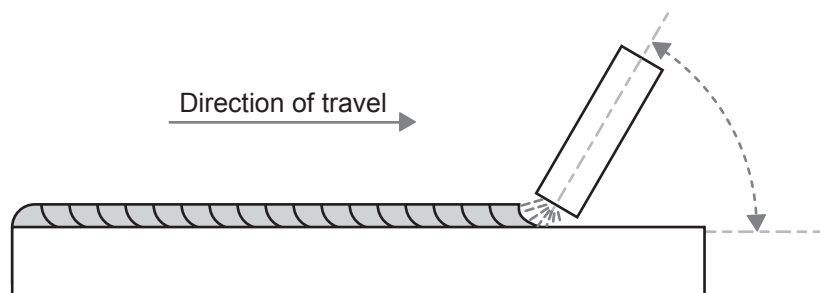
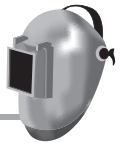


Fig 4.5 – Angle of travel



Term	Definition
slag inclusions	imperfections of the weld metal or surface caused by slag (impurities in the molten mix)

## Manual metal arc welding faults

The defects commonly encountered in MMAW are:

- weld cracking
- porosity
- slag inclusions
- lack of fusion
- insufficient or excessive penetration
- contour faults
- undercut
- excessive spatter
- stray arcing.

### Cracking

Cracking is considered to be a serious weld fault and rarely is any amount of cracking tolerated.

Cracks may be described depending on how, when and where they occur, eg longitudinal, transverse, crater, centre line, hot, cold, toe and underbead. Cracks may occur in either the parent metal, usually as fusion or heat affected zone cracks, or in the weld metal.

**Hot cracking** – Usually occurs in metals that are hot, short and/or have high rates of thermal expansion. Hot cracking most commonly occurs in the weld metal with the most common examples being longitudinal and crater cracks.

**Cold cracking** – Most commonly occurs in the base metal adjacent to the fusion zone. The most common example of this is underbead cracking in hardenable steels.

**Crater cracks** – These come from hot shrinkage. The crater solidifies around all sides toward the centre, leading to a high concentration of stress at the centre of the crater. If the metal lacks ductility, or the hollow crater cannot accommodate the shrinkage, cracking may result. Crater cracks may, under stress, spread from the crater and lead to failure of the weldment.

Cracking in MMAW welds on mild steel is generally not a major problem.



### **Porosity**

Porosity in MMAW welds can be the result of welding on a parent metal that is susceptible to this condition (such as steel that contains high amounts of dissolved gases or sulphur). Porosity may also be caused by welding on dirty material or material contaminated with moisture, oil, paint or grease. The electrode may have been contaminated, or too much current or too long an arc length used.

### **Slag inclusions**

Slag inclusions in MMAW can occur at the weld root; between weld runs, or on the weld surface. They generally occur in MMAW as a result of low amperage, poor electrode manipulation, working on dirty or contaminated metal, or incorrect joint preparation.

### **Lack of fusion/lack of root penetration**

With MMAW, lack of fusion or lack of root penetration is commonly caused by low amperage, working on dirty or contaminated material or using the wrong joint configuration, electrode angle or travel rate.

### **Excessive penetration**

Excess weld metal protruding through the root of a butt weld may occur in MMAW because of incorrect joint preparation, wrong electrode choice, excessive amperage or incorrect variables.

### **Contour defects**

Contour defects may be in the form of insufficient or excessive leg size, overroll or overlap, excessive convexity or concavity of the bead, or simply a rough, uneven appearance.

These are mainly caused by the operator but by using the correct electrode, amperage, travel speed and electrode angle adjustments, many of these problems can be fixed.

### **Undercut**

Undercut in MMAW is defined as a groove or channel in the parent metal, occurring continuously or intermittently along the toes or edge of a weld.

Undercut is a common problem in MMAW and can be caused by excessive amperage, too long an arc length, wrong electrode angles, or wrong travel rate.

### **Excessive spatter**

Although some spatter is a normal part of MMAW, excessive spatter is ugly and difficult to remove. Some electrode types produce more spatter than others, but generally excessive spatter is caused by high amperage or too long an arc length.

### **Stray arcing**

Defined as damage to the parent metal resulting from the accidental striking of an arc away from the weld.





Even though stray arcing is not a major problem associated with the MMAW of mild steel, it is good practice to take precautions against accidental arcing of the electrode anywhere other than in the weld zone.

Stray arcing can lead to serious weld failure in a material that is crack sensitive, or is going to be put in a stressed situation.

## Manual metal arc welding (MMAW) electrodes

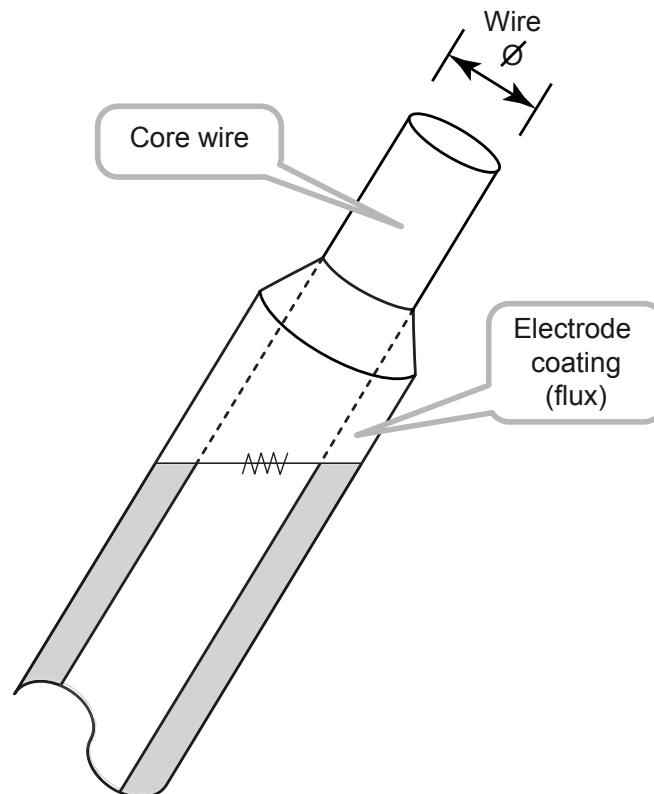


Fig 4.6 – Electrode construction

The manual metal arc welding electrode consists of a core of wire surrounded by a flux coating. The wire is generally of similar composition to the metal to be welded. The flux is applied to the wire by the process of extrusion. For welding carbon and low alloy steels (the metals most commonly fabricated using the MMAW process) electrodes will have one of four flux types, either:

- cellulose type coating
- rutile type coating
- hydrogen controlled coating (low hydrogen)
- iron powder type coating.

The flux coatings (from which the electrode types take their name) account for the major differences between electrode types.

The ingredients of the flux coating are carefully controlled so as to give desirable running characteristics and weld metal properties.



Among these desirable running characteristics are:

- arc stability
- ease of striking
- elimination of porosity
- minimum spatter
- elimination of noxious fumes and odours
- a tough durable coating
- control of penetration
- high deposition rates
- desirable physical and mechanical weld metal properties.

The aforementioned list is by no means exhaustive and many characteristics are incompatible, eg deep penetration and minimum spatter. Therefore when choosing an electrode for use, compromises must be made.

The choice of an electrode for a particular application depends upon:

- the composition of the parent metal
- the size and thickness of the parent metal
- the mechanical properties required of the weld metal
- the physical properties required of the weld metal
- the welding position
- the amount of penetration required
- the amount of spatter allowable
- available welding current
- deposition rate required
- appearance
- cost
- slag detachability
- weld contour and size
- fluidity of the slag
- operator appeal.

### **Functions of the flux coating**

In the early days of arc welding, bare wire electrodes were used. The results obtained from these electrodes left much to be desired. Over the years, electrodes have improved and flux coatings have evolved to the stage where the deposited weld metal, in many cases, has better metallurgical properties than the parent metal.







The flux coating of the electrode has many functions. It:

- provides a gaseous shield to protect the weld from atmospheric contamination
- provides arc ionisation. This gives a stable arc and enables the use of AC
- controls the chemical composition and properties of the deposited weld metal
- controls the deposition rate
- controls spatter
- influences the degree of penetration
- provides slag which performs the following functions:
  - forms a protective cover over the weld metal to prevent the formation of oxides while the weld metal is cooling
  - acts as a scavenger to remove oxides and impurities from the weld
  - helps to produce the correct bead shape and improve weld appearance
  - slows the cooling rate of the weld metal
  - enables 'positional' welding.

Some of the ingredients used in flux are:

- wood pulp (cellulose), titanium dioxide (rutile), limestone, fluorspar, silica, and feldspar – for producing slag and shielding gas
- ferro-manganese and ferro-silicon – used as deoxidisers
- potassium and sodium silicates, used as binders
- clays and gums – used as binders
- ferro-chromium, ferro-molybdenum and nickel powder – for alloying
- iron powder and iron oxide – to increase deposition.

### Electrode coating types

Electrodes by coating types				
cellulose (wood pulp base)	rutile (titanium dioxide)	basic (calcium carbonate)	rutile plus iron oxide	rutile plus iron powder

As shown above, there are five basic electrode coating types used to make electrodes for the welding of carbon and low alloy steels.

These coating types are then arranged into four basic electrode types or groups, which are:

- cellulose
- rutile
- hydrogen-controlled
- iron powder.



The general characteristics for each of these groups are as follows.

### Cellulose

These electrodes contain a high percentage of alpha flock (wood flour) and 3–7% moisture in the coating. This provides the fiery, deep-penetrating arc characteristic of cellulose electrodes. Cellulose electrodes run on low amperages compared to rutile electrodes (approximately 15%) and the thin, fluid slag does not completely cover the finished weld deposit. High spatter levels are produced and the weld appearance is characterised by coarse, uneven ripples.

Application – used for the first (root) run on pipes and plates, welding in the vertical position (particularly vertical down) and wherever deep penetration is required.

Storage conditions – should contain 3–7% moisture for best results. Do not store in electrode ovens.

### Rutile

These electrodes contain a high proportion of titanium-dioxide and are known as the general purpose group of electrodes. They are used for general welding of low carbon steels, and are suitable for use in all welding positions.

Rutile electrodes have a smooth running and stable arc, low to moderate spatter levels and moderate penetration. Most of them operate on AC or DC and have good appearance and easy slag detachability.

Rutile electrodes may also have small amounts of iron oxide added to them to give them a fiery more penetrating arc.

Application – used for general purpose welding on most joint types and weld positions.

Storage conditions – rutile electrodes have no special storage requirements. Storage in a warm dry place is sufficient.

Electrode diameter	E4312	E4313	E4314
2.6 mm	50–90	50–90	60–110
3.25 mm	90–40	90–140	95–150
4.0 mm	130–190	130–190	140–200

Table 4.1 – Approximate amperages for rutile electrodes

### Hydrogen-controlled (low hydrogen)

These electrodes have coatings of calcium carbonate and are designed to produce low hydrogen levels in the deposited weld metal as a means of minimising cracking in the heat affected zone. They are characterised by a globular transfer of metal across the arc, low penetration as a means of minimising weld metal dilution, and fluid slag.





Term	Definition
globular transfer	a type of metal transfer in which molten filler metal is transferred across the arc in large droplets

Application – hydrogen-controlled electrodes are used for welding high strength steels and produce tough, ductile weld metal with tensile strengths in excess of 490 N/mm<sup>2</sup>. Amperages used are similar to rutile electrodes but they require a minimum of 60 OCV.

Storage conditions – should contain less than 0.2% moisture. They are supplied in sealed packets or cans to prevent absorption of moisture from the atmosphere. Upon opening, the electrodes should be transferred to an electrode oven and conditioned at 300 °C for at least one hour before use. Once they have been conditioned (all moisture is driven off) they should be kept at a minimum temperature of 100 °C. They should be used 'hot' from the oven and not allowed to cool.

### Iron powder/iron oxide

These electrodes have coatings which contain a high percentage of iron in the form of iron powder and/or iron oxide. They are characterised by high deposition rates, smooth arcs, low spatter, good appearance and excellent slag detachability. The heavy flux coating necessitates higher amperages be used as compared to other electrode types.

Application – electrodes containing iron powder in the flux coating are commonly used for structural welding of low carbon steels and are suitable for welding in the flat position only.

### Care and storage of electrodes

The condition of electrodes can seriously affect the quality of the welded joint, particularly when dealing with alloy and high strength steels.

#### Types of electrode deterioration

The condition of flux-coated electrodes may deteriorate due to:

- excessive absorption or loss of moisture
- mechanical breakage of coverings
- formation of surface deposits
- contamination.

#### Excessive absorption or loss of moisture

During the manufacturing process the coated electrodes are dried to a predetermined moisture level, giving the optimum welding characteristics for that particular electrode. Hydrogen-controlled electrodes require the minimum of moisture; on the other hand, cellulose electrodes require up to 7% moisture.



The absorption of excessive moisture by the coating, either from the atmosphere, condensation, or from other sources, can cause:

- weld metal porosity
- excessive spatter
- arc instability
- poor weld contour
- undercut
- difficulty with slag removal
- blistering of the flux coating, especially with cellulose types
- increased risk of lamellar tearing
- increased risk of hydrogen induced cracking.



Term	Definition
lamellar tearing	damage or tearing of layers

### Mechanical breakage of coverings

Coated electrodes are reasonably robust but the covering can be damaged by rough careless handling or by excessive bending. Loss of covering leads to erratic arcing, and inadequate protection of the molten weld metal. For this reason, it is good practice to discard electrodes with mechanically damaged coverings.

### Formation of surface deposits

Electrodes that have been kept for long periods of time in non-ideal storage conditions, usually form a white powdery deposit on the flux coating. This deposit is produced by a chemical reaction between the carbon dioxide in the atmosphere and the sodium silicate of the flux binder. This reaction forms crystals of sodium carbonate and silica powder. If there are heavy deposits on the covering it is possible that rusting of the core wire has occurred, which may lead to hydrogen-induced cracking. Heavy surface deposits indicate that redrying of the electrodes is required.

### Contamination

The coating of electrodes can become contaminated by oil, grease, paint and other fluids through bad handling or storage practices. Some contaminants, such as paint, may introduce undesirable material into the weld and others may interfere with the welding process. Oil, for instance, is also a source of hydrogen and may lead to hydrogen-induced cracking.

### Recommended practices

Deterioration of the types described above can be prevented or sometimes corrected by adopting good practices in packaging, handling, transport and storage.





### Storage of electrodes

Electrodes are supplied in sealed packets or cans to prevent absorption of moisture. They should be stored in a moisture-free environment that has a fairly even temperature. Electrode packets, cans, and bulk packs should not be opened until required for use.

Once the electrode container is opened the following procedure should be adopted.

- Mild steel electrodes should be stored in a warm dry place.
- Cellulose electrodes must not be stored in an electrode oven.
- Hydrogen controlled electrodes should be conditioned and stored in an electrode oven at a minimum temperature of 100 °C.

When retrieving electrodes from storage they should be used in order of receipt. This method will ensure that electrodes do not remain in storage for any length of time.

### Redrying of electrodes

Redrying of electrodes when their moisture content exceeds the recommended range should be carried out in accordance with the manufacturer's specifications. The manufacturer provides guidance in this area.

- Electrodes (other than hydrogen controlled) that are affected by excessive moisture content can be redried at 120 °C for approximately one hour.
- Hydrogen controlled electrodes that are affected by excessive moisture content can be redried at 400 °C for half to one hour's duration. If facilities to carry out this procedure are not available then drying for a minimum of one hour at 250 °C will do for most applications. Note: the redrying or reconditioning of hydrogen controlled electrodes is not recommended for critical welds.

### Electrode classification

MMAW electrodes are classified under the Australian Standard® AS/NZS 4855 Covered electrodes for manual metal arc welding of non-alloy and fine grain steels – Classification.

This standard deals with the manufacture, testing, marking and packaging, and classification of covered electrodes for manual metal arc welding.

The classification system of the code provides a mechanism for identification of the various electrodes; their description, characteristics and applications.



### Australian Standard® AS/NZS 4855

The Classification system consists of the following, as per ISO 2560B.

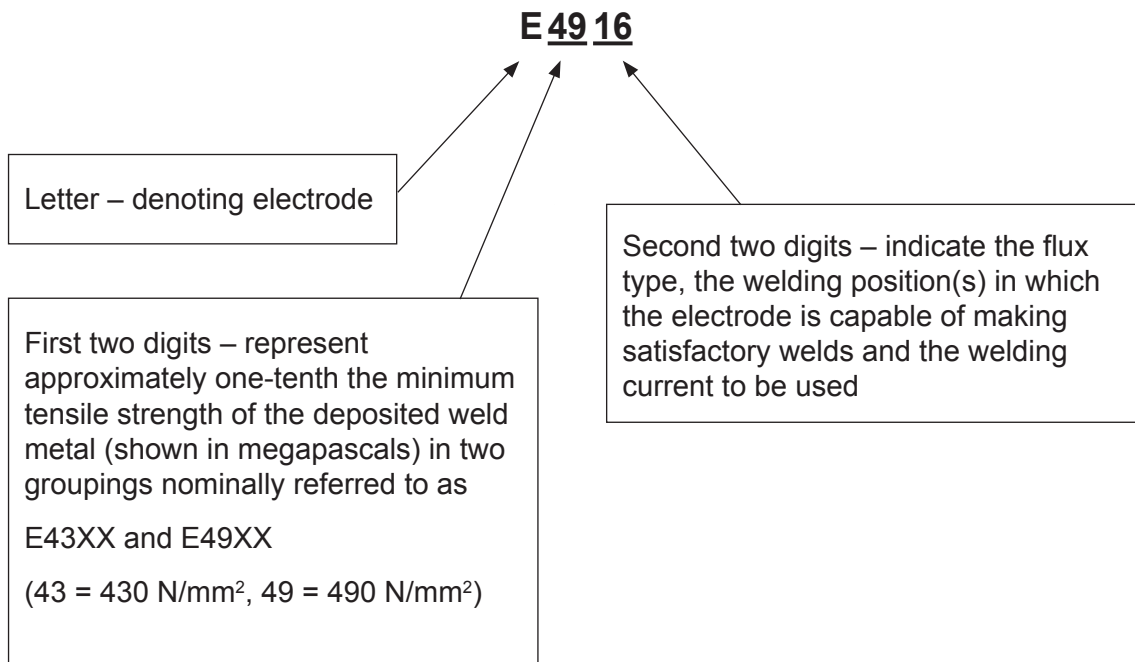


Fig 4.7 – Electrode classification to AS/NZS 4855

#### **EXX10 and EXX11 electrodes (E4310, E4311, E4910)**

Electrodes of EXX10 and EXX11 classification have thin coatings which contain at least 15% cellulose and up to 30% titania as rutile or titanium white.

Cellulose electrodes operate with a forceful, deeply penetrating spray type arc with fairly high spatter. As a result of the decomposition of the cellulose material, a voluminous gas shield is formed around the arc region, protecting the weld metal from atmospheric contamination. The slag is very fluid, thin, friable and easily removed when cold, but may not appear to completely cover the deposit.

Table 4.2 shows a brief summary of the electrode types covered in Australian Standard® AS/NZS 4855.





Symbol	Type of covering	Welding positions <sup>a</sup>	Type of current
03	Rutile basic	All <sup>b</sup>	a.c. and d.c. (±)
10	Cellulosic	All	d.c. (+)
11	Cellulosic	All	a.c. and d.c. (+)
12	Rutile	All <sup>b</sup>	a.c. and d.c. (-)
13	Rutile	All <sup>b</sup>	a.c. and d.c. (±)
14	Rutile + iron powder	All <sup>b</sup>	a.c. and d.c. (±)
15	Basic	All <sup>b</sup>	d.c. (+)
16	Basic	All <sup>b</sup>	a.c. and d.c. (+)
18	Basic + iron powder	All <sup>b</sup>	a.c. and d.c. (+)
19	Ilmenite	All <sup>b</sup>	a.c. and d.c. (±)
20	Iron oxide	PA, PB	a.c. and d.c. (-)
24	Rutile + iron powder	PA, PB	a.c. and d.c. (±)
27	Iron oxide + iron powder	PA, PB	a.c. and d.c. (-)
28	Basic + iron powder	PA, PB, PC	a.c. and d.c. (+)
40	Not specified	manufacturer's recommendations	
48	Basic	All	a.c. and d.c. (+)
99	As described by manufacturer	As specified by manufacturer	As specified by manufacturer

NOTE: A description of the characteristics of each of the types of covering is given in annex C.

<sup>a</sup> Positions are defined in ISO 6947. PA = flat, PB = horizontal vertical fillet, PC = horizontal, PG = vertical down.

<sup>b</sup> All positions may or may not include vertical down welding. This shall be specified in the manufacturer's trade literature.

**Table 4.2 – Welding position, current and covering type**



Term	Definition
friable	easily broken into small fragments or reduced to a powder



These electrodes are readily used in all positions and are suitable for all types of welding on low-carbon steel. Special applications recommended for these electrodes involve changes in welding position during the running of the electrode (eg pipe welding in situ). Sizes larger than 5 mm are not generally used in all positions.

For optimum performance, the coating of these electrodes must contain 3–7% moisture. Operating characteristics will be adversely affected if excessive drying occurs.

Owing to the burn out of the coating and high spatter loss, maximum current values are limited. However, with current values near the maximum these electrodes can be used for deep penetrating welds in the flat and horizontal positions (eg square butt joints).

EXX11 electrodes can be used with AC or DC current. EXX10 electrodes can only be used with DC. When operating on DC current, positive polarity is preferred.

### **EXX12 electrodes (E4312)**

EXX12 electrodes have thin coatings containing a high proportion of titania as rutile, titanium white or ilmenite.

These electrodes are designed to operate from AC or DC power sources. Electrode negative is the preferred polarity with DC current. The arc is usually stable at low open circuit voltages.

The electrodes have a fairly viscous, full-covering slag that is easily removed when cold, except perhaps from the first run of a deep vee. The arc is quiet, medium penetrating and with low spatter.

These electrodes are recommended for general purpose use with structural fabrications and sheet steels. Due to the viscosity of the slag, some of these electrodes are suitable for vertical down welding.

### **EXX13 electrodes (E4313)**

EXX13 electrodes have thin coatings containing a high proportion of titania as rutile, titanium white or ilmenite with the addition of basic materials to increase the fluidity of the slag.

These electrodes demonstrate the same arc characteristics as EXX12 electrodes and can be operated from AC or DC power sources. Electrode negative is the preferred polarity with DC current.

Due to the fluid slag that the EXX13 electrode produces (more fluid than other types of rutile electrodes) the EXX13 electrodes are more suitable for welding in the vertical up or overhead positions, and are unsuitable for welding vertical down.

### **EXX14 electrodes (E4314)**

EXX14 electrodes have medium-thick coatings containing a high proportion of titania white or ilmenite, and sufficient iron powder to give metal recovery rates 105–130% of the mass of the core wire melted.

The slag is fairly viscous, full covering and easily removed when cool. It is sometimes self-releasing. The arc is medium penetrating and with low spatter.

These electrodes are successfully operated from AC or DC power sources including those with low open circuit voltages. Electrode negative is the preferred polarity when welding with DC current.







Due to the medium-thick coating containing iron powder, operating characteristics are improved allowing touch welding to be carried out. Slag is not excessive and these types of electrodes are recommended for use in general shop and structural fabrication.

### EXX15 and EXX16 electrodes (E4915, E4916)

EXX15 and EXX16 electrode classifications have coatings containing a high proportion of basic material such as limestone, and fluorides such as fluorspar. The coating ingredients are specially selected for low-hydrogen content and during manufacture the electrodes are baked at high temperatures to remove moisture.

EXX15 electrodes are designed to operate from DC power sources only. EXX16 can be operated satisfactorily on AC or DC, with electrode positive being the preferred polarity.

The arc is quiet, medium to low penetrating with globular transfer of metal from the electrode to the weld pool and produces moderate spatter. The slag is very fluid, full covering and easily removed when cool.

These electrodes are particularly recommended for steels affected by underbead cracking. The virtual elimination of hydrogen from the arc atmosphere reduces the possibility of the defect occurring in difficult to weld steels such as medium and high carbon steels and low-alloy high tensile steels. Tough, ductile welds are produced with these electrodes and by keeping the hydrogen content low, preheat and post-heat temperatures can be reduced. Other uses include the welding of highly restrained joints in heavy sections, as the tendency for weld metal cracking is reduced, and the welding of free machining (high sulphur content) steels, as well as malleable cast iron.

It is recommended that as short an arc as possible be maintained in all positions of welding to prevent porosity, and that the electrode be used in a properly dried condition.



Term	Definition
underbead cracking	cracking in the heat affected zone, not extending to the surface of the base material

### EXX18 electrodes (E4918)

EXX18 electrodes have medium-thick coatings containing a high proportion of basic material such as limestone, fluorides such as fluorspar and sufficient iron powder to give metal recovery rates of 105–130% of the mass of the core wire melted. Manufacture of these electrodes is very similar to that of the EXX15 and EXX16 electrodes ensuring low hydrogen content.

Deposition rates are higher than with EXX15 and EXX16, owing to the iron powder content, and the extra thickness of the coating allows a higher current per corresponding core wire diameter to be used.

They are suitable for use with AC or DC, with electrode positive being the preferred polarity.



### **EXX19 electrodes**

Electrodes of EXX19 classification have coatings based on the mineral ilmenite and consequently have an arc action and slag characteristics between the EXX1 2/13 titania types and the EXX20 iron-manganese oxide type.

The electrodes are characterised by a rather fluid slag. They provide deeper penetration than the EXX13 group and excellent radiographic quality weld metal. They are designed for use on AC or DC electrode negative or positive, and are suitable for multi-pass welding steel up to 25 mm thick. Stable arc and good operational characteristics provide smooth even beads in all positions including the vertical (using the upward progression only). The weld metal has excellent ductility and crack resistance with good impact properties.

### **EXX20 electrodes (E4920)**

These electrodes have medium-thick coatings containing a high proportion of oxides and/or silicates of iron and manganese.

Using either AC or DC power sources, a spray type arc is produced with medium to deep penetration according to the current being used. The slag is voluminous, completely covers the deposit and is honeycombed on the underside. The slag is easily removed, even from the first run of a deep groove.

These electrodes are principally used for horizontal fillet and flat butt welds in heavy carbon steel plate where good penetration is required.

### **EXX24 electrodes (E4924)**

EXX24 electrodes have thick coatings containing a high proportion of titania as rutile, titanium white or ilmenite, and sufficient iron powder to give metal recovery rates in excess of 130% of the mass of the core wire melted.

Using AC or DC power sources (negative polarity preferred), these electrodes operate with a low to medium penetrating smooth spray type arc with very low spatter. The slag is fluid, full covering and dense, and when cool is self-releasing or easily removed.

Owing to the high iron powder content and increased coating thickness, high currents are required.

These electrodes are recommended for the high-speed welding of low carbon steel in the flat and horizontal positions. Touch welding technique is normally used.

### **EXX27 electrodes (E4927)**

EXX27 electrodes have thick coatings containing a high proportion of oxides and/or silicates or iron and manganese, and sufficient iron powder to give metal recovery rates in excess of 130% of the mass of core wire melted.

They are similar to the EXX20 electrodes but contain iron powder to increase deposition rates. They demonstrate similar arc characteristics and can be used with AC or DC current. Electrode negative is the preferred polarity.

Recommended usage of these electrodes is in the flat and horizontal fillet positions and they are particularly applicable to high speed welding of low-carbon steel where good penetration and ease of deslagging are required. Touch welding techniques are usually employed.





### **EXX28 electrodes (E4928)**

EXX28 electrodes have thick coatings containing a high proportion of basic material such as limestone, fluorides such as fluorspar, and sufficient iron powder to give metal recovery rates in excess of 130% of the mass of core wire melted.

They operate with a medium penetrating spray type arc and low spatter. The slag is fluid, full covering and easily removed. Power sources can be either AC or DC, with electrode positive being preferred.

These electrodes are restricted to use in flat and horizontal positions, and are generally used where large amounts of low-hydrogen weld metal in heavy sections is required. Touch welding techniques are usually used.

As with all hydrogen controlled electrodes, it is important to maintain a close arc to reduce the possibility of porosity, and that the electrodes used are properly dried.

### **EXX48 electrodes**

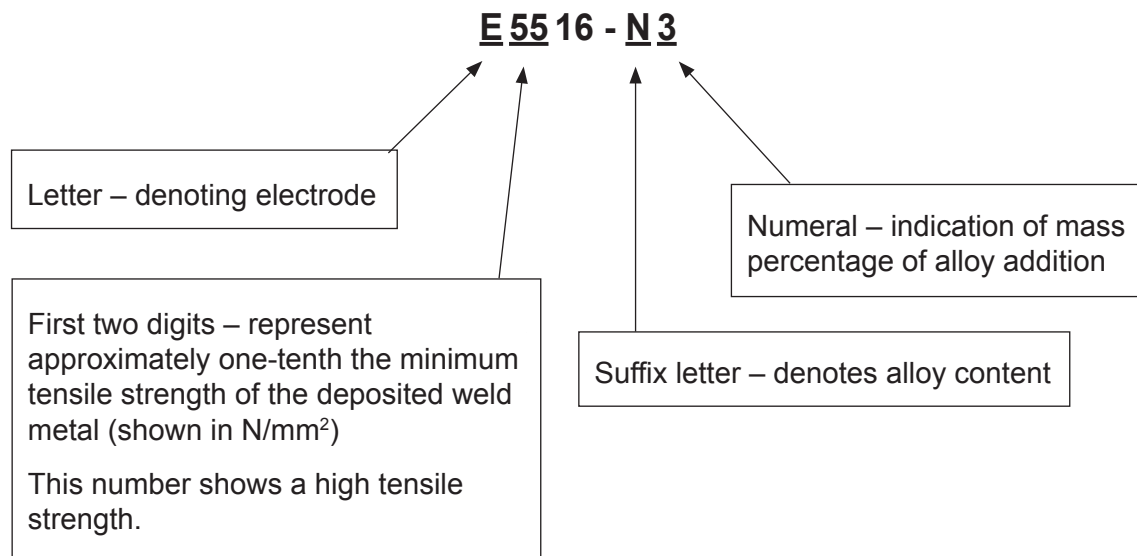
EXX48 electrodes demonstrate the same usability, composition, and design characteristics as EXX18. In addition these electrodes are specially designed for vertical down welding. Some electrodes of this type are designed to provide a flat to slightly concave, fully-loaded penetration bead without undercut on single vee welding, such as in piping and pipelines.

### **EXX99 electrodes**

The coating and running characteristics of electrodes in this classification are such that one or more features prevent their classification in any of the preceding classes.



An example of an electrode of this classification is shown below.



Importantly, the end of this classification contains the following.

- A suffix – the suffix consists of a letter (or letters) followed by a numeral. The letters denote the type of weld metal which the electrode deposits.  
eg: N3 = Ni  
mass % 1, 5
- Numerals – the numerals are used to give an indication of the percentage of alloy addition. As the percentage increases, so does the magnitude of the suffix numeral. The numerals range from one through five.





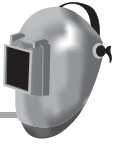
## Activity

In the workshop:

- identify safe working practices and protective equipment in the workshop
- identify a suitable MMAW welding plant
- with the mains power switch **OFF**, set up the MMAW plant (start by checking the electrical cable connections to the work lead and electrode handpiece)
- fit a 3.2 mm general purpose electrode into the electrode holder and adjust the amperage to suit
- with your lecturer's assistance, strike an arc between the electrode and scrap work piece
- with your lecturer's assistance, produce a weld on a practice piece of material.

Further information and understanding of the covered electrode classification system can be obtained by consulting Australian Standard® AS/NZS 4855 Welding consumables – Covered electrodes for manual metal arc welding of non-alloy and fine grain steels – Classification.





# Appendix

## Metals and fabrication competency mapping

### Basic Manual Metal Arc Welding (MMAW)

Chapter title	Comp code	Competency title	Full = ✓ Partial = *
1. Arc welding safety	MEM 5.12C	Perform routine manual metal arc welding	*
	MEM 5.13C	Perform manual production welding	*
	MEM 5.49B	Perform routine gas tungsten arc welding	*
	MEM 5.19C	Weld using gas tungsten arc welding	*
	MEM 5.15C	Weld using manual metal arc welding	*
	MEM 5.16C	Perform advanced welding manual metal arc welding	*
	MEM 5.50B	Perform routine gas metal arc welding	*
	MEM 5.17C	Weld using gas metal arc welding	*
	MEM 5.18C	Perform advanced welding gas metal arc welding	*
	MEM 5.23C	Weld using submerged arc welding	*
	MEM 5.51A	Select welding processes	*
	MEM 5.52A	Apply safe welding practices	*
	2. Electricity and welding machines	MEM 5.12C	Perform routine manual metal arc welding
MEM 5.13C		Perform manual production welding	*
MEM 5.49B		Perform routine gas tungsten arc welding	*



Chapter title	Comp code	Competency title	Full = ✓ Partial = *
	MEM 5.19C	Weld using gas tungsten arc welding	*
	MEM 5.15C	Weld using manual metal arc welding	*
	MEM 5.16C	Perform advanced welding manual metal arc welding	*
	MEM 5.50B	Perform routine gas metal arc welding	*
	MEM 5.17C	Weld using gas metal arc welding	*
	MEM 5.18C	Perform advanced welding gas metal arc welding	*
	MEM 5.23C	Weld using submerged arc welding	*
	MEM 5.51A	Select welding processes	*
	MEM 5.52A	Apply safe welding practices	*
3. Welding preparation and workmanship	MEM 5.4C	Perform routine oxy acetylene welding	*
	MEM 5.12C	Perform routine manual metal arc welding	*
	MEM 5.13C	Perform manual production welding	*
	MEM 5.15C	Weld using manual metal arc welding	*
	MEM 5.16C	Perform advanced welding manual metal arc welding	*
	MEM 5.50B	Perform routine gas metal arc welding	*
	MEM 5.17C	Weld using gas metal arc welding	*
	MEM 5.18C	Perform advanced welding gas metal arc welding	*
	MEM 5.51A	Select welding processes	*
4. Air-arc gouging	MEM 5.8C	Perform advanced manual thermal cutting, gouging and shaping	*





### **Basic Manual Metal Arc Welding (MMAW)**

This resource is specifically designed to provide basic underpinning knowledge related to a number of competency units used in the Engineering Tradesperson Fabrication (Heavy) pathway across TAFEWA from January 2007. This pathway was specifically designed to meet the needs of the heavy metal fabrication industry after industry consultation and TAFE WA moderation sessions held in 2006. This pathway is also designed to be common across all colleges of TAFEWA (customisation to suit local conditions is however encouraged). The pathway meets the requirements and guidelines of the MEM05 Training Package.

#### **Context of assessment**

Assessors are reminded the individual units may be assessed on the job, off the job or a combination of both on and off the job. Where assessment occurs off the job, that is the candidate is not in productive work, then an appropriate simulation must be used where the range of conditions reflects realistic workplace situations.

#### **Project work, integration**

These units could be assessed in conjunction with mandatory units addressing the safety, quality, communication, mathematics etc. Units may also be assessed with other units requiring the exercise of the skills and knowledge.

#### **Method of assessment**

Assessors should gather a range of evidence that is valid, sufficient, current and authentic. Evidence can be gathered through a variety of ways including direct observation, supervisor's reports, project work, samples and questioning. Questioning should not require language, literacy and numeracy skills beyond those required in this unit. The candidate must have access to all tools, equipment, materials and documentation required. The candidate must be permitted to refer to any relevant workplace procedures, product and manufacturing specifications, codes, standards, manuals and reference materials.

#### **Consistency of performance**

Assessors must be satisfied that the candidate can competently and consistently perform all elements of the units as specified by the criteria, including required knowledge, and be capable of applying the competency in new and different situations and contexts.



## Appendix – Competency mapping

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# BASIC MANUAL METAL ARC WELDING (MMAW)

## Learner's Resource

### DESCRIPTION

This book provides an introduction to basic manual metal arc welding (MMAW), specifically for the services tradesperson. It has four topics, as follows:

- Arc welding safety
- Electricity and welding machines
- Weld preparation and workmanship
- Manual metal arc welding

The content meets the requirements of the Unit MEM5.12 from the Metals Training Package. The book is divided into separate chapters, each containing workshop-based activities that will provide opportunities for practice before assessment.

Detailed technical drawings, diagrams and photographs are provided throughout.

### EDITION

2008

### CATEGORY

Metals & Engineering

### TRAINING PACKAGE

- MEM05

### RELATED PRODUCTS

- This book contains chapters from Arc Welding 1, Basic Arc Welding Information Book – refer product code ENG093.



Government of **Western Australia**  
Department of **Training**  
and **Workforce Development**

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