

ENG093



METALS & FABRICATION

ARC WELDING 1

Basic Arc Welding Information Book



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

www.vetinfonet.dtwd.wa.gov.au

ENG093

Arc Welding 1
Basic Arc Welding Information Book

Learning Resource

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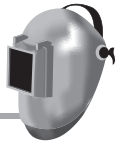


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Chapter 1 – Arc welding safety

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

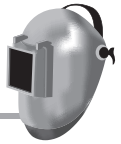


Fig 1.1 – Electric shock

- fumes



Fig 1.2 – Fumes



- radiation

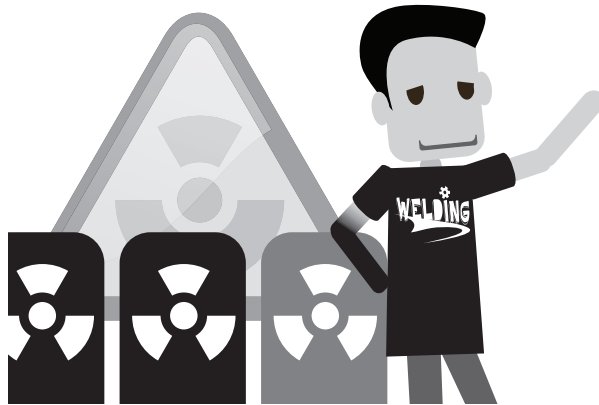


Fig 1.3 – Radiation

- 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.

1. That the OCV of welding machines is low enough to prevent easy passage of current through the body.	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
2. That electrical resistance in the welding circuit is low. The current will take the path of least resistance.	Maintain insulation on leads and handpiece Avoid moisture and use insulating gloves
3. That the current path is confined to the welding circuit.	Don't touch live parts Don't put body in current path

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

The amount of current passing through the body Increased voltage will result in greater current flow. Even quite low voltages can be dangerous where resistance is low.
The direction of the current flow If the current path is via vital organs then the risk of serious injury is much greater.
The body resistance 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.
The duration of the current flow A longer exposure to electric current means a greater risk of consequence.
The state of health of the person receiving the shock 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.



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



BOC Limited © 2006

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.

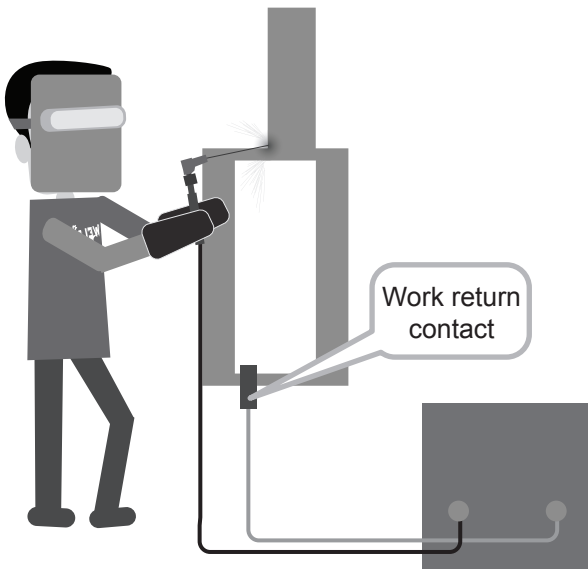
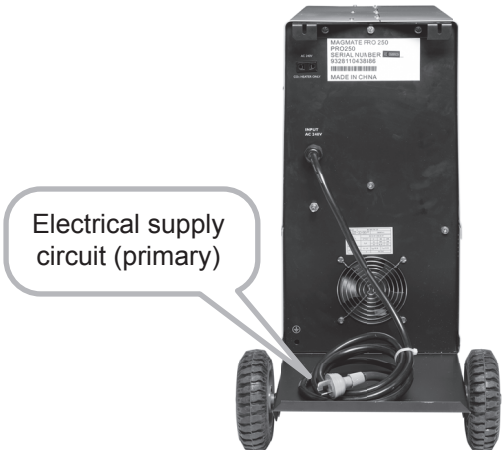


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Fig 1.5.3

Welding equipment should be in good repair and fully insulated.



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

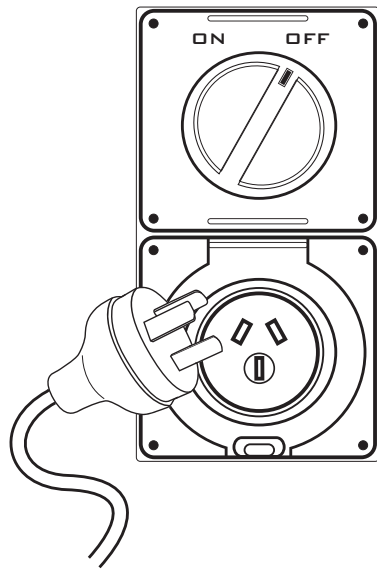


Fig 1.5.7

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

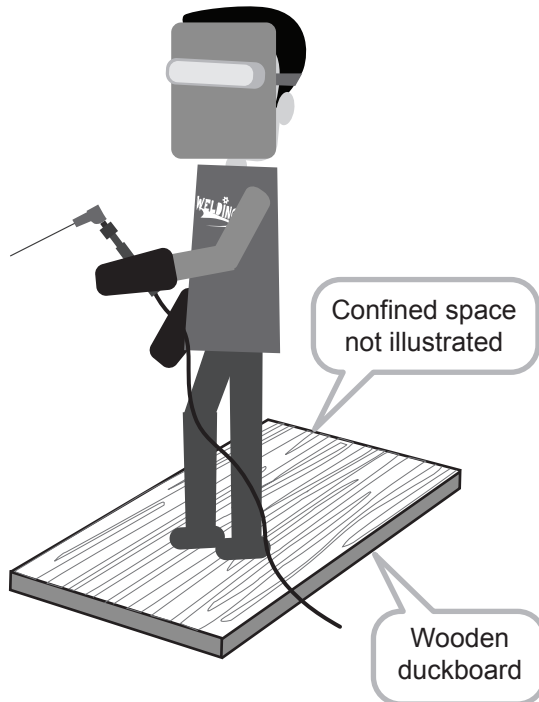
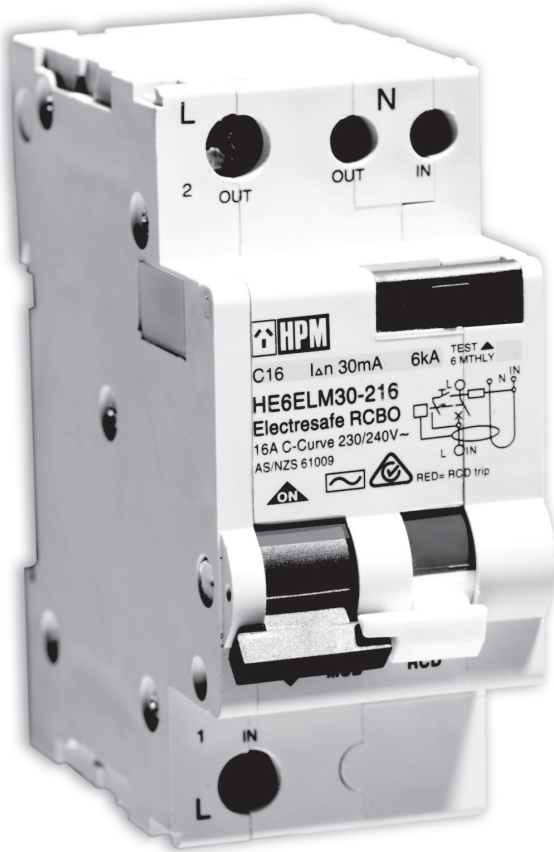


Fig 1.5.8

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.

Metal	Effect	Typical fume source	Ventilation
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 ₂ O=1)	EVAPORATION RATE: (BUTYL ACETATE=1)	N/A
SOLUBILITY (H ₂ 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 BREATHES 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.

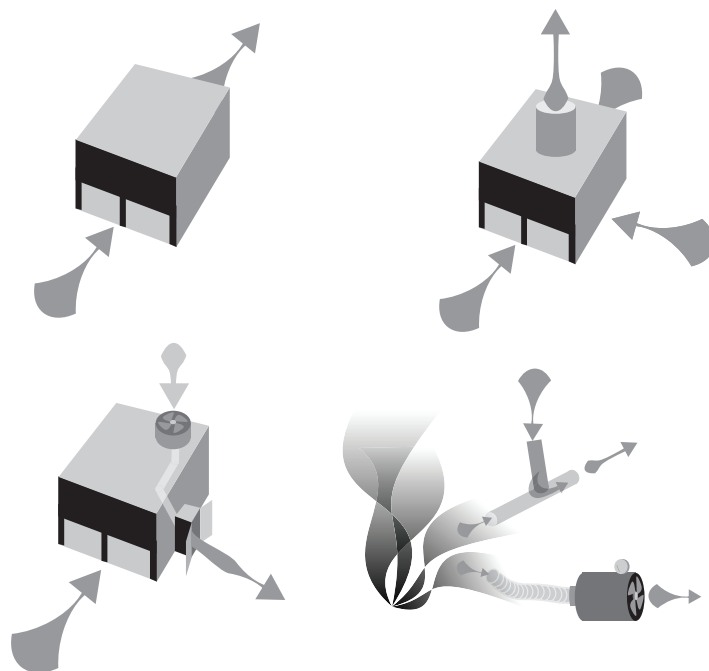


Fig 1.6 – Ventilation types for welding



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.

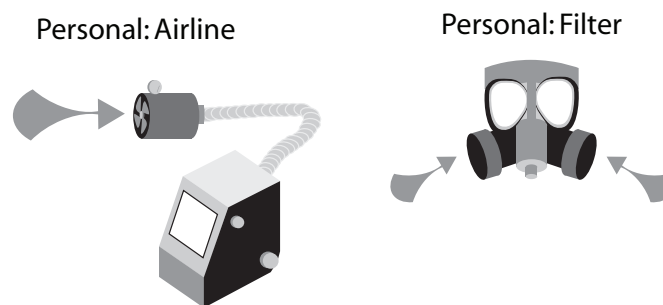


Fig 1.7 – Local dispersion ventilation

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)

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.

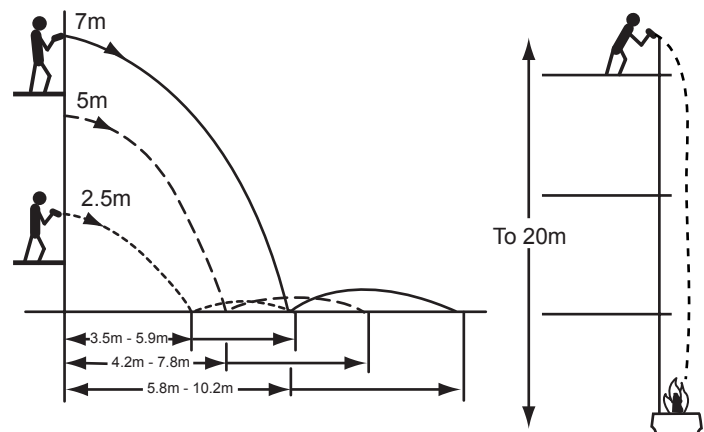


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Fig 1.9 – Typical travel distances for hot or molten metal particles in cutting or welding

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.

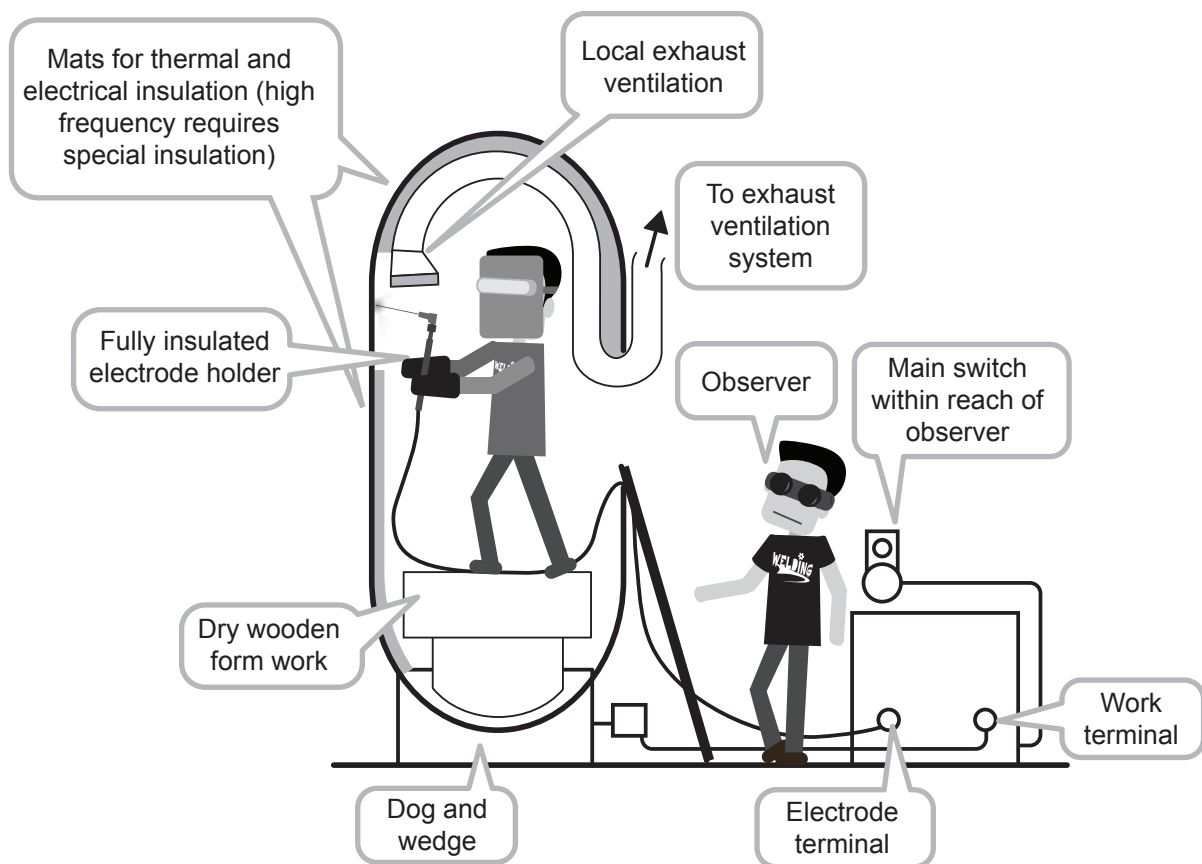


Fig 1.11 – Precautions for welding in confined spaces



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.

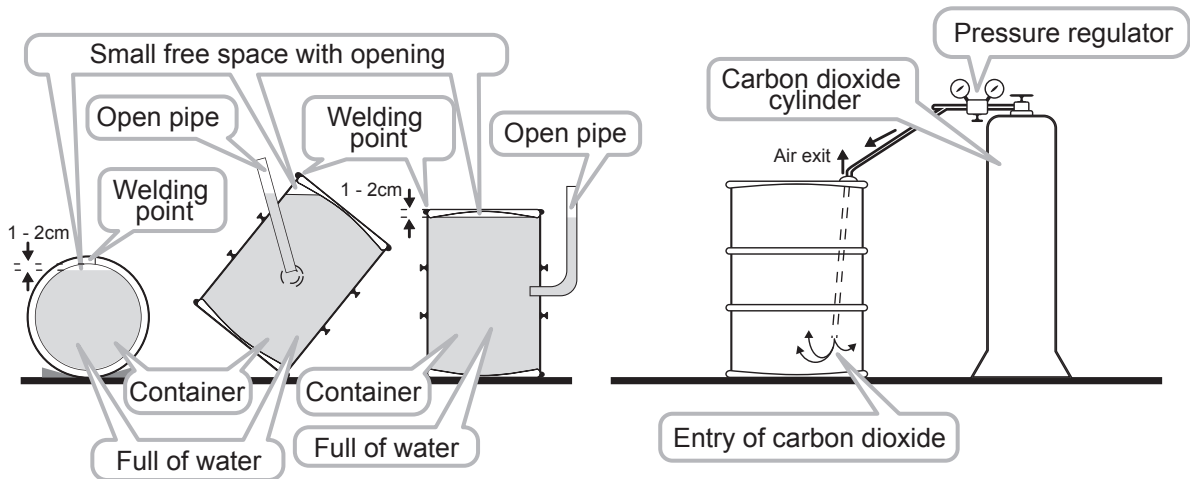


Illustration reproduced with the permission of Welding Technology Institute of Australia (WTIA)

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.

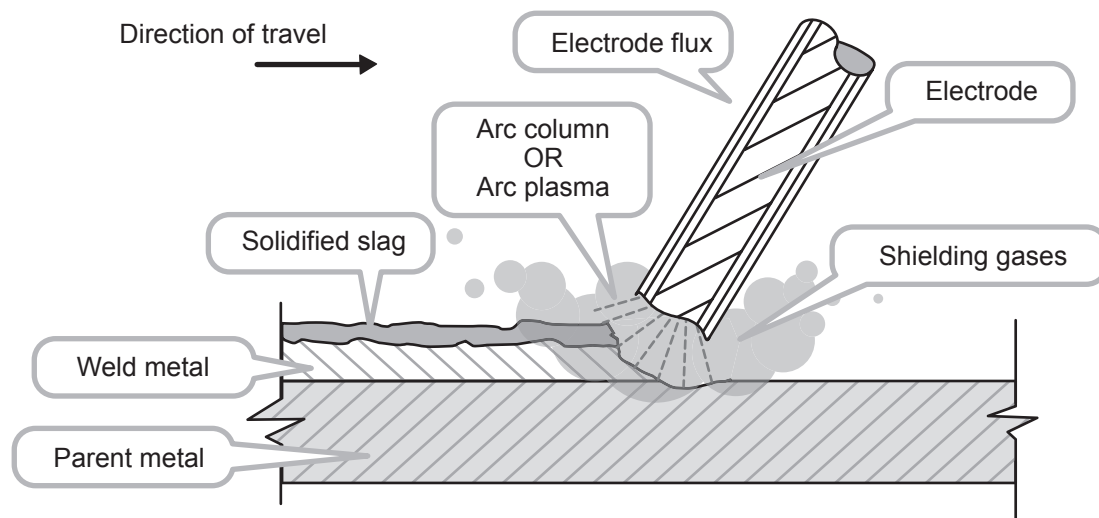
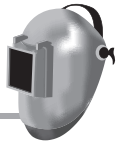


Fig 2.1 – MMAW process

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.

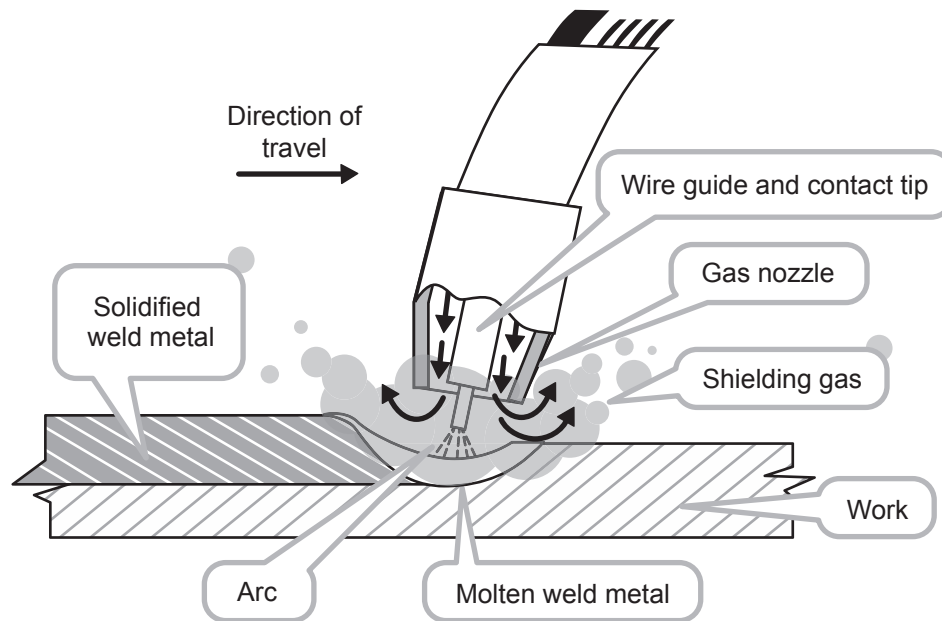


Fig 2.2 – GMAW process

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.

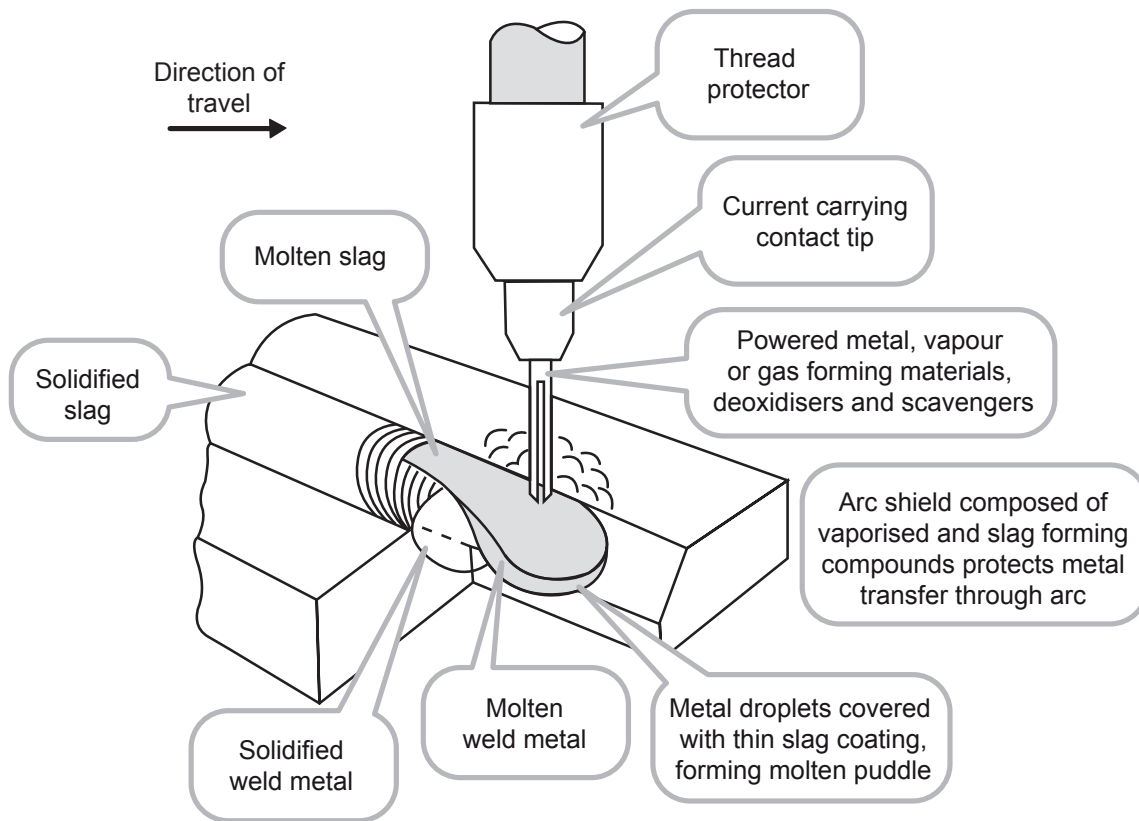


Fig 2.3 – FCAW process

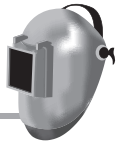
The FCAW welding process needs a suitable and constant voltage power source (DC), wire feed unit, consumable flux-filled electrodes, an optional shielding gas supply, a welding gun, a work clamp and leads.

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.

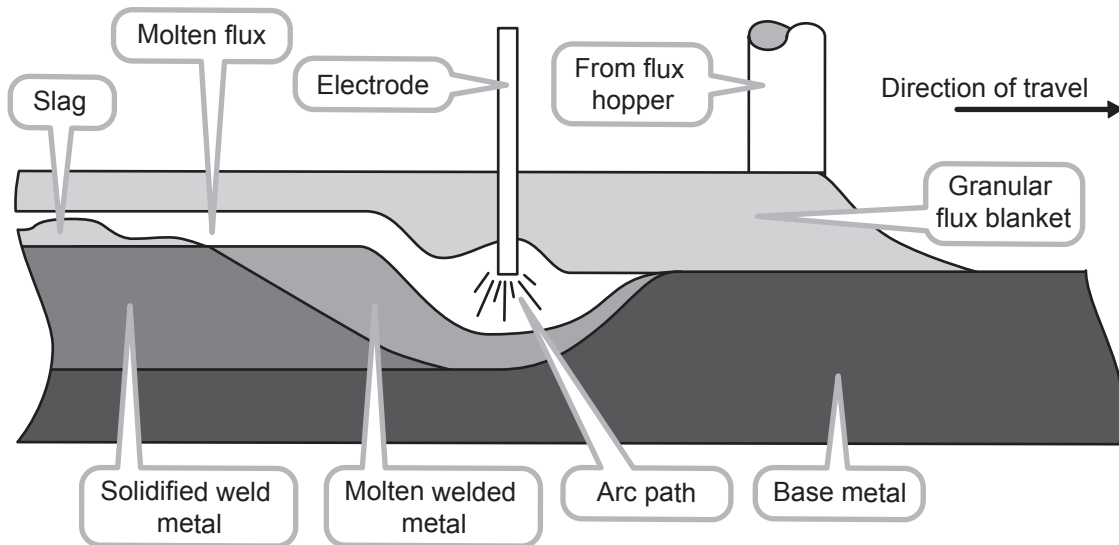


Fig 2.4 – SAW process

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.

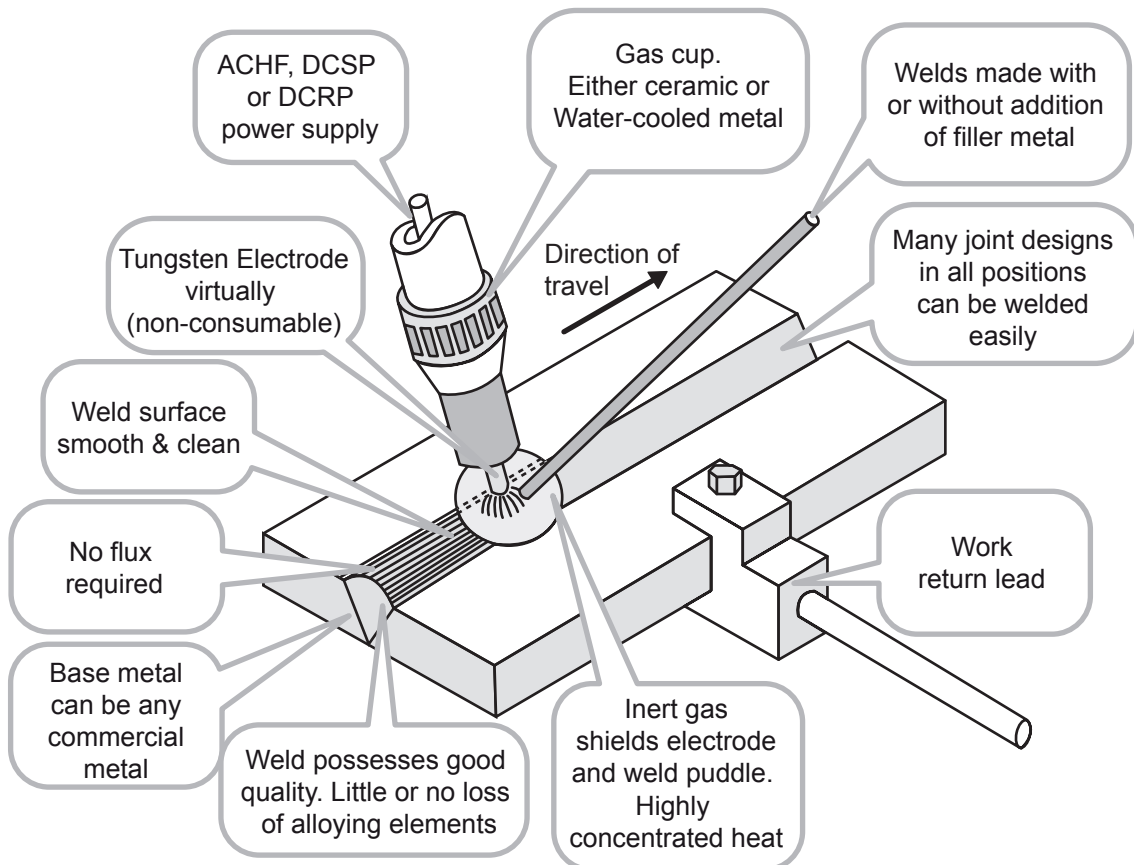


Fig 2.5 – GTAW process

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.

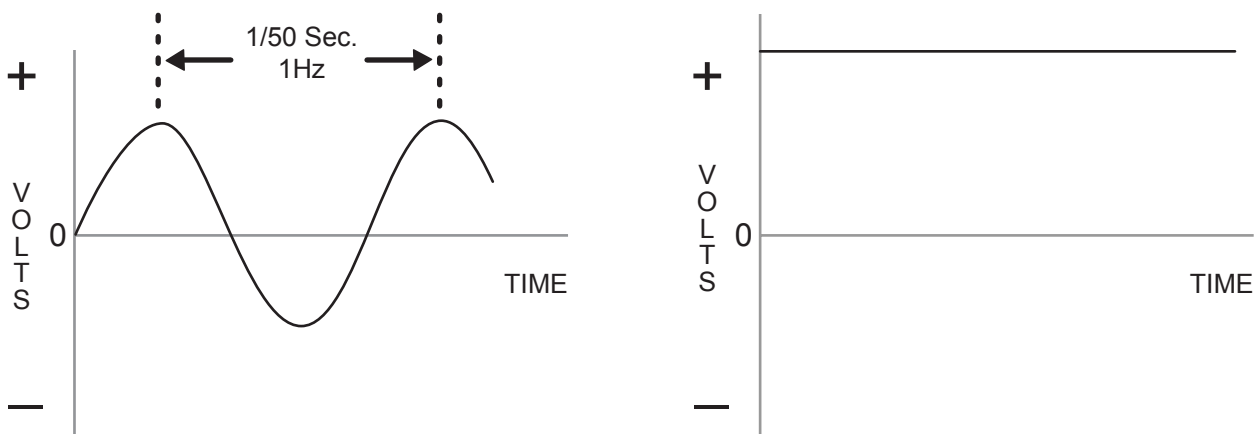


Fig 2.6 – Typical AC and DC output curves as seen in an oscilloscope



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.

	Alternating current (AC)	Direct current (DC)
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.

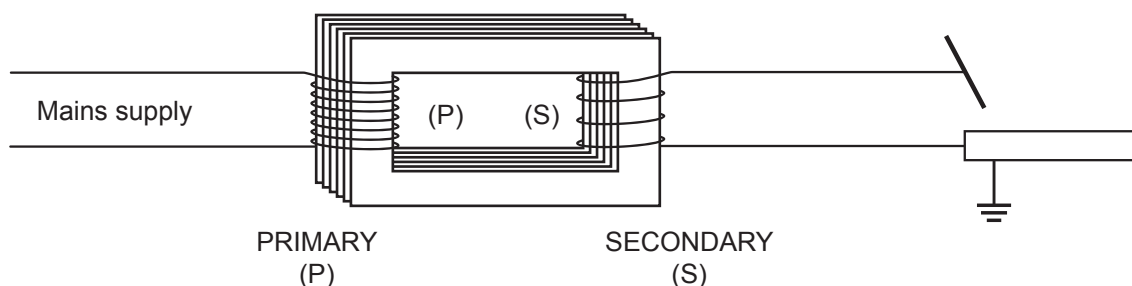


Fig 2.7 – Step-down transformer

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

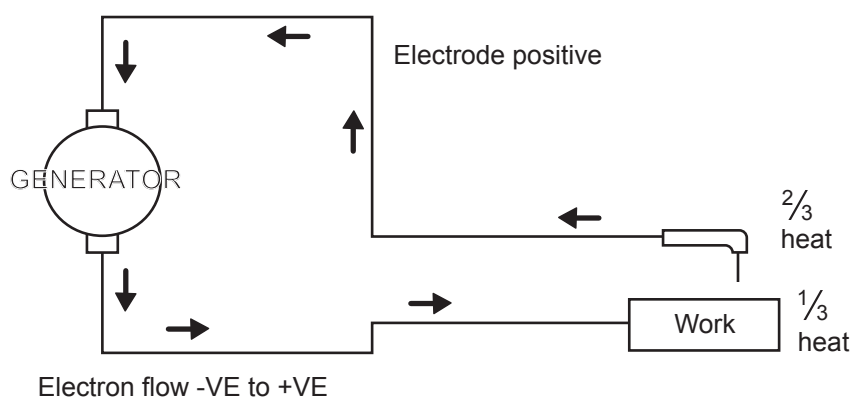


Fig 2.8 – Direct current circuit with electrode positive

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.

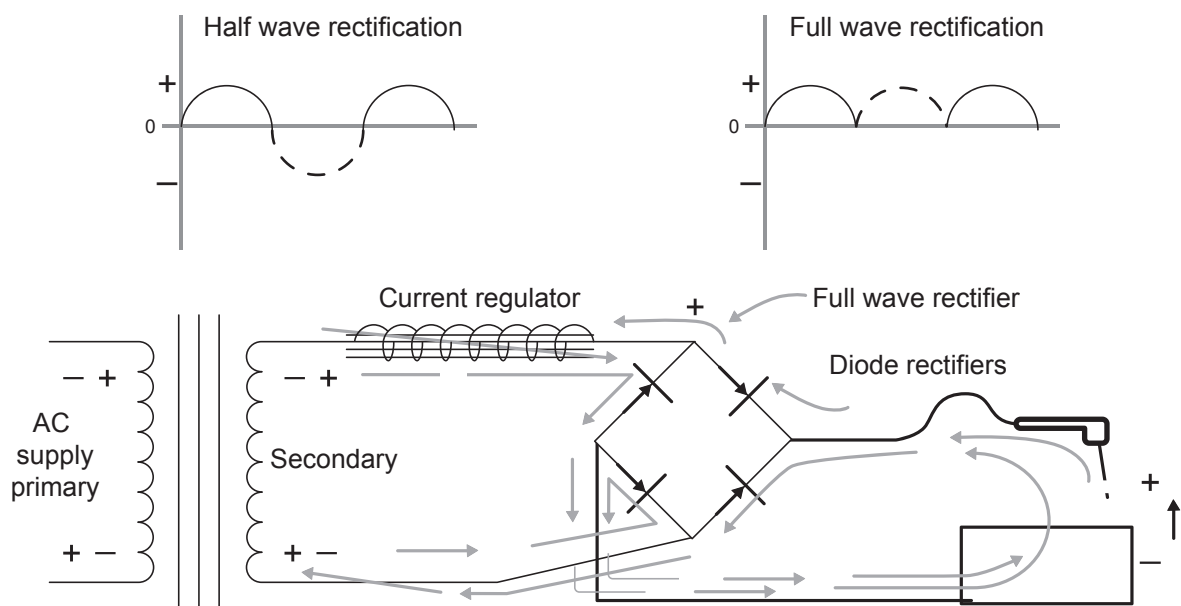


Fig 2.9 – Single phase transformer with bridge (full wave) rectifier

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.

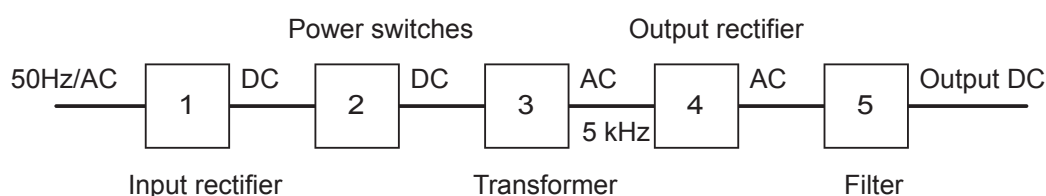


Fig 2.10 – Inverter cycle

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.

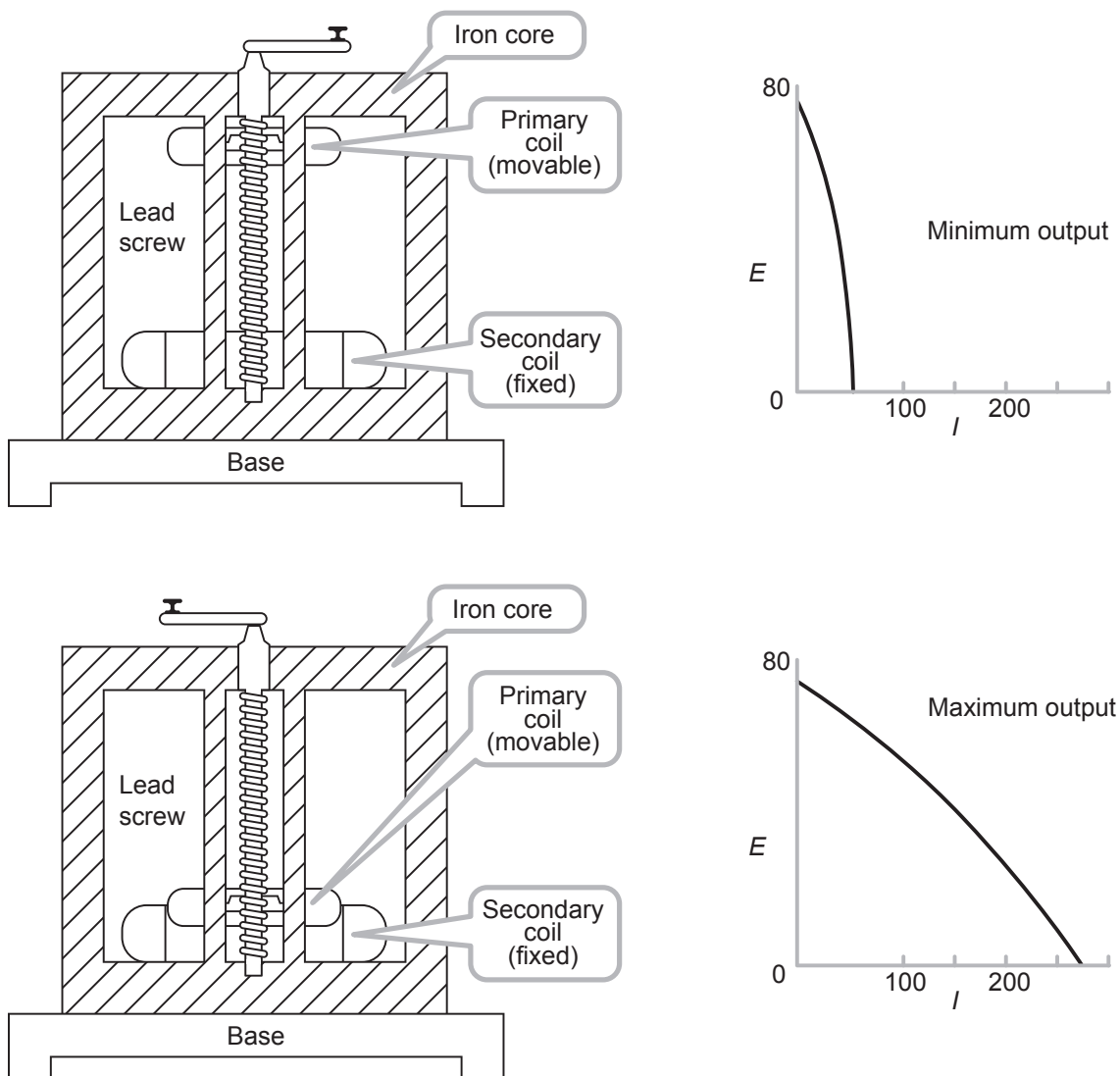
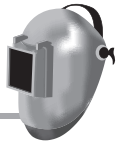


Fig 2.11 – Movable coil AC transformer



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.

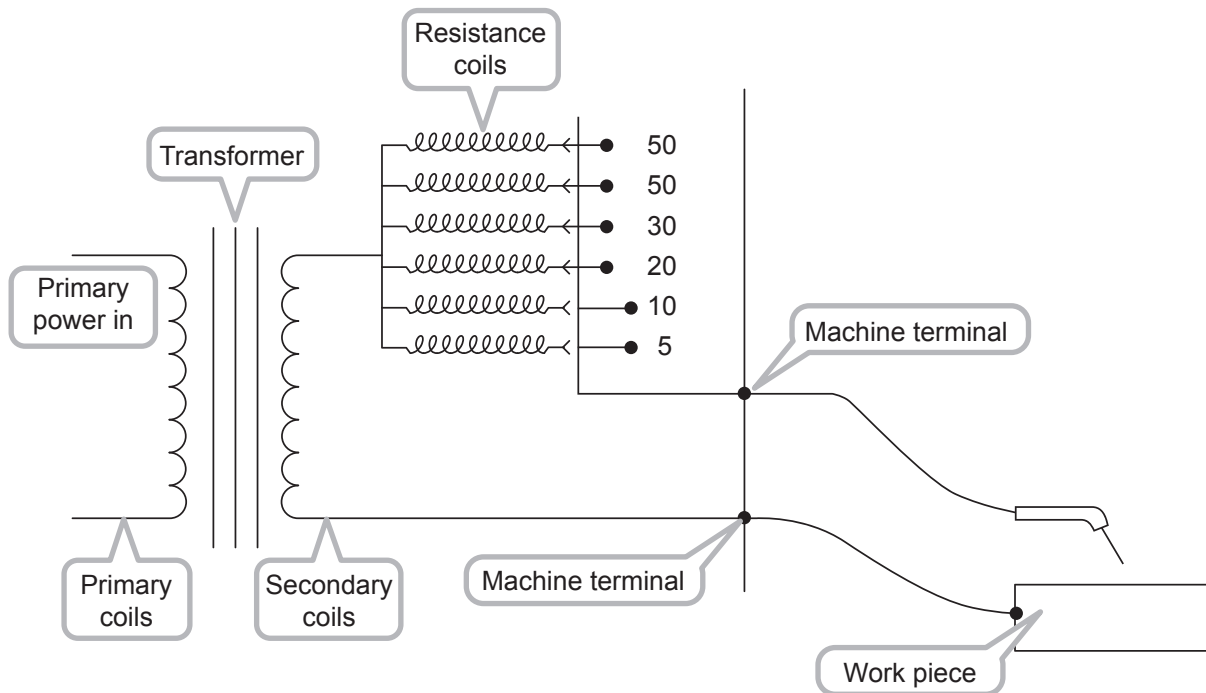


Fig 2.12 – Fixed resistance coils

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.

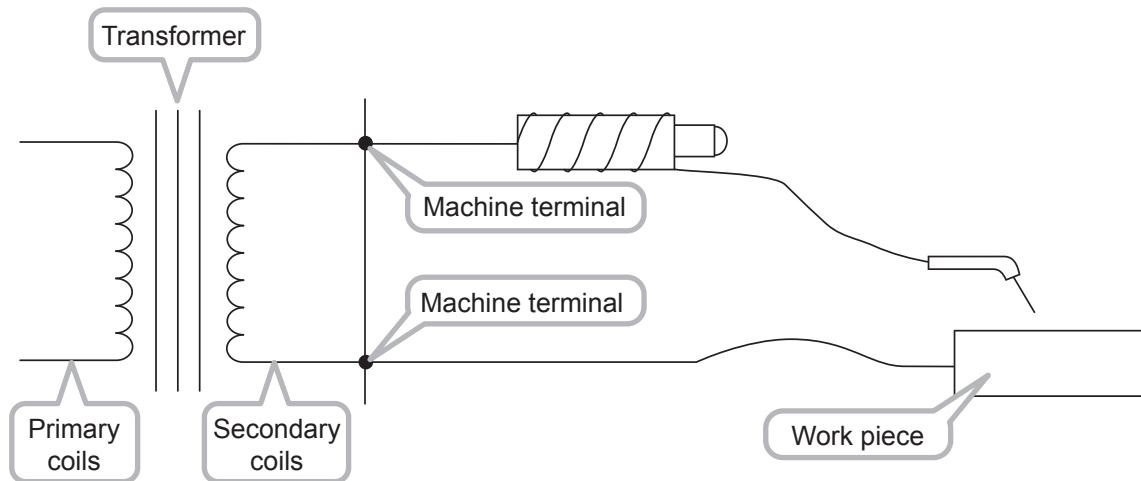


Fig 2.13 – Moving core choke transformer

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.

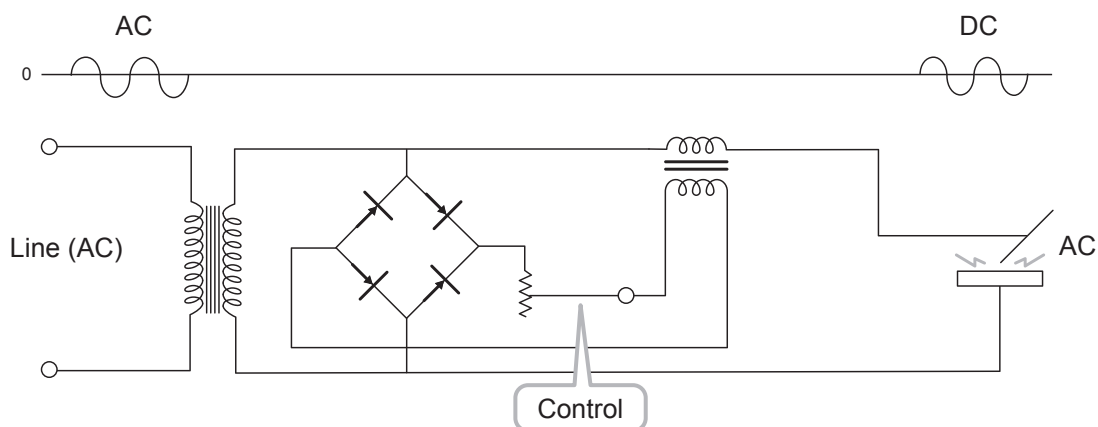
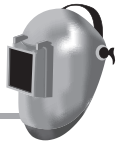


Fig 2.14 – Saturable reactor



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.

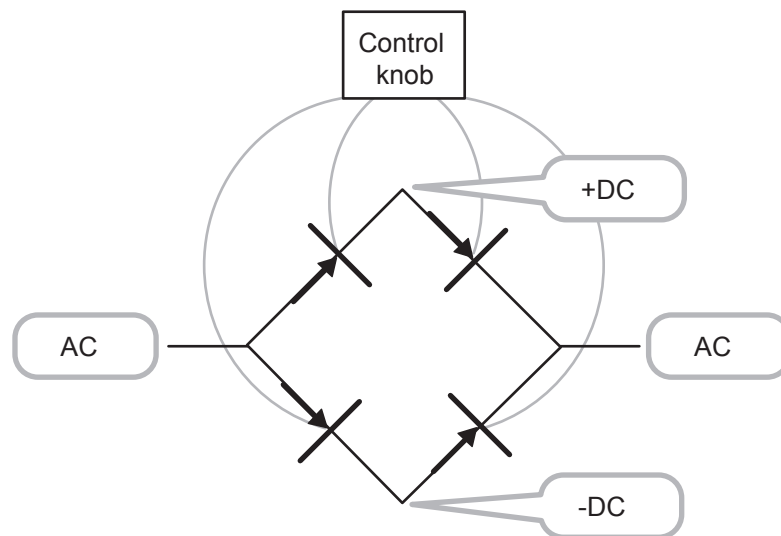


Fig 2.15 – Silicon control rectifier (SCR)



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.

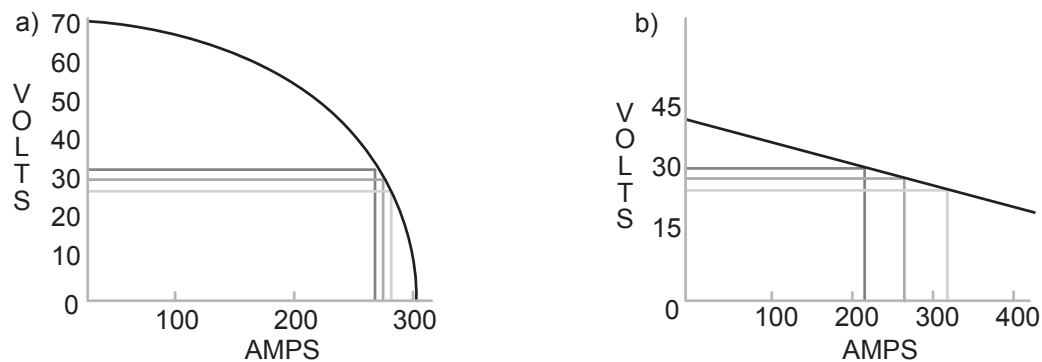


Fig 2.16 – Volt/amp curves (a) constant current machines (CC) and (b) constant voltage machines (CV)

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.

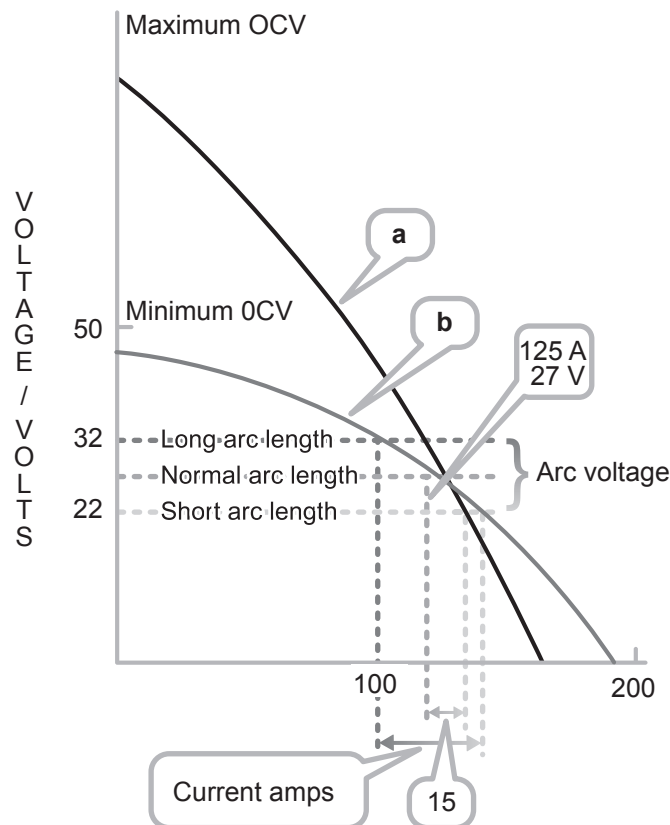


Fig 2.17 – Typical volt-ampere curves possible with a variable voltage power source
 The steep curve (a) allows minimum current change
 The flatter curve (b) permits the welder to control current by changing the length of the arc



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.

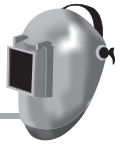
AC motor generators



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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.

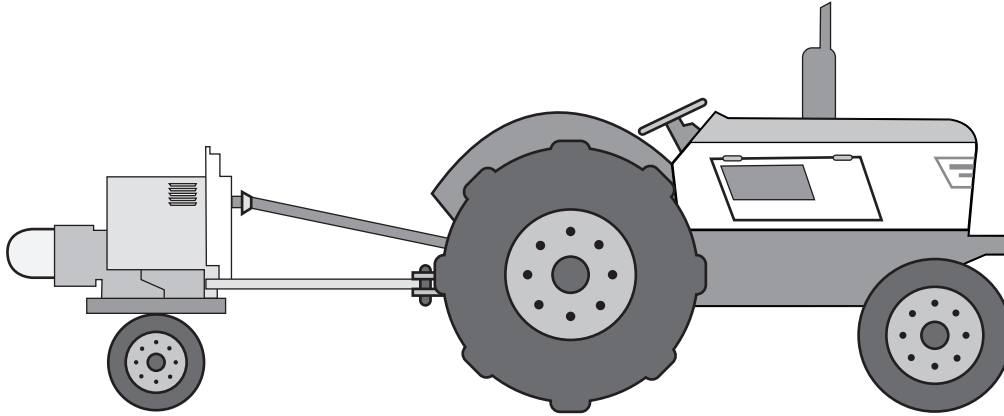


Fig 2.22 – Independent driven generator

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

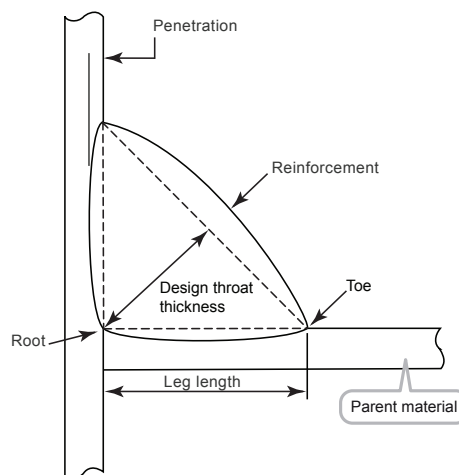


Fig 3.2 (a) – Parts of a fillet weld

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.

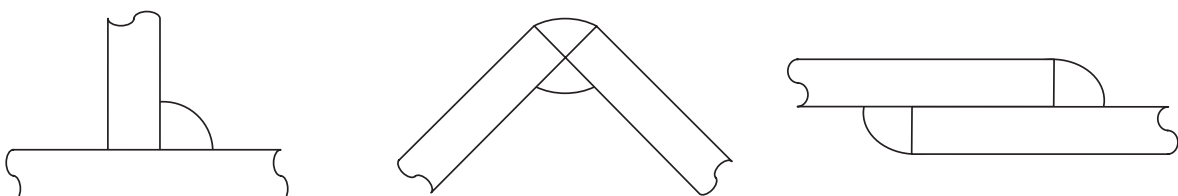
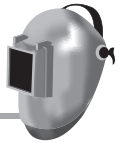


Fig 3.2 (b) – Fillet weld configurations



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.

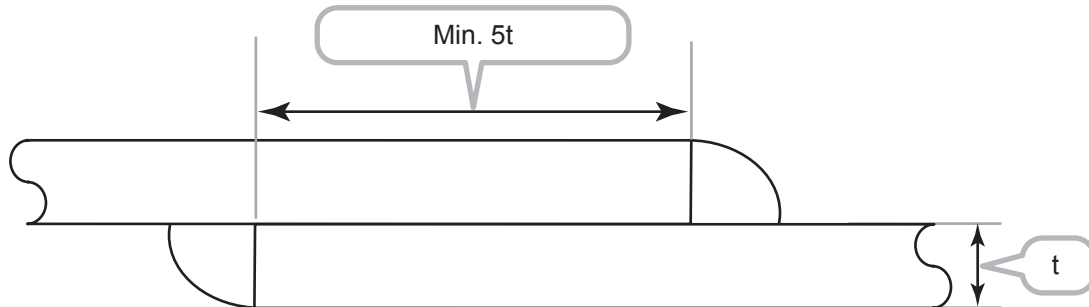


Fig 3.3 – Lap joint overlap

eg	Minimum lap of 2 x 6 mm plates	$5 \times 6 \text{ mm} = 30 \text{ mm}$
	Minimum lap of 5 mm plate lapped onto 8 mm plate	$5 \times 5 \text{ mm} = 25 \text{ mm}$

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).

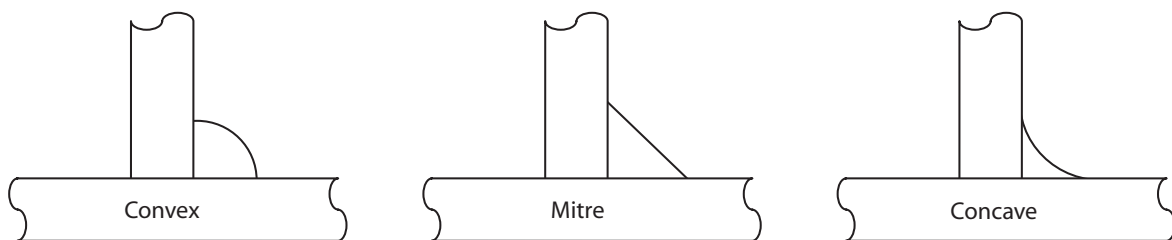


Fig 3.4 – Fillet weld profile

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.

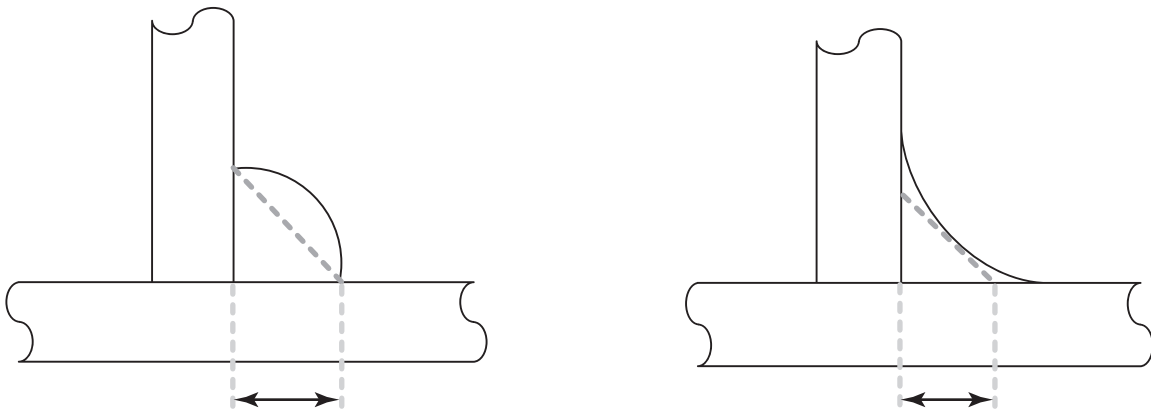


Fig 3.5 – Nominal size

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.

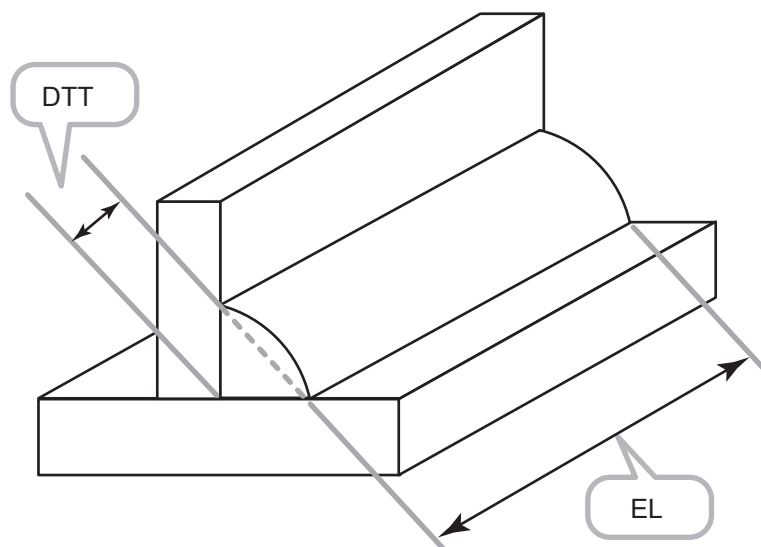


Fig 3.6 – Weld effective area



Example 1

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

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

Example 2

A lifting lug requires 1600 mm² of fillet weld to provide the necessary strength. What length of 10 mm² 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 mm² 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.

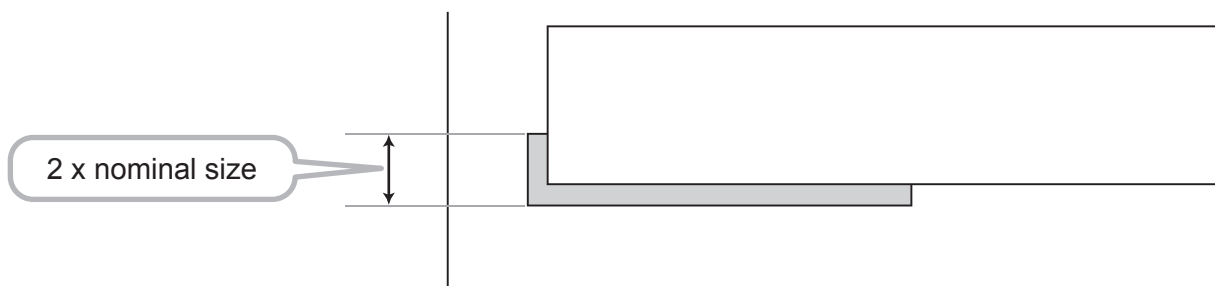


Fig 3.7 – End returns



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.

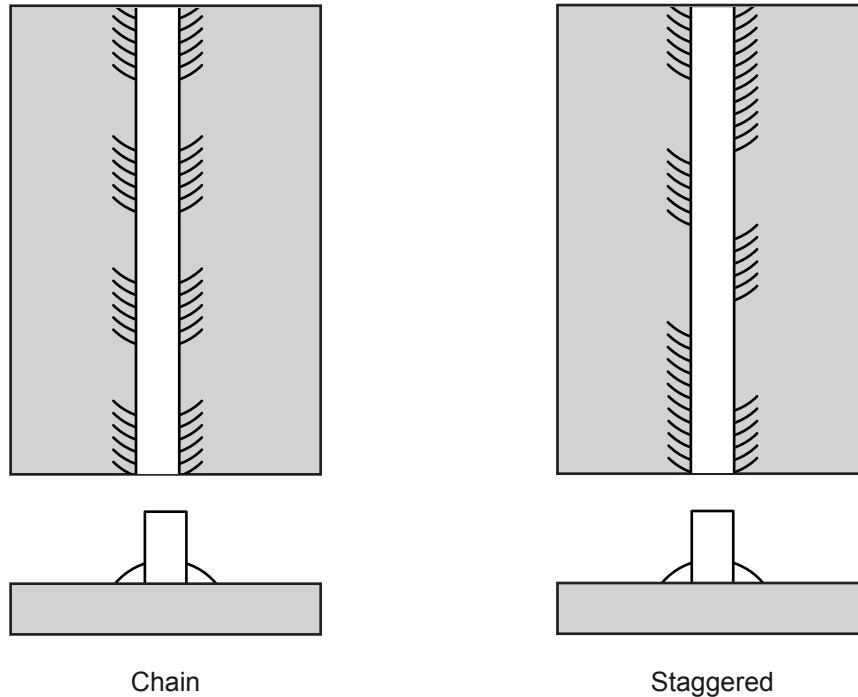


Fig 3.8 – Intermittent fillet welds

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



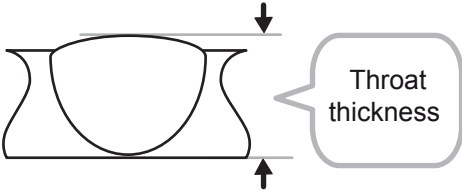
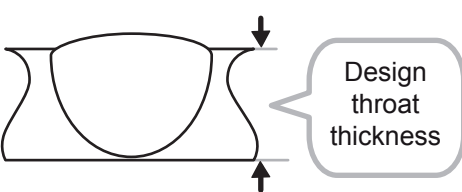
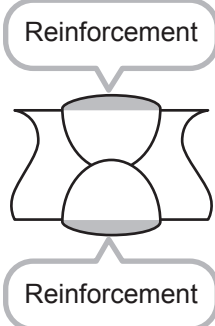
	throat thickness	the distance from the root to the weld face measured through the centre of the weld
	design throat thickness	in a full penetration butt weld the design throat thickness is equal to the thickness of the thinner part joined
	reinforcement	reinforcement in a butt weld is the term given 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.

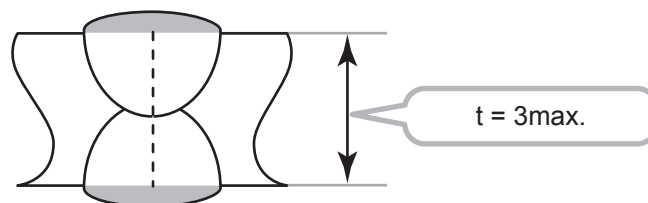


Fig 3.10 – Closed square butt



- 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.

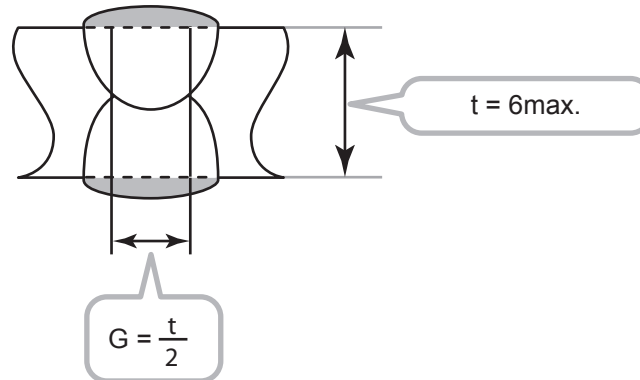


Fig 3.11 – Open square butt

- 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.

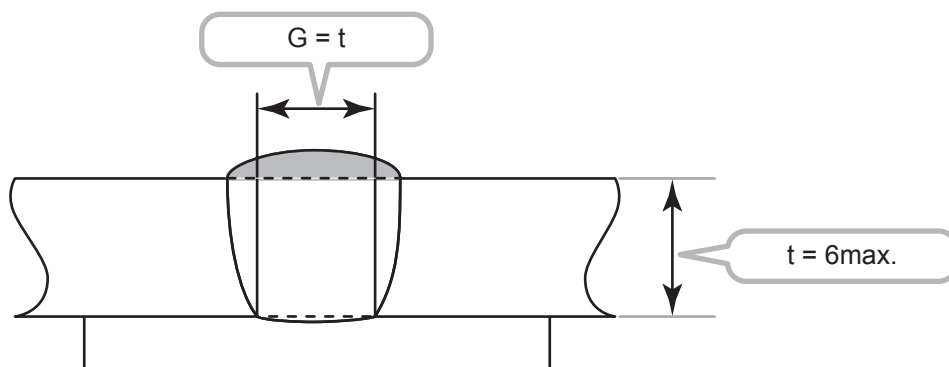
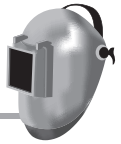


Fig 3.12 – Open square butt with backing material



- 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.

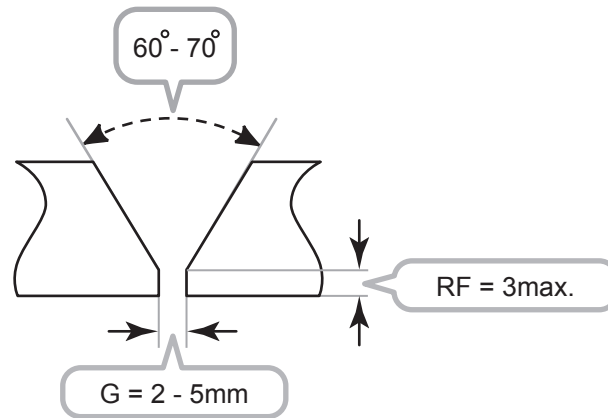


Fig 3.13 – Single vee butt

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

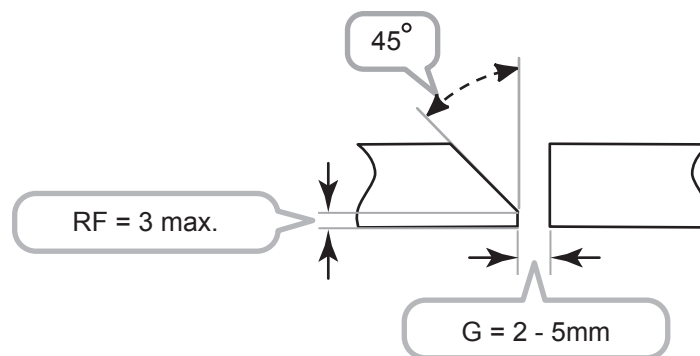


Fig 3.14 – Single bevel butt



- 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.

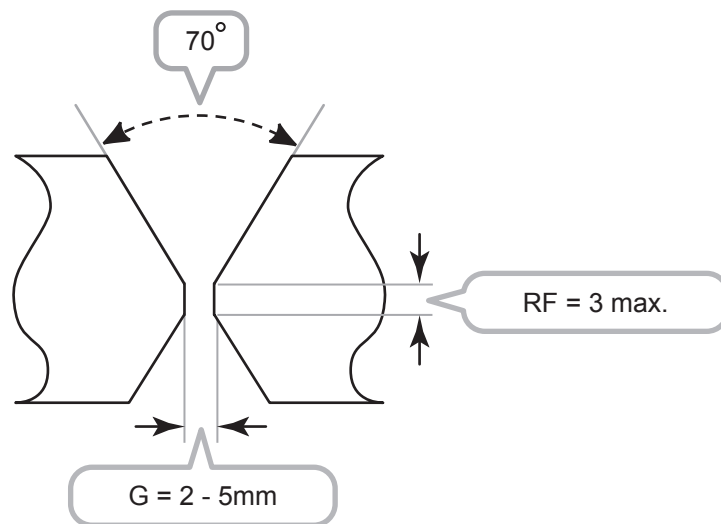


Fig 3.15 – Double vee butt

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

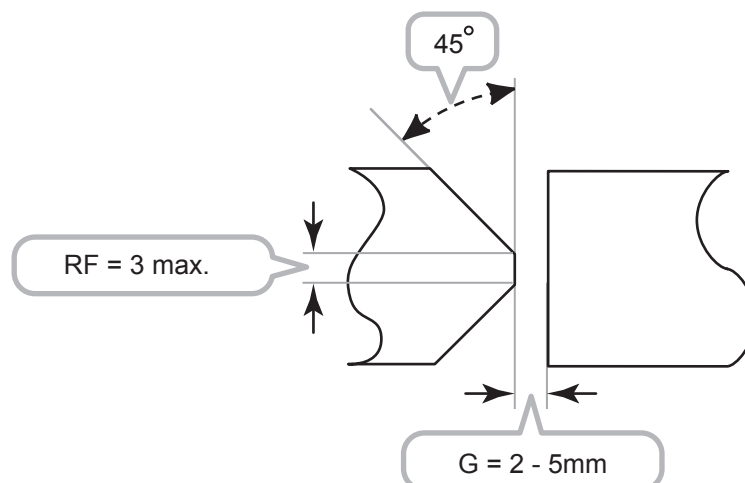


Fig 3.16 – Double bevel butt



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

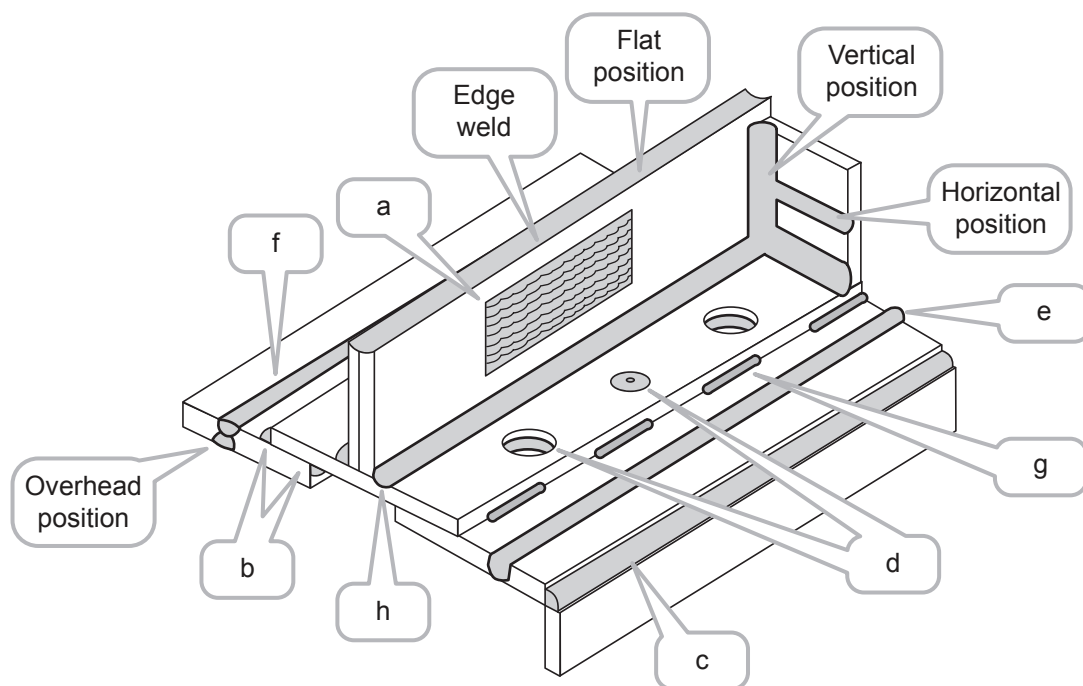
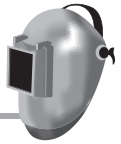


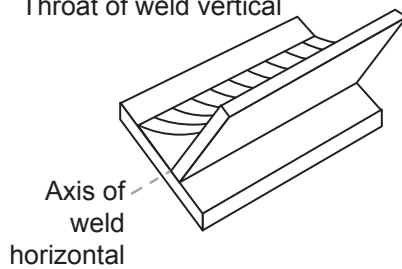
Fig 3.17 – Weld types



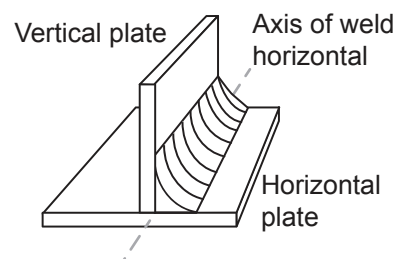
Terms	Weld description
1.F	flat fillet
2.F	horizontal fillet
3.F	vertical fillet
4.F	overhead fillet

1.F

Throat of weld vertical

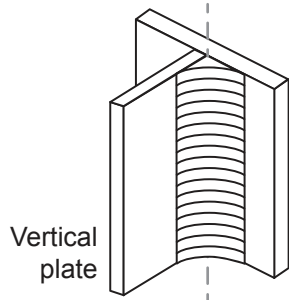


2.F



3.F

Axis of weld vertical



4.F

Axis of weld horizontal

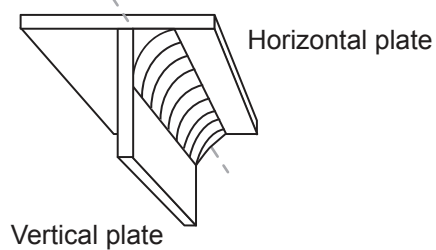


Fig 3.18 (a) – Fillet weld terms



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

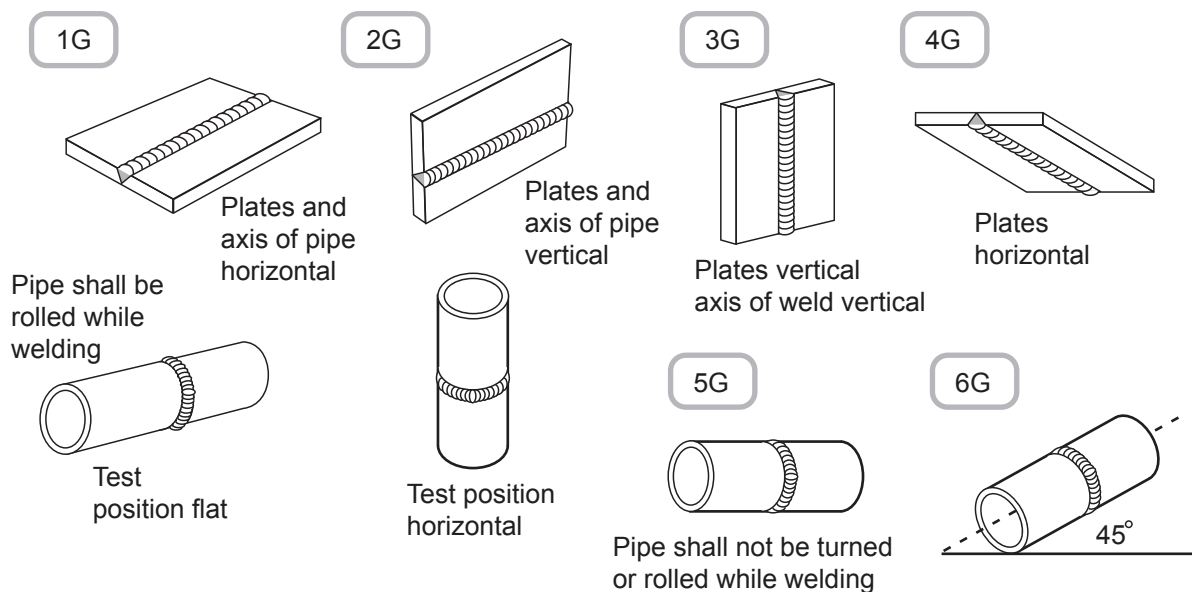


Fig 3.18 (b) – Butt weld terms



- 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 – Air-arc gouging

Introduction

Air-arc gouging has similar applications as those for oxy-flame gouging but the process differs in its equipment and method.

In this chapter you will look at the following.

- Air-arc gouging process
- Air-arc gouging applications
- Equipment
 - power source
 - electrode holder
 - air supply
 - electrode materials
- Air-arc gouging technique.

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

Air-arc gouging process

The air-arc gouging process removes metal by melting it with the heat of an electric arc and directing a jet of compressed air to clear away the molten metal. As the process does not depend on oxidation it may be used for materials which do not oxy-gouge, such as non-ferrous metals. Further advantages over oxy-flame gouging include faster operation and a reduced heat-affected zone with less distortion. The advantages are offset (to some extent) by reduced portability and the need to guard against increased fumes and long streams of hot sparks. Care needs to be taken that carbon is not in the prepared area.

Air-arc gouging applications

The applications of air-arc gouging are the same as discussed under oxy-flame gouging; namely, removing welds and preparing edges. Precise control of the groove is possible and increased speeds are provided by the air-arc process. As already noted, materials which do not flame gouge can be successfully gouged by this process.

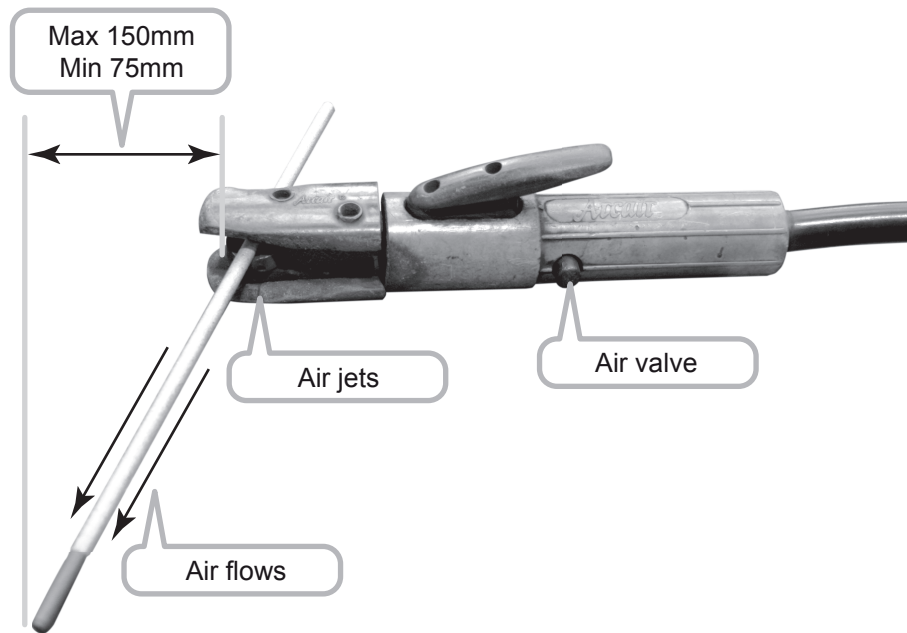
Additionally air-arc gouging is ideally suited to alloy steels, quenched and tempered steels, and other metals where the high heat input of flame gouging may prove damaging.



Equipment

Electrode holder

The gripping jaw of the holder is fitted with a self-aligning rotating head. When the air valve in the holder is opened, jets of compressed air are emitted parallel to the axis of the carbon electrode. The self-aligning rotating head permits the torch to be used in any position and ensures that the air stream is always directed to converge at the arc.



Photograph reproduced with permission Lincoln Electric Co (Aust) Pty Ltd

Fig 4.1 – Electrode holder

Air supply

Compressed air may be supplied by shop air, a local compressor or from cylinders, usually at a pressure of 560 kPa. The air supply hose must have a bore of not less than 6 mm and be free from restrictions. Although the actual pressure is not critical, it is important that sufficient air is supplied to ensure a clean and slag free cut or gouged surface.

Electrode materials

Electrodes are made of a blended mixture of carbon and graphite, bonded together and enveloped in a thin layer of copper. The copper coating aids electrical conductivity through the electrode and acts as a stiffener to the carbon, increasing its working life and reducing radiated heat.



Term	Definition
electrode	an electrically conductive structure which transfers electrons

Electrodes are available in a range of sizes from 4 mm to 12 mm and suit both DC and AC. The choice will depend on the job application, ie the amount of metal to be removed, and the equipment available.

A hollow design electrode is also available which delivers the compressed air down the centre of the electrode.

Air-arc gouging technique

The current setting should conform to the manufacturer's guide on the electrode packets, and be sufficient to obtain a smooth and continuous forward movement, but without overheating and rapid burning of the electrode. Compressed air pressure of at least 500 kPa is necessary to clear molten metal from the groove. In addition, the flow of air will tend to cool the electrode and increase its life.

The electrode is gripped in the holder jaws with a forward projection of 75 mm to 150 mm from the air jets. Note that the air jets are underneath the electrode.

Gouging is commenced by turning on the air flow and touch-starting the arc. Once the groove is started and reaches the correct size, a smooth forward movement is made along the line of gouge. Groove size is determined by electrode size, speed of travel, current and electrode angle. The angle between electrode and work is usually 20°, increasing the angle will deepen the groove. Widening of the groove may be achieved by sideways movement of the electrode.

A recent design innovation is an apparatus that uses a hollow steel electrode that consumes oxygen. The gouging action is started by initiating the oxygen flow and then creating an arc between the electrode and a striking pad, while they are connected to a suitable battery.

Care must be taken to use the appropriate protective practices and protective equipment as there is a greater risk of eye and body injury from the intense arc radiation created by this process. Proper precautions also need to be taken against the excessive noise created.



Activity

Setting up for air-arc gouging

In the workshop:

- identify safe working practices and protective equipment in the workshop
- select an appropriate power source and parts
- set machine variables
- obtain correct electrodes
- test air supply.

With your lecturer's assistance, produce a test gouge on a practice piece of material.



Chapter 5 – 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.

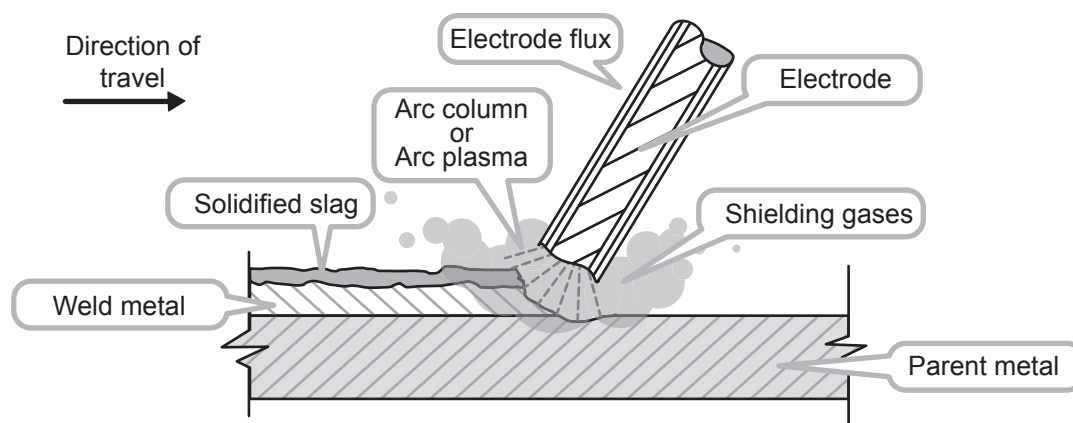


Fig 5.1 – Arc welding



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).

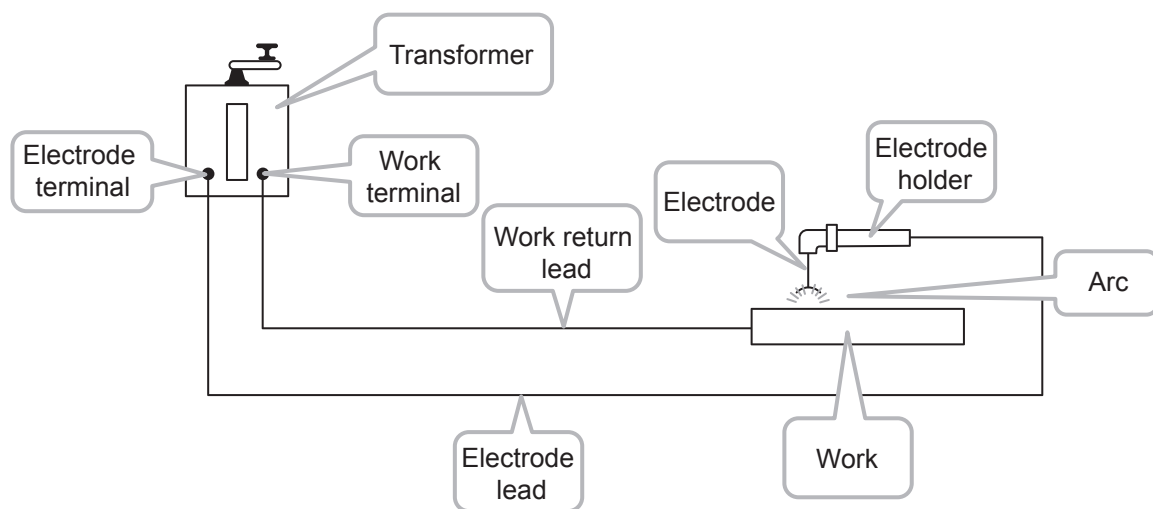


Fig 5.2 – Manual metal arc welding equipment

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.

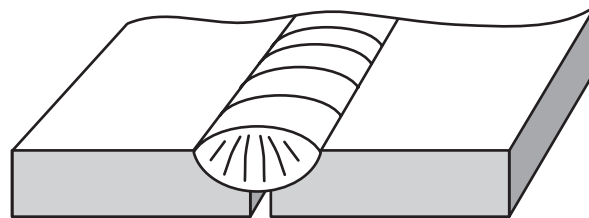


Amperage

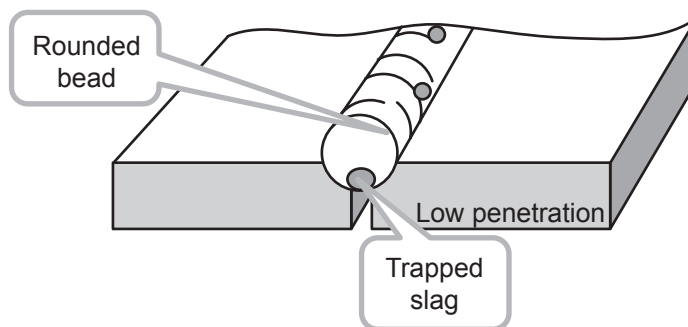
An increase in amperage will:

- 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

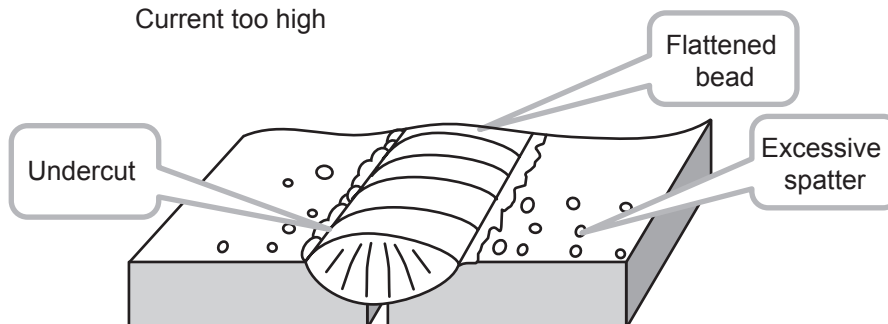


Fig 5.3 – Effects of amperage



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.

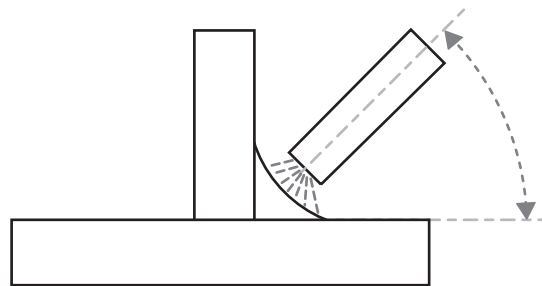


Fig 5.4 – Angle of approach

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.

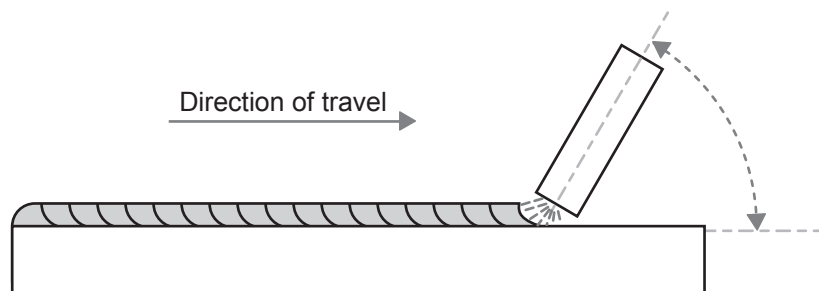


Fig 5.5 – Angle of travel



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

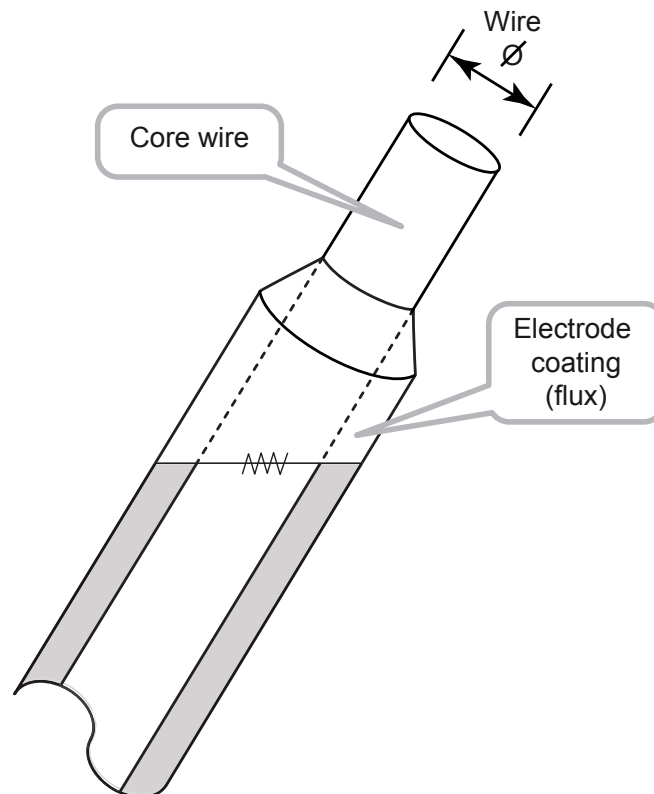


Fig 5.6 – Electrode construction

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/mm². 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.

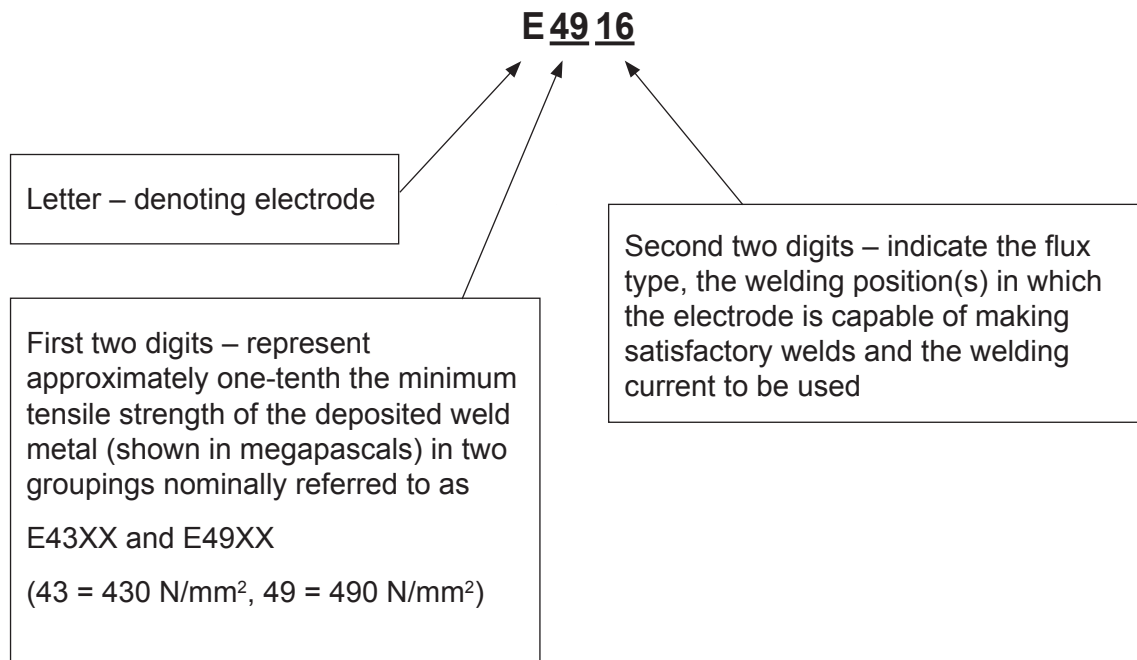


Fig 5.7 – Electrode classification to AS/NZS 4855

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 ^a	Type of current
03	Rutile basic	All ^b	a.c. and d.c. (±)
10	Cellulosic	All	d.c. (+)
11	Cellulosic	All	a.c. and d.c. (+)
12	Rutile	All ^b	a.c. and d.c. (–)
13	Rutile	All ^b	a.c. and d.c. (±)
14	Rutile + iron powder	All ^b	a.c. and d.c. (±)
15	Basic	All ^b	d.c. (+)
16	Basic	All ^b	a.c. and d.c. (+)
18	Basic + iron powder	All ^b	a.c. and d.c. (+)
19	Ilmenite	All ^b	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.			
^a Positions are defined in ISO 6947. PA = flat, PB = horizontal vertical fillet, PC = horizontal, PG = vertical down. ^b 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

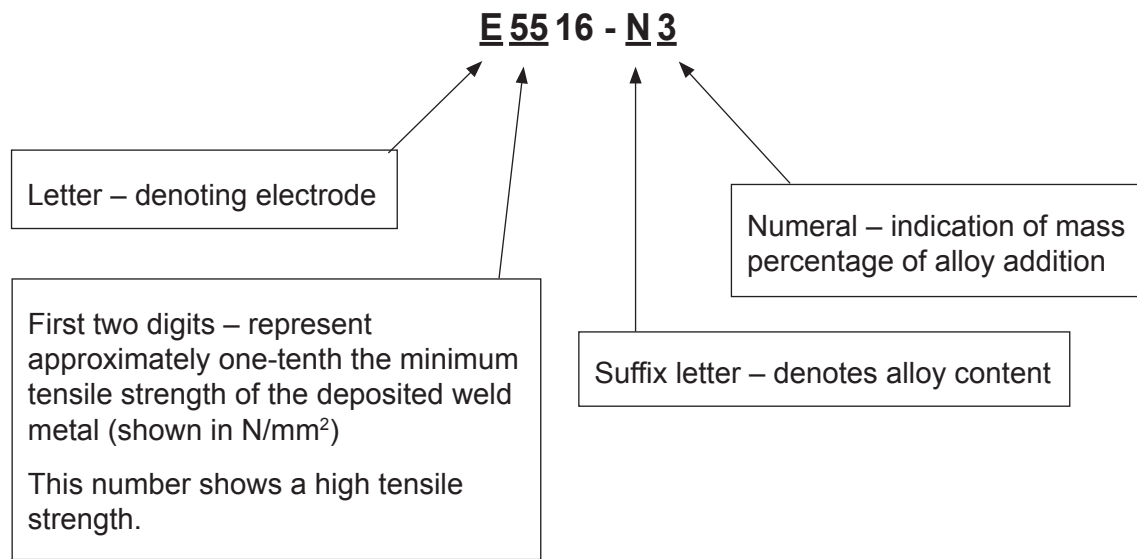
EXX48 electrodes demonstrate the same usability, composition, and design characteristics as EXX18. In addition these electrodes are specially designed for vertical down welding. Some electrodes of this type are designed to provide a flat to slightly concave, fully-loaded penetration bead without undercut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





Chapter 6 – Gas tungsten arc welding (GTAW)

Introduction

Gas tungsten arc welding (GTAW) has increased in popularity because of the relative ease with which it can be applied to difficult weld materials (notably aluminium and stainless steel), and the increased use of these materials in various industries. Thin metals, out of position work, and automatic applications are well within the scope of the GTAW process, and it is in these areas that it excels. Welds produced are of high quality in terms of both soundness and appearance.

In this chapter you will look at the following.

- The process
 - applications
 - advantages
 - limitations
- Equipment
 - power source
 - shielding gases
 - welding torches
 - gas nozzles
 - electrodes
- Gas tungsten arc welding techniques
 - starting the arc
 - arc wander
 - butt welds
 - fillet welds
 - pipe welding
 - weld backup.

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

The process

The GTAW process operates as follows.

The gas tungsten arc process employs an electric arc created between a hand-held non-consumable tungsten electrode and the work piece, to melt the parent metal and provide the heat required for fusion. Under normal conditions the tungsten electrode does not melt and become part of the weld. A separate inert gas shield is introduced around the arc zone to exclude the atmosphere and its undesirable effects. Additional weld metal may or may not be required, and is added by dipping compatible filler rods into the weld pool.

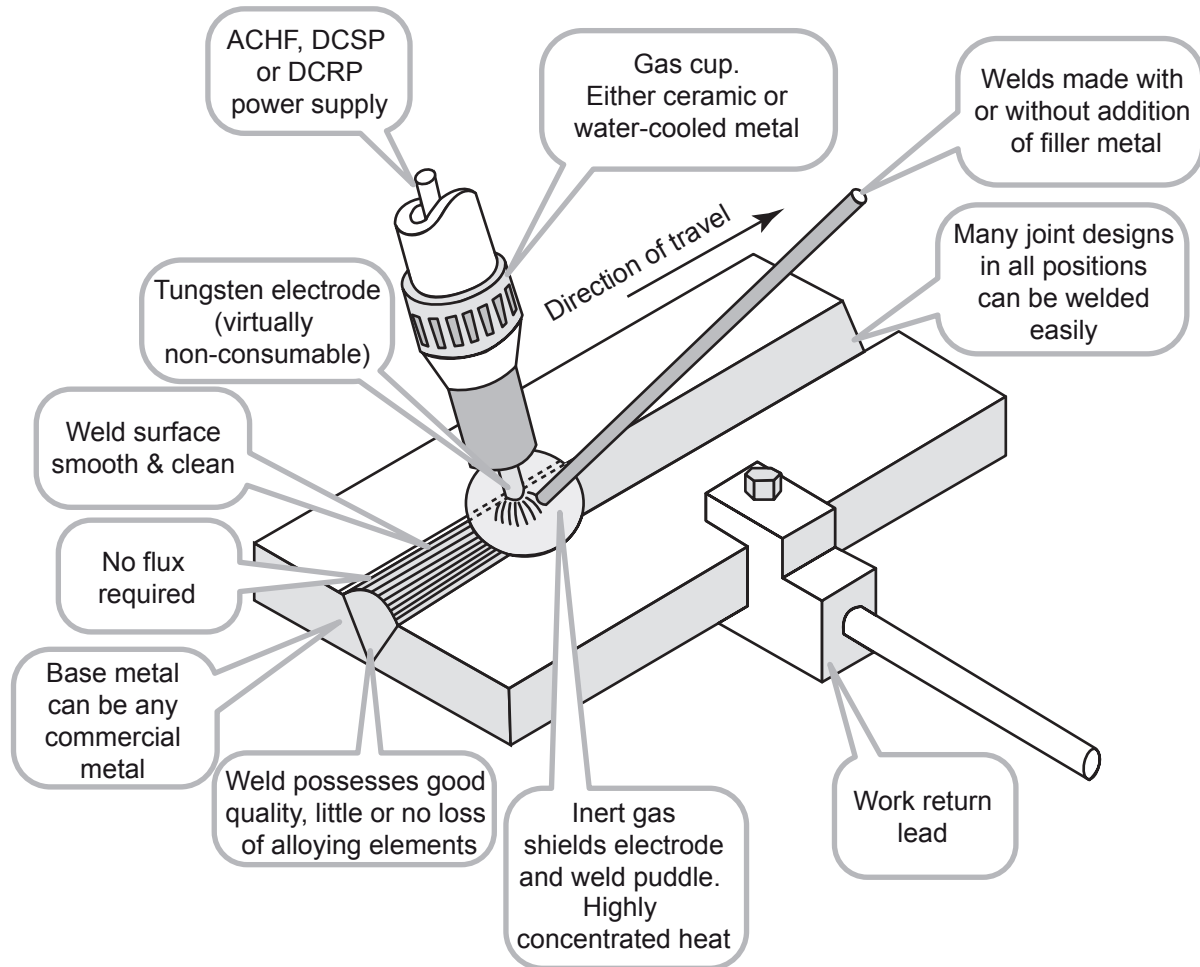


Fig 6.1 – Gas tungsten arc welding

Applications

GTAW has a wide range of applications, particularly its use on ferrous materials (such as plain carbon, carbon-manganese and alloy steels), and non-ferrous metals (such as aluminium and its alloys) and also copper and copper-based alloys (such as brass and bronze). It can be used to weld a wide variety of metal thicknesses in all types of applications, including:

- general engineering applications
- transport industries
- sheet metal industries
- marine and transport industries
- boiler and pipe welding.



Advantages

Some of the greatest advantages of the GTAW process are as follows.

- Its open arc, which means the weld zone is highly visible to the operator and thus gives greater control of the weld pool and fusion zone.
- The arc heat is highly concentrated and there is virtually no sparks, spatter or fumes.
- The process operates in an inert atmosphere and therefore does not produce any adverse effects on the weld or weld area.
- High quality welds with a good visual appearance can be produced easily.
- That no flux is required, therefore no slag is produced, saving time required for post-weld clean-up.
- That the process has a wide range of applications (nearly all the ferrous and non-ferrous materials, together with some of the more exotic materials such as nickel and titanium).

Limitations

Some limitations of the GTAW process are as follows.

- Equipment is relatively expensive and to make full use of the process a high degree of skill is required from the operator.
- The process is not suitable for use on dirty material and does not like a windy environment.
- It is not really suitable for thicker sections or high productivity work, although it can be mechanised to improve quality and efficiency.
- It has more intense arc radiation and fume safety hazards, dependent on the material being welded.

Equipment

Power source

Gas tungsten arc welding power sources can be obtained to operate on domestic or industrial mains supply voltages. Most industrial machines operate on a 440 volt supply and provide current in the range 200–500 amperes with a 60 per cent duty cycle.

Any AC or DC manual metal arc welding machine (constant current) can be used to supply the current for GTAW. It is important, however, that the machine has a good current control for low amperages in order to maintain a steady arc when welding thin material. When using DC for welding, a high-frequency unit is desirable but not essential. With AC a high-frequency unit is definitely required. This will be discussed later. The ideal power source for GTAW is one that has been specially designed for the process (Fig 6.2).



These welding machines are typically transformer rectifiers or inverters which supply both AC and DC and have a high-frequency unit incorporated in them. They usually have other controls peculiar to the GTAW process, such as the following.

- Remote current control – usually foot operated which enables the welder to alter the amperage whilst welding.
- Soft start switch – which reduces the current when starting the arc. This is an advantage when welding aluminium or magnesium.
- High-frequency spark intensity control – which is useful when welding aluminium and magnesium.
- Pre-gas timer – to allow the gas to flow before the arc is started and a post gas timer which allow the gas (and water if used) to flow for a set time after the arc is extinguished. This prevents atmospheric contamination of the weld pool and assists in tungsten electrode cooling.

A better GTAW power source will provide the ability to control upslope and down slope on the main current as well as a pulsing option.

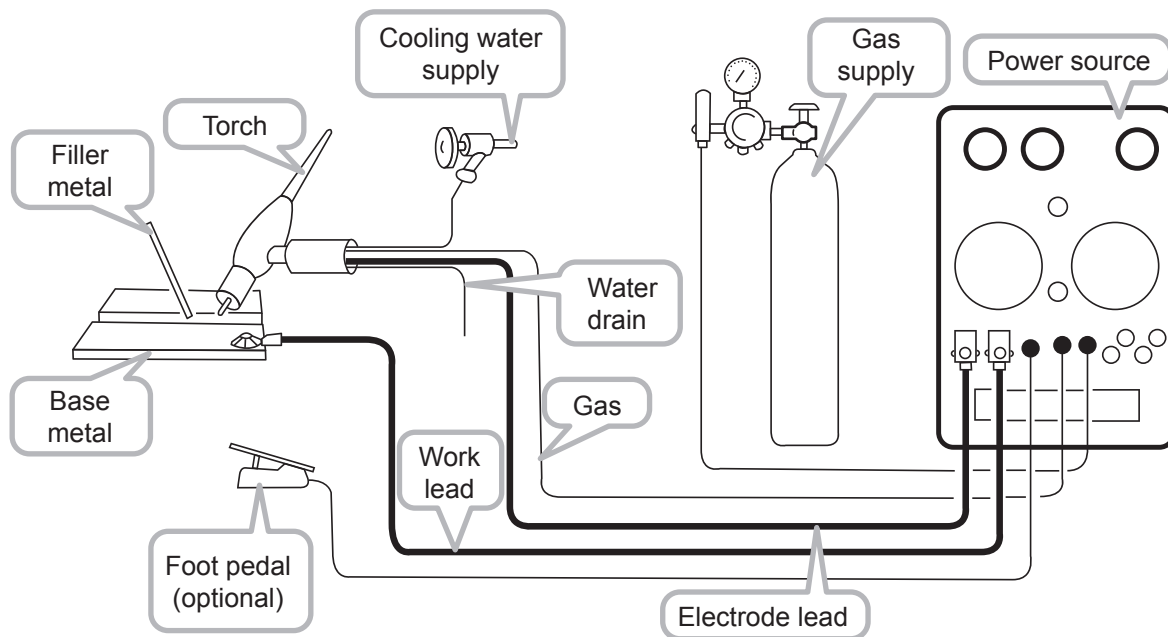


Fig 6.2 – Equipment used in gas tungsten arc welding

Current type is important in GTAW and the choice depends mainly on the metal to be welded and its thickness, which in turn decides the current level required.

Choice of current

With GTAW the operator has the choice of three types of welding current:

- DC (-) electrode negative
- DC (+) electrode positive
- AC (hf) AC with superimposed high-frequency.



DC electrode negative

In the GTAW process two-thirds of the heat generated at the arc occurs at the positive terminal and one-third of the heat at the negative terminal. Therefore it is beneficial, whenever possible, to connect the tungsten electrode to the negative terminal since higher amperages can be used without the tungsten becoming overheated. Also, because most of the heat is concentrated in the parent metal, deeper penetration is obtained.

With electrode negative the flow of electrons is from the tungsten electrode to the parent metal (from negative to positive). The shielding gas, as it passes through the arc, becomes electrically charged (ionised) and the ions of gas which are positively charged are attracted to the negative electrode (Fig 6.3). No cleaning action occurs with this polarity; it is only needed when welding metals with a high melting-point surface oxide. Electrode negative is preferred for most of the common fabrication metals (except aluminium). GTAW with electrode negative produces deep penetration because it concentrates the heat in the joint area.

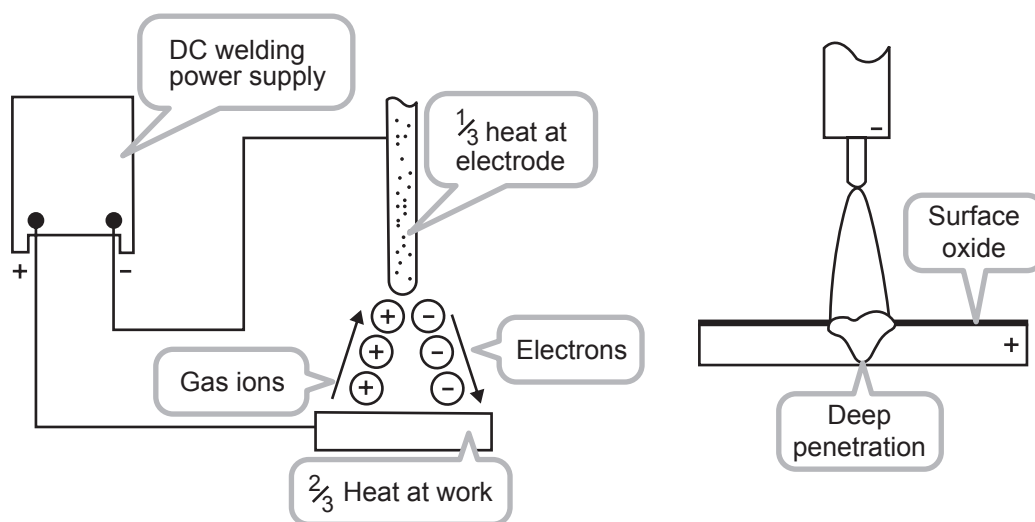


Fig 6.3 – Direct current electrode negative

DC electrode positive

With electrode positive, the gas ions are still positively charged but are now attracted to the negative parent metal. They bombard the plate surface causing any oxide on the plate surface to be chipped away, exposing bare metal which is easily melted. This cleaning action is most useful when metals with a high melting-point surface oxide have to be welded, eg aluminium, magnesium and titanium.

With electrode positive, the bulk of the heat is now concentrated at the tungsten electrode which can become overheated unless a sufficiently large electrode diameter is used. The penetration is wide and shallow and the arc tends to be erratic due to the large electrode and relatively low amperage being used (Fig 6.4). Generally, electrode positive is not recommended for GTAW.

GTAW with electrode positive produces good cleaning action as the argon ions flowing towards the work strike with sufficient force to break up oxides on the surface of the material. Since the electrons flowing towards the electrode cause a heating effect at the electrode, weld penetration is shallow.

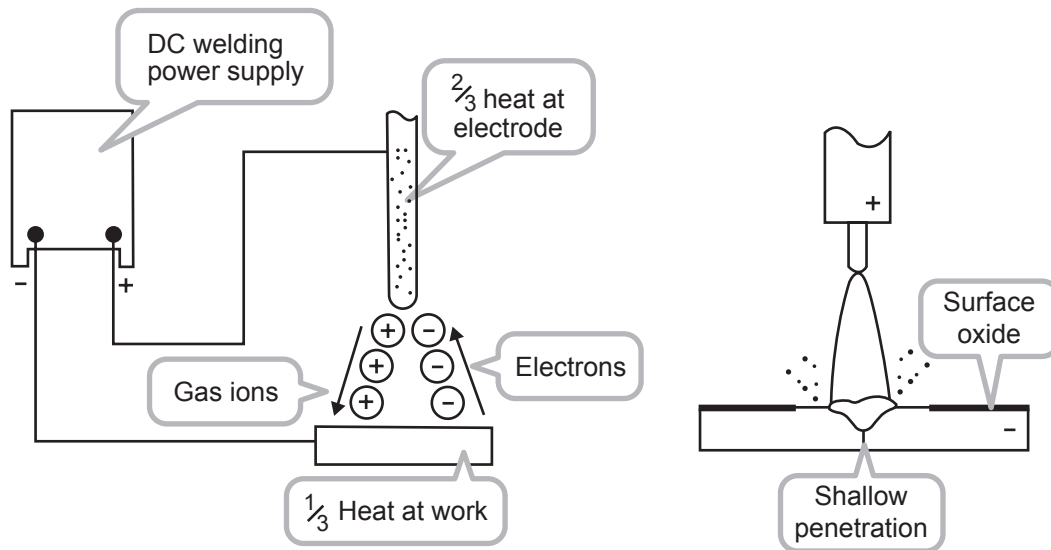


Fig 6.4 – Direct current electrode positive

Alternating current

The ideal type of welding current for metals with a high melting-point surface oxide, is one which gives good cleaning action during the electrode positive cycle and deep penetration, cooler electrode of the electrode negative cycle. AC is actually a combination of electrode negative and electrode positive. One half of the cycle is negative and the other half positive (Fig 6.5). The heat is equally distributed at the electrode and work piece.

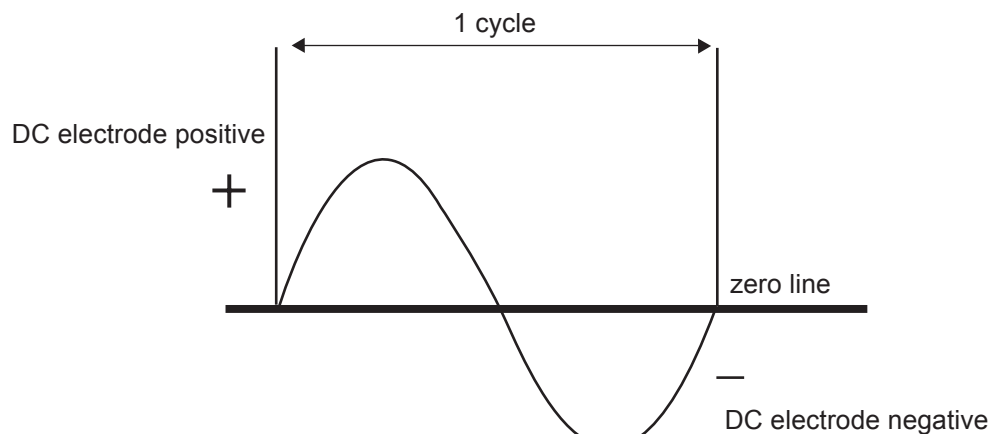


Fig 6.5 – AC cycle

Unfortunately, the strong surface oxide on metals (such as aluminium) prevents the full flow of current in the positive polarity direction of the cycle, causing the arc to become unstable. Also, as the cycle passes through the zero voltage point, the arc goes out and must re-ignite. To prevent instability or complete loss of the arc, a continuous high-frequency spark is required. The high-frequency current is able to jump the gap between the electrode and the parent metal during the period of arc shut down, and penetrate the oxide film to form a path for the welding current to follow. Continuous high-frequency is needed with AC, so this type of current is usually identified as AC(HF) (Fig 6.6).

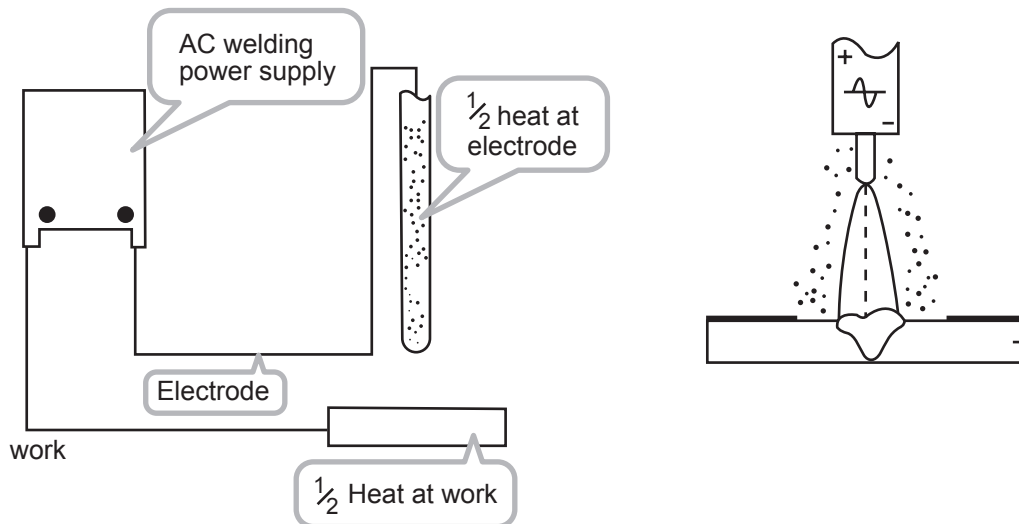


Fig 6.6 – Alternating current high-frequency

The electrode diameter required for a given amperage will vary depending on the current type being used. A 1.6 mm tungsten electrode on DC electrode negative will carry the same current as a 2.4 mm tungsten electrode on AC (hf), while a 3.0 mm electrode would be required to carry the same current on DC positive.



Electrode cooling is provided by the torch through the copper collet, gas diffuser and torch body.

Direct current electrode negative is the most common type of current used for welding materials such as mild steel, stainless steel and alloy steels. Direct current electrode negative is used also to obtain narrow, deep penetrating welds.

Direct current electrode positive may be applied to welding very thin aluminium and magnesium parts, but is not commonly used because a large diameter electrode is required to carry low current and the arc may be unstable.

Alternating current, with a superimposed high-frequency current, is most commonly used for aluminium and magnesium as it combines good oxide clearing when the electrode is positive, with good penetration when the electrode is negative.

Pulsed current

Pulsed current is also available on some GTAW equipment. The welding current is set to fluctuate between a high fusion current level and a low solidification or background current level; both of which are adjustable, as is the time for which each current level is effective. The number of pulses can be varied from ten per second down to one per second.

Pulsed current, which may be AC or DC, is particularly useful for welding very thin materials, providing good penetration during the high cycle with cooling of the molten pool during the low cycle. In effect, pulsed current produces a series of spot welds, penetration is good, distortion is minimised, and control is improved for difficult welding situations involving thin materials and positional welds.

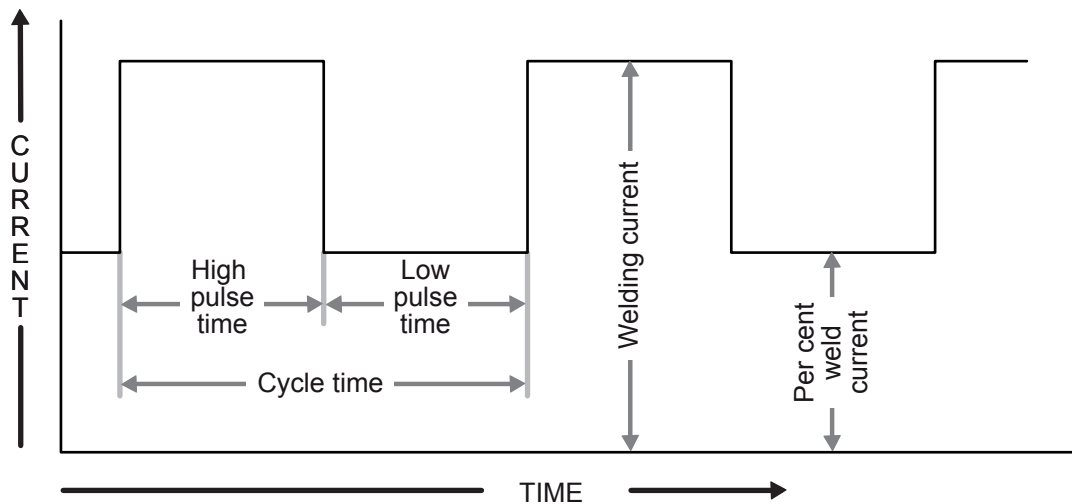


Fig 6.7 – Pulsed current

Shielding gases

Generally an inert gas is used as the shielding medium to protect the weld zone from contamination by the atmosphere. Argon is the inert gas most commonly used in Australia. It is preferred to helium because of its lower cost and its general suitability for a wide variety of metals. Argon is an electron carrier and also exhibits better oxide removal characteristics than helium and aids the welding operation, as heat input to the weld puddle is less affected by variations in arc length. On the other hand, helium as an insulator gas provides higher arc voltages and greater heat input which increases penetration and travel speeds.



Term	Definition
argon	a colourless, odourless inert gas
inert	having only a limited ability to react chemically; chemically inactive

Mixtures of the two gases, in some special applications, and also other brews (or combinations of gases) will prove advantageous, particularly in mechanised applications. Those seeking further information should contact the local supplier.

Fixed pressure reduction regulators are used to supply gas to the torch, together with a flow meter to give a precise indication of the gas flow rate being used. Gas flows are adjusted between five and 14 litres per minute to suit the particular application.



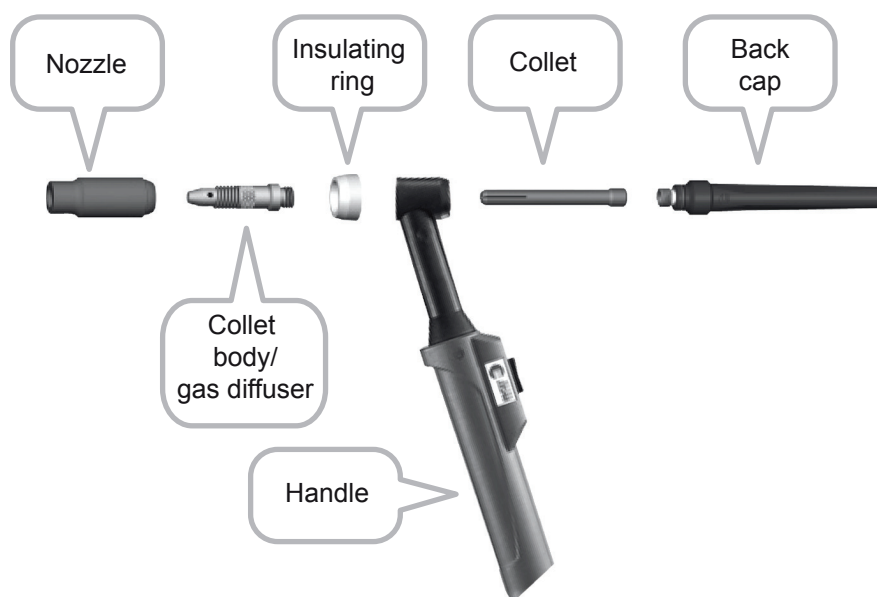
Welding torches

Handheld GTAW welding torches may be air cooled for low to medium amperage applications (these are also gas cooled by the gas supply). Water cooled torches are required for industrial operations involving higher amperages and longer welding periods. The electrode is held by a collet in a collet body/gas diffuser which allows the removal and setting of the electrode in relation to the torch nozzle, or gas shroud.

Projection of the electrode should not be excessive as it may touch the work and contaminate the electrode. Minimum projection of the electrode, normally 2 mm to 5 mm, will provide good welding conditions and satisfactory gas coverage of the electrode and work. The collet is tightened by screwing in the torch back cap which also provides insulation for the electrode.



Term	Definition
collet	grips electrode and passes electric current to tungsten electrode
gas diffuser	fits into torch and distributes gas flow evenly (also retains electrode collet)



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Fig 6.8 – Welding torch parts



A control for gas flow is located on the torch and this may incorporate a current on/off switch. Some equipment allows gas to flow for short periods before the arc is struck (pre-purge) and after welding current is switched off (post-purge), which provides gas coverage of the electrode and work as they cool.



Term	Definition
pre-purge	flow of gas before the arc starts to ensure shielding gas is around arc zone and to facilitate arc starting
post-purge	flow of gas after the arc is stopped to allow time for tungsten electrode and weld area to cool

Gas nozzles

Gas nozzles or gas cups are used to protect the tungsten electrode from the atmospheric gases and to deliver the shielding gas to the weld area. They may be made from cheap alumina-type material, ceramic material or even metal or fused silica (glass). The gas cup is available in a variety of sizes ranging from 8 mm to 20 mm.

The general rule for the gas cup size is four to six times the electrode diameter. This may be altered however depending on the joint type and material being welded. For example, an outside corner weld may require a larger gas cup size to give more shielding, while an inside corner can be achieved easily with a small gas cup because the gas will be trapped in the corner. Typically, aluminium or stainless steel may also need a one size larger cup to give better gas coverage.

Electrodes

Different types of tungsten electrodes are available and provide a comprehensive range for specific applications. Tungsten electrodes are identified by their tip colour. This colour tip should be preserved, as identification of a tungsten electrode that has lost its code can be difficult.

Pure tungsten electrodes (green tip)

Tungsten has the highest melting point of all metals – typically 3400 °C for pure tungsten. These electrodes are recommended chiefly for use with balanced wave alternating current power sources on the welding of aluminium, where other electrode types are not generally used due to their emission characteristics. When used with standard power sources, pure tungsten electrodes provide good stability with direct current and high-frequency, stabilised alternating current with argon, helium or a mixture of both as a shielding gas.

Pure tungsten electrodes have a lower current carrying capacity and poorer arc starting characteristics than other electrodes, but have a reasonably good resistance to contamination and maintain a clean balled end (which is preferred for aluminium and magnesium welding). They are a general purpose electrode for less critical work.



2% Thoriated tungsten electrodes (red tip)

These electrodes contain one to two per cent thorium as an alloy and this gives the electrode a greater ability to resist transfer across the arc and thus help to maintain the sharpened point (when used chiefly for direct current electrode negative). This is because they offer increased life, compared with pure tungsten type, due to their higher electron emission. They have better arc starting, particularly at low open circuit voltages, and good arc stability. The thoriated tungsten range of electrodes have a higher current carrying capacity and greater resistance to weld pool contamination.

Thoriated tungsten electrodes are generally used when DC electrode negative is selected for welding of ferrous materials and alloys such as mild steel, alloy steel and stainless steel. They may be used on high-frequency, stabilised alternating current work, but there can be difficulty maintaining the satisfactory balled end required for good arc stability (when welding aluminium and magnesium). This condition frequently produces arc wander and tungsten emission, resulting in contamination of the weld metal.

0.8% Zirconiated tungsten electrodes (white tip)

These electrodes are treated with zirconium and are preferred for applications where tungsten contamination of the weld metal must be minimised. They are recommended for use with high-frequency, stabilised alternating current for the welding of aluminium and magnesium due to the fact that they retain a clean balled end during welding and have a high resistance to contamination. They have a longer life and higher current carrying capacity than that of pure tungsten electrodes.



In recent studies related to health issues for welding operators, the thoriated and zirconiated type electrodes have been found to produce a slight amount of radiation when they are ground up. For this reason they should be used only when special precautions are used. Due to this problem, new types of electrodes for GTAW have been developed.

Ceriated tungsten electrodes (orange tip) and lanthanated tungsten electrodes (grey tip)

These are relatively new types of non-radioactive alloy tungsten electrodes. They can be used in situations where either thoriated or zirconiated tungsten electrodes would normally be used. The tip may be ground to a point when using DC(–) or to a ball if AC(hf) is to be used and they demonstrate good welding characteristics in all applications.

The only drawback is that these electrodes are more expensive to buy than the thoriated or zirconiated electrodes. However, if an operator has been instructed to use the GTAW process on a particular job but does not know what type of metal or alloy the item is made from, ceriated or lanthanated tungsten electrodes should be selected. This will ensure that a sound weld can be produced no matter what welding current is required.



The chart below sets out general recommendations for choosing operating conditions.

Electrode diameter	Gas cup size	AC(hf)	DC(-)
0.5 mm	6 mm	5–15	5–20
1.0 mm	6 mm	15–40	15–70
1.2 mm	6 mm	20–60	40–90
1.6 mm	6 mm or 10 mm	20–90	65–120
2.4 mm	10 mm	60–160	140–250
3 mm	12 mm	120–220	250–380
5 mm	15 mm	160–340	300–550
6 mm	15 mm	280–470	500–700

Table 6.1 – Typical operating conditions for tungsten electrodes

Before assembling the electrode in the torch, one end should be prepared to suit the type of welding current being used. For DC(-) it should be ground to a taper with the nose section having an approximately 30° included angle; do not grind to a sharp point but leave approximately $\frac{1}{3}$ of the electrode diameter unground as a sharp point can be lost from the electrode into the weld pool during welding. For AC welding, grind with a chamfer to provide rapid formation of the balled end necessary for AC welding.

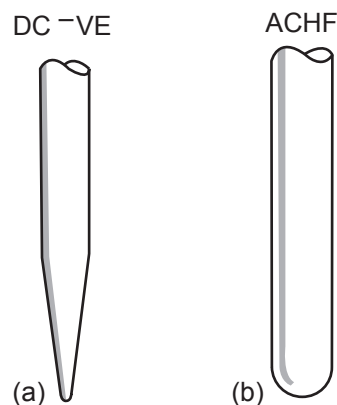


Fig 6.9 – Electrode tip preparation (a) and (b)

Gas tungsten arc welding techniques

Starting the arc

After the gas flow is established and providing high-frequency current (hf) is used to initiate the arc, the electrode does not have to touch the work piece or starting block to effect arc initiation. The superimposed high-frequency current jumps the gap between the electrode and the work piece or starting block and thus establishes a path for the welding current to flow. On some machines there is facility for a flow of gas before welding starts (pre-purge) and the current rate and rise time can also be adjusted (up slope).



Term	Definition
up slope	welding current rate and rise time can be adjusted from a base or start current to allow for heating up of the weld area
down slope	welding current rate and fall time can be adjusted from main current to allow for crater fill and cooling down of the weld area

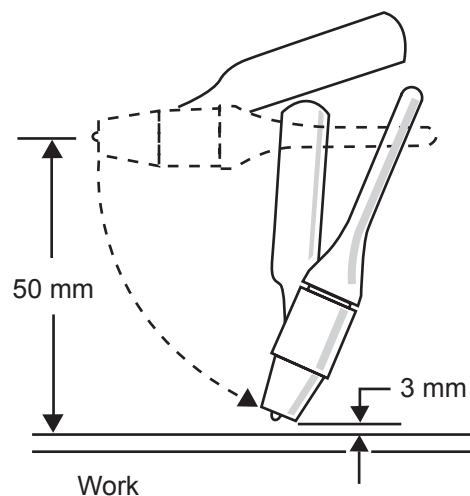


Fig 6.10 – Initiating the arc

When DC is employed without high-frequency, it will be necessary for the electrode to make actual contact with a starting block. At the moment of contact and when the arc is struck, the electrode should be raised 3 mm above the starting block to the work piece. The torch is then moved quickly towards the work area.

To stop an arc, the current should be switched off and the torch held over the cooling weld to provide a protective gas shield whilst the electrode and work are cooling. Some care will be necessary, particularly with high quality work and in pipe preparations when breaking the arc. In some instances it can be advisable to run off on to a tab or up the side of the pipe preparation when completing a pass.

Equipment controls are available so that:

- the operator may be able to adjust a gas flow and time (post-purge) to prevent the risk of contamination
- the current may gradually be decreased (down slope) at the end of a weld pass, thus allowing the crater to be filled, instead of being finished in a concave contour.



Arc wander

Occasionally the point from which the arc leaves the electrode can move and waver without any apparent reason. This is termed 'arc wander' and is generally attributed to one of the following causes:

- low-electrode current density (too large an electrode for the current being employed)
- contamination of the electrode
- magnetic effects.

In AC welding, a ball-ended electrode is used and, when the current density of the electrode is at a sufficiently high level, the entire end of the electrode will be in a molten state and completely covered by the arc. When too low a current density is used only a small area of the electrode becomes molten, resulting in an unstable arc which has poor directional characteristics and is difficult for the operator to control. Too high a current density results in excessive melting of the electrode end.

Arc wander in GTAW can be reduced by careful selection of the electrode diameter. It is much less serious in DC welding, due to the fact that a tapered point is ground on the electrode.

Electrode contamination can be caused by excessive amperage or careless striking of the arc. It may be preferable to use a piece of copper for starting purposes. Carbon blocks are not recommended because of carbon pickup producing arc instability. Contamination may also result from allowing the electrode to enter the molten pool or from being touched by the filler rod. When contamination does occur, the only course of action is to remove the electrode and either replace or clean it by grinding or breaking off the contaminated end.

Magnetic effects are not frequently encountered and one remedy is to re-position the work return clamp.

Butt welds

After the arc has been struck, the torch should be positioned at about 70° to the work piece. The starting point of the work is first preheated by moving the torch in small circles until a molten pool is formed (see Fig 6.11).

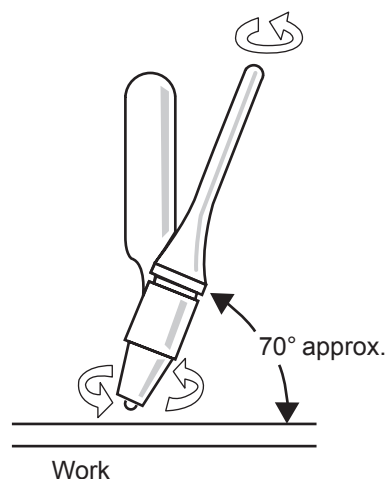


Fig 6.11 – Formation of weld pool



The end of the electrode should be held approximately 3 mm above the work piece. When the puddle becomes bright and fluid, move the torch slowly and steadily along the joint at a speed that will produce a bead of uniform width. No oscillating or other torch movement is required, other than a steady forward motion.

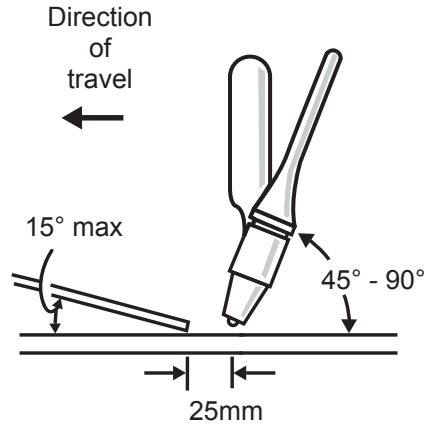


Fig 6.12 – Positioning of filler rod

When filler metal is required to provide adequate reinforcement, the filler rod is held at about 15° to the work and about 25 mm away from the starting point. Fig 6.12 illustrates torch and filler rod angle. First preheat and develop the puddle as described. When the puddle becomes bright and fluid, move the arc to the rear of the puddle and add filler metal by quickly touching the rod to the leading edge of the puddle. As soon as the puddle is again bright, repeat the same procedure. Care should be taken to ensure the filler rod end does not leave the protection of the gas shroud during the welding process.

The rate of forward speed and amount of filler metal added will depend on the desired width and re-inforcement of the weld bead. Fig 6.13 illustrates the filler rod movement.

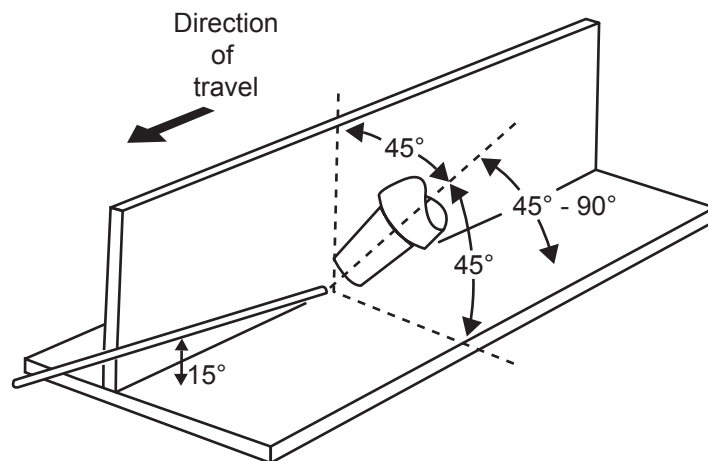


Fig 6.13 – Method of adding filler rod



Fillet welds

The torch should be held at approximately 45° to 90° to the work piece with the electrode bisecting the angle between the joint members. All fillet welds require the addition of a filler rod to provide the necessary build-up, with the filler rod being added to the weld pool in a similar manner as described in butt welds. After establishing the arc, the weld pool should be developed on both parts of the work piece by using an oscillating movement similar to that used for butt welding, before the addition of filler metal is applied. In awkward corners it may be desirable to extend the electrode to provide better visibility and complete root fusion. Fig 6.14 illustrates torch and filler rod relationship to the work piece.

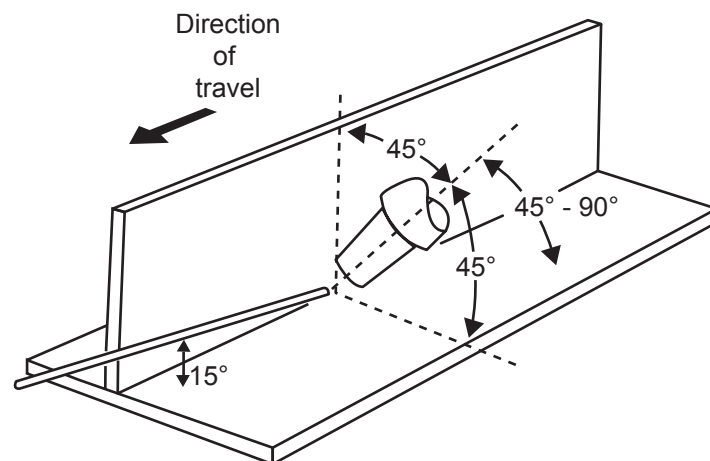


Fig 6.14 – Fillet joint torch and filler rod relationship

Pipe welding

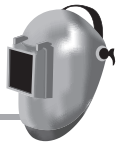
The GTAW process is commonly used for pipe welding. High-quality welds with uniform penetration may be readily made in such metals as mild and low alloy steels, stainless steels, and aluminium and copper. The welds may be root passes in heavy pipe or completely welded joints with root, filler and finishing passes.

In GTAW pipe welding you can gauge the success of the process by observing the weld puddle. The shape of the puddle and its size clearly indicates the degree of penetration inside the pipe. By manipulating the torch properly, the weld puddle can be controlled at all times, so that it has the correct shape for the pipe joint being welded. Thus smooth, fully penetrated, porosity free welds can be produced.

Argon is recommended as a backing gas for pipe welding, since it is most effective in preventing oxidation of the back side of the weld.

The argon backing may be confined to the weld areas by paper baffles, by completely filling the pipe or by the use of a removable backing device. Joint designs include 'V' and 'U' groove preparations for horizontal and vertical applications.

Consumable inserts (consumable backing rings) are available which will produce the higher weld quality and the strongest inside weld reinforcements. The inserts fit into a special 'U' groove preparation.



The joint preparation requires close joint tolerances, and fitting the insert into the joint is time consuming, but since the composition of the insert may be selected to vary the composition of the weld, the weld results may be superior. These inserts are available in mild steel, low alloy steel, and stainless steel.

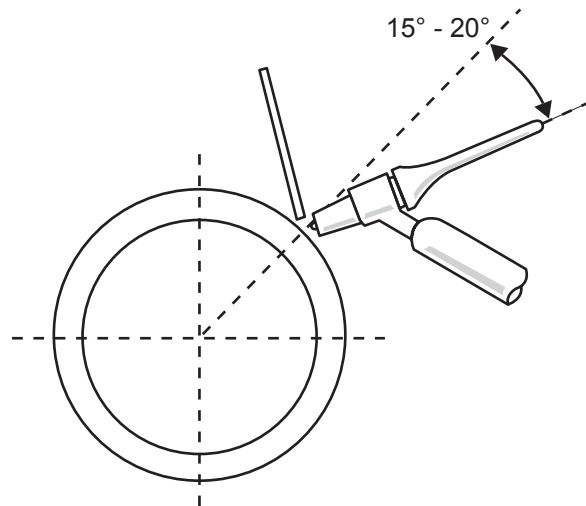


Fig 6.15 – Relative position of torch and filler rod to pipe

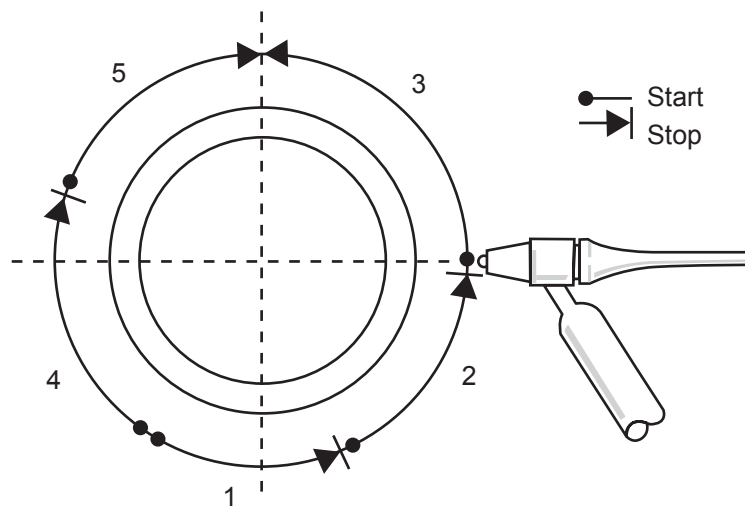


Fig 6.16 – Recommended welding sequence for pipe in the horizontal fixed position

The relative position of the torch and filler rod to the pipe is illustrated in Fig 6.15, whilst the recommended welding sequence for pipe in the horizontal fixed position is illustrated in Fig 6.16.



Weld backup

On many GTA welding applications, the joint should be backed up, particularly on light gauge material. Backing is generally used to protect the underside of the weld from atmospheric contamination, that may result in possible weld porosity or poor surface appearance. In addition to protecting the underside of the weld, backup prevents the weld puddle from dropping through by drawing away from the work piece some of the heat generated by the intense arc, and can also physically support the weld puddle. A weld can be backed up by:

- metal backing bars
- introducing an inert gas atmosphere on the weld underside
- a combination of both methods.

Weld backing bars may be of a temporary or permanent type. The temporary type does not form part of the welded joint and can be copper, stainless steel, mild steel etc, depending on the material to be welded, and may be removed on completion of the weld. The permanent type is usually of the same composition as the material to be welded and becomes part of the welded joint as illustrated in Fig 6.17. They are generally used where access does not allow the removal of the temporary type.

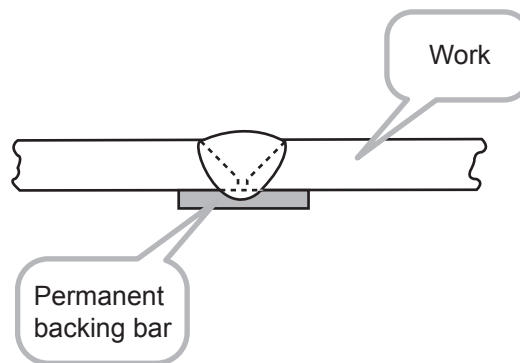


Fig 6.17 – Permanent backing bar

A type of temporary backing bar commonly used is shown in Fig 6.18 where the surface is cut or machined out directly below the joint. A bar of this type will protect the bottom of the weld from excessive contamination by the atmosphere, as well as draw heat away from the weld zone.

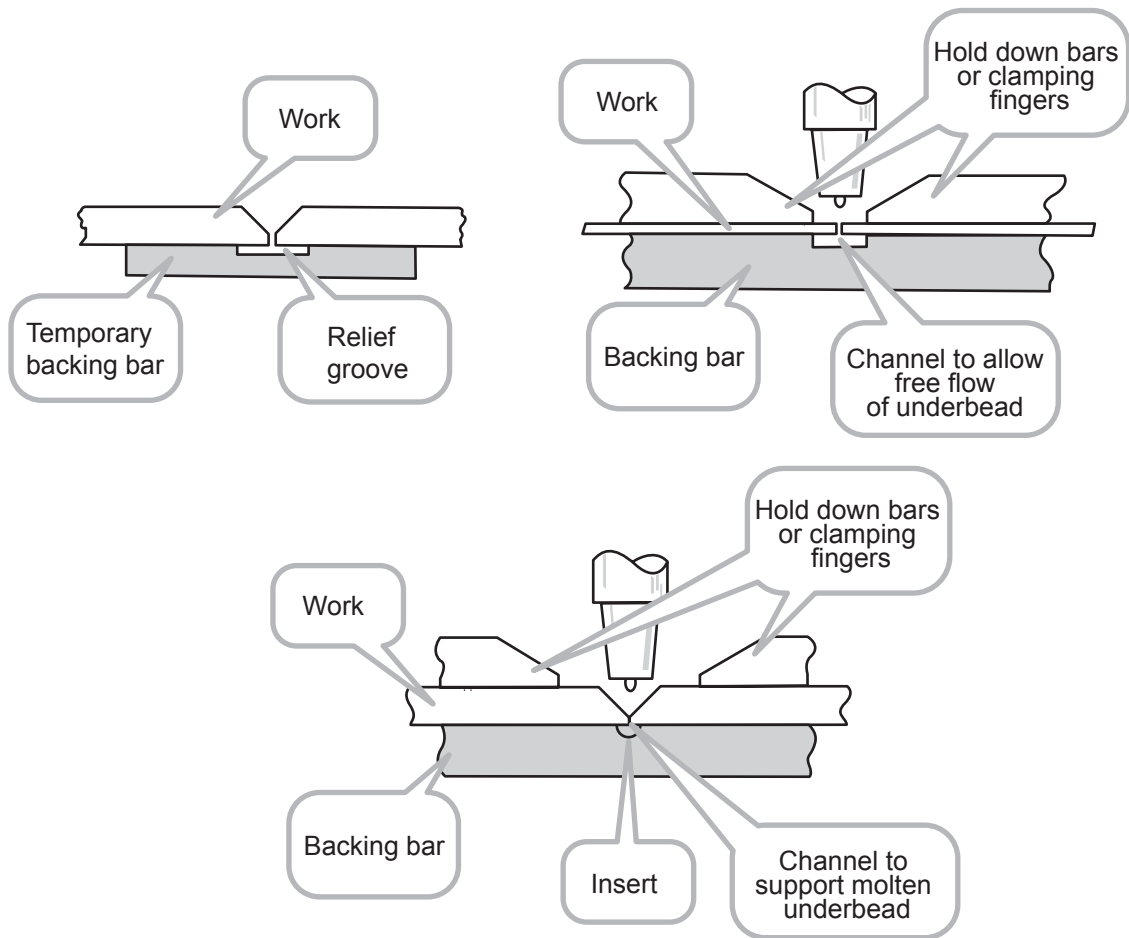


Fig 6.18 – Temporary backing bar

On applications where the final weld composition must conform to extremely rigid specifications, extra care must be taken to exclude all atmospheric oxygen from the weld underside. The use of temporary backing bars that will trap gas on the under side can achieve this. A supply of inert gas can also be offered up to the under side.

Nitrogen may be used for stainless steel. Argon should be used for aluminium, magnesium and other metals that oxidise readily or react with nitrogen at high temperatures.



Activity

In the workshop:

- identify safe working practices and protective equipment in the workshop
- identify a suitable GTAW plant
- with the mains power switched **OFF**, set up the GTAW plant (start by checking the electrical cable connections to the work lead and electrode handpiece, then the gas connections from the cylinder through to the handpiece)
- select the necessary collet holder/gas diffuser and collet to suit a 2.4 mm thoriated tungsten electrode
- prepare the electrode by sharpening and fit it into the welding torch
- fit a 10 mm diameter gas cup to the torch
- adjust the power source current type and polarity to produce direct current electrode negative DC(-)
- have your lecturer check the equipment and settings and help you to adjust the argon gas flow rate to nine to ten litres per minute with the power source turned on
- with your lecturer's assistance, produce a weld on a practice piece of material.

Variable	Description
current (amps)	adjustable range
current type	AC, ACHF, DC-, DC+
pulse	adjustable pulse wave settings
AC wave control	adjustable wave control
voltage control	weld voltage control

Fig 6.19 – Chart showing variables that can be set on quality GTAW plant





Chapter 7 – Gas metal arc welding (GMAW)

Introduction

Since its introduction in the 1940s, gas metal arc welding (GMAW) has become the most popular welding process in Australian industry. It is particularly suited to a wide range of light and general fabrication applications. Gas metal arc welding is a semi-automatic process where the wire is fed into the weld pool. This produces higher deposition rates and greater efficiency over the manual metal arc welding process.

In this chapter you will look at the following.

- GMAW principles
 - advantages
 - limitations
- Safety in gas metal arc welding
 - darker welding filters
 - body protection
 - ventilation
- Equipment
 - power source
 - wire feed unit
 - gun cable assembly
 - gas supply system
 - interconnecting cables
 - wire feed systems
 - drive rollers
 - wire conduit (liner)
 - contact tip
- Metal transfer
 - dip transfer
 - globular transfer
 - spray transfer
 - pulsed current
- Classification of consumables



- o solid wire electrodes classification system
- Gas metal arc welding variables
 - o wire speed/amperage
 - o arc voltage
 - o travel speed
 - o electrical stick-out
 - o torch angle
 - o angle of travel
- Shielding gases
 - o carbon dioxide
 - o argon
 - o gas mixtures
 - o flow rates
- Other machine controls
 - o spot timer
 - o burnback control
 - o spool brake
- Joint design for gas metal arc welding
- Gas metal arc welding defects
 - o porosity
 - o lack of fusion
 - o lack of root penetration
 - o excessive penetration
 - o contour defects
 - o undercut
 - o cracking
 - o stray arcing
 - o excessive spatter
- Trouble shooting/equipment malfunction.

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

(GMAW) principles

Gas metal arc welding is an arc welding process where the necessary heat for fusion is produced by an electric arc maintained between a continuously fed wire electrode and the part to be welded. The heated weld zone, the molten weld metal, and the consumable electrode are shielded from the atmosphere by a shroud of gas, fed through the welding torch.

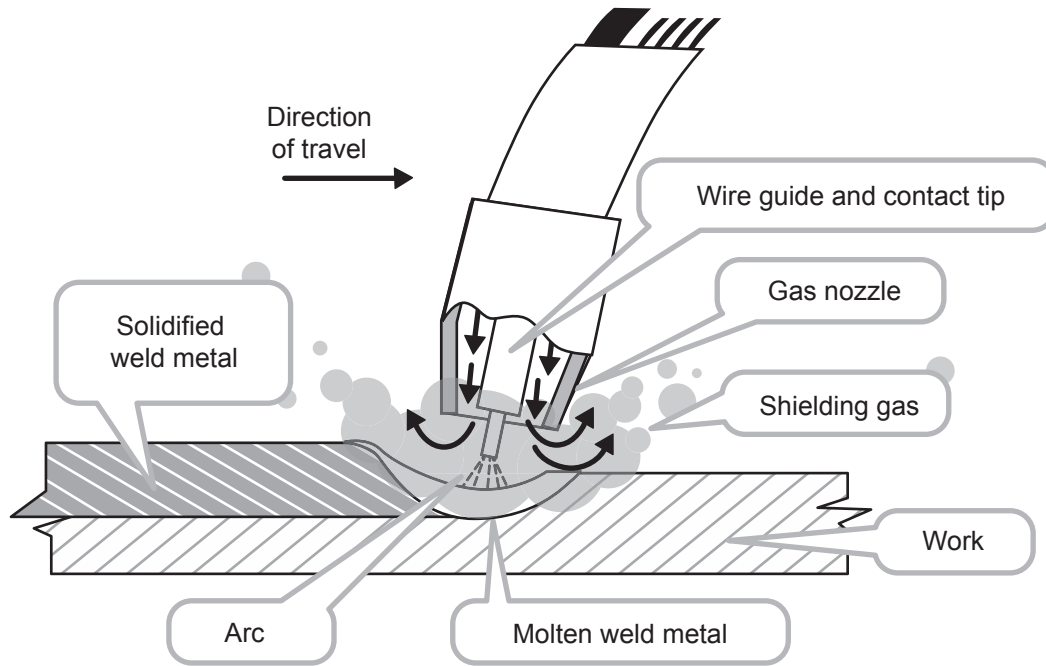


Fig 7.1 – The gas metal arc welding process

Advantages

The major advantage of the GMAW process is its high deposition rate compared with the manual metal arc, and gas tungsten arc welding processes. This is brought about by the automatic wire feed, the high ratio of current to wire diameter, and the removal of the need to change electrodes, chip slag etc. The advantages of this include:

- high deposition rates when compared to manual metal arc welding
- high operating factor
- no wastage from electrode stubs
- elimination of slag removal
- has a wide range of applications
- low hydrogen deposit
- reduced distortion on thin materials.

Limitations

Whilst GMAW is a popular and versatile welding process offering the advantages listed above, it is also limited by the following.

- High initial equipment cost.
- High maintenance requirements and low mechanical reliability.
- Cannot be used in windy conditions Australian Standard® AS/NZS 1554.1 Structural steel welding – Welding of steel structures, limits the use of gas shielded processes where the wind velocity exceeds 10 km/hr. This makes the process generally unsuitable for site work.
- Lack of fusion defects can be a major problem under some circumstances.
- More variables to set.



Safety in gas metal arc welding

Darker welding filters

The primary concern in regard to safety is the open arc and intensity, which is much greater than that associated with MMAW electrodes. Thus a darker welding filter than is normally used is required for GMAW – a filter one shade darker than that used for welding at the same amperage with the MMAW process is required.

For example:

- up to 200 amps – a shade 11 is recommended
- 200–300 amps – a shade 12 is recommended.

Clear safety glasses must be worn at all times, due to the high emission of UV radiation, resulting in more frequent and severe arc flashes.

Body protection

This same arc intensity will also require the operator to ensure their body is completely covered with protective clothing. Even extraneous light from the arc (ie UV radiation bouncing from a reflecting wall) can result in a rather uncomfortable 'ray burn'.

Experience has shown that cotton materials have less resistance to ultraviolet rays than woollen materials. Cotton, and particularly synthetics, quickly break down and eventually disintegrate. Consequently, it is preferable to wear leather or woollen materials.



Term	Definition
UV radiation	ultraviolet radiation sources are invisible rays of energy from the sun (natural), and welding processes (artificial). Ultraviolet radiation can damage the skin causing varying types of cancer

Ventilation

When arc welding, a toxic gas called ozone (O_3) is given off from the arc. Processes which employ higher current densities produce more ozone. Although ozone is not dangerous under most conditions, it is advisable when working in confined spaces (where ventilation is restricted) to use exhaust extraction. Natural ventilation and exhaust fans can also be advantageous. Any ventilation system used must not interfere with the gas shielding of the weld zone.



Term	Definition
ozone	an unstable, poisonous allotrope of oxygen (O_3) that is formed naturally in the ozone layer from atmospheric oxygen and in the vicinity of an electric arc

The major equipment items which make up a GMAW plant are:

-
- This schematic diagram illustrates the components and connections of a gas metal arc welding system. The system includes a power source (transformer rectifier) connected to an inductor, which is linked to a wire feeder. The wire feeder contains a wire reel and feed rolls. A flow meter and a heater (if required) are connected to the wire feeder. A regulator is connected to a shielding gas supply. A power cable and a work lead are connected to the wire feeder and the work, respectively. A cooling water (if required) line is also connected to the wire feeder. The wire feeder feeds welding wire through a contact tip into a nozzle, which is used to weld the work. Shielding gas is supplied to the nozzle. The diagram is labeled with various components: Power source, Transformer rectifier, Inductor, Wire feeder, Wire reel, Feed rolls, Flow meter, Heater (if required), Regulator, Shielding gas supply, Cooling water (if required), Power cable, Welding wire, Contact tip, Shielding gas, Nozzle, Work, and Work lead.

Power source



Term	Definition
DC	direct current. An electric current flowing in one direction only



Wire feed unit

The primary function of the wire feed unit is to feed wire to the arc. The unit houses a reel of wire and a DC motor, to which feed rollers are attached. The feed rollers feed wire to the arc down through a hollow conduit. The speed of the drive motor is governed by a potentiometer (the wire feed control). Increasing the wire speed rate usually increases amperage because the increased wire feed rate effectively decreases the arc length slightly. This loads up the arc voltage and the machine will then increase welding current to compensate. Incorporated into the wire feed unit are the shielding gas connections, gas solenoid, and water connections (in the case of a water-cooled torch).

Most wire feed units have a gas purge control so that the gas flow can be set without any current or wire flow, and a wire inch control so that wire may be fed through without the welding current being turned on. Some wire feeders may also have pre-gas flow and post-gas flow (useful for aluminium and stainless steel).

Gun cable assembly

The gun cable assembly is the vehicle by which wire, current and shielding gas are conveyed to the welding arc. It connects to the wire feeder and terminates at the gun or handpiece.

The electrode wire travels through the wire conduit or 'liner' which runs through the centre of the gun cable. Welding current is carried through the cable by a heavy copper lead within the cable.

Shielding gas is also carried through the cable, and is distributed at the weld via the gas diffuser and gas nozzle.

Welding is commenced by depressing the torch trigger. This initiates three separate functions, as follows.

1. The welding current contactor is 'pulled in' (closed) and welding current becomes available. Welding current is transferred to the wire as it passes through the contact tip.
2. The gas solenoid valve opens and allows shielding gas to flow.
3. The wire feed motor starts up and feeds wire at the preset, constant speed through the torch conduit.

Due to the heat generated in the weld pool and through electrical resistance at the contact tip, torches have to be efficiently cooled. The majority of torches are gas-cooled, however, water-cooled torches may be required when high amperages are used on a continuous basis.

Welding guns are usually provided with a bent neck to improve operator comfort but some guns may have a straight neck, which allows better wire feed.



Term	Definition
gas solenoid valve	an electromechanical valve controlled by running (or stopping) an electrical current through a solenoid (a coil of wire) thus changing the state of the valve
electrical resistance	a measurement of properties which limit the ability of a substance to conduct electricity

Gas supply system

Shielding gases for GMAW are usually supplied from a single cylinder, however, large consumers may use manifolded systems. The components of the gas supply system are:

- a cylinder of gas – CO₂ or argon/CO₂ mixtures for carbon steels
- a regulator – to reduce cylinder pressure
- a flowmeter – to control shielding gas flow rate
- a heater – when CO₂ is used as a shielding gas, a heater is fitted between the cylinder and the regulator to prevent freezing at the regulator.

Interconnecting cables

These consist of:

- the work return lead
- the electrode lead – from the power source to the gun cable adaptor of the wire feeder
- the control cable from the power source to the wire feeder.

Wire feed systems

There are three basic types of GMAW wire feed systems, each requiring different torches.

1. The push system

The push system is by far the most popular wire feed system. The wire feed unit pushes the electrode wire from the drive rolls along the gun conduit, through the gun and contact tip and to the weld pool. Push systems are generally robust, lightweight and very functional (also the least expensive). The system works very well with hard wires such as steel and stainless steel, in cables up to 4.5 metres in length. Wires in spools of 15 kg or larger are usually used with this system. This keeps costs down and increases convenience.

The major disadvantage of the push system is the unreliability of wire feeding caused by friction which causes dust to accumulate in the conduit. Wires may also become kinked and this is a particular problem when feeding soft wires such as aluminium. Because the conduit in most wire feed systems is live (connected to the wire feeder and/or the contact tip) the conduit may experience internal arcing caused by dust, or a faulty or dirty contact tip and this results in



wire feed problems. Any wire feed rate problem caused by a dirty contact tip and/or faulty wire feed will reflect itself in altered or changing weld parameters (voltage/amperage).



Fig 7.3 – Push system

2. The pull system

The pull system is sometimes known as spool on gun and is ideally suited to feeding soft wires such as aluminium, or where welding is to be carried out at a location remote from the power source. The drive motor and drive rollers are built into the handle of the gun. This offers short, direct wire travel, with little friction through the conduit.

The drawbacks of this system are the high initial cost of equipment, the susceptibility of damage to the torch, the cost of consumable wire on small spools, and the weight of wire carried on the gun. Though this system is mainly used for aluminium work, mild steel and stainless steel wires can also be used.

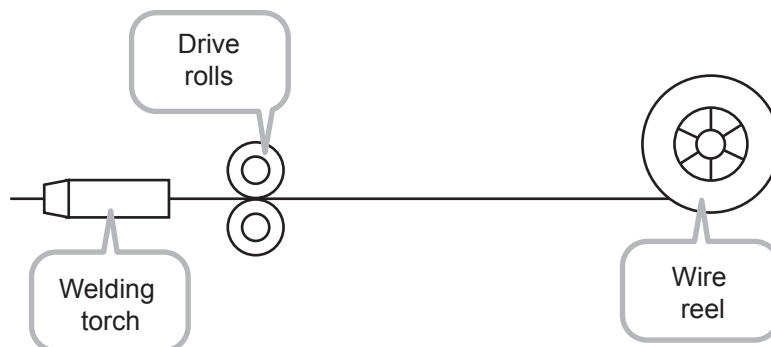


Fig 7.4 – Pull system

3. The push/pull system

As the name implies, both the push motor at the wire feeder and a pull motor at the torch are employed. In the best brands the two motors are synchronised to feed the wire at the same speed, although there are some cheaper brands on the market that allow the torch motor to only apply a set tension to the wire feed whilst all the speed control is maintained at the main wire feeder. The push/pull wire feed system enables the feeding of both hard and soft wires up to 10 metres from the welding machine and still offers the economy of 15 kg (or larger) spools of wire. The push/pull system is versatile, particularly suited to aluminium but may also be used for hard wires as well.

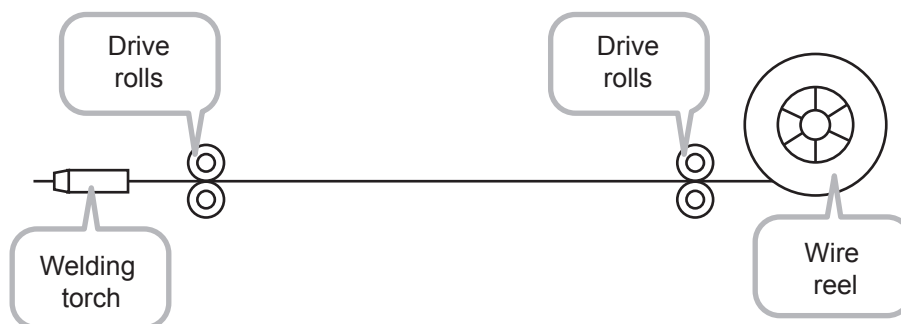


Fig 7.5 – Push/pull system

Drive rollers

Friction, caused by pressure applied to the wire as it passes through the rotating drive rolls, is the mechanism by which the wire is fed. Resistance in the gun cable may cause the wire to slip as it passes through the drive rolls. Increasing the pressure of the top roller increases friction and prevents this slippage. However, excessive pressure can deform the wire making it more difficult to feed (Fig 7.6).

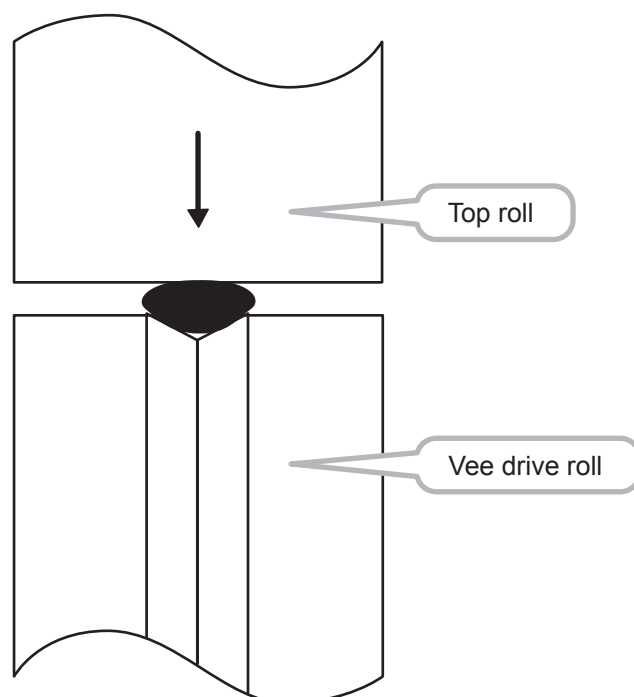


Fig 7.6 – Deformation caused by excessive roll pressure

Wire feeders use either a two or four-roller drive system. Two-roll systems are cheaper to buy and are best suited to feeding hard wires such as carbon and stainless steels through short gun cables.

Four-roll feeders allow greater friction between the rollers and the wire with less roller pressure, giving a smoother feed with less slippage and less distortion of the wire.



The four-roll system offers advantages for:

- feeding soft wires such as aluminium
- feeding wires through long gun cables
- use with cored wires.

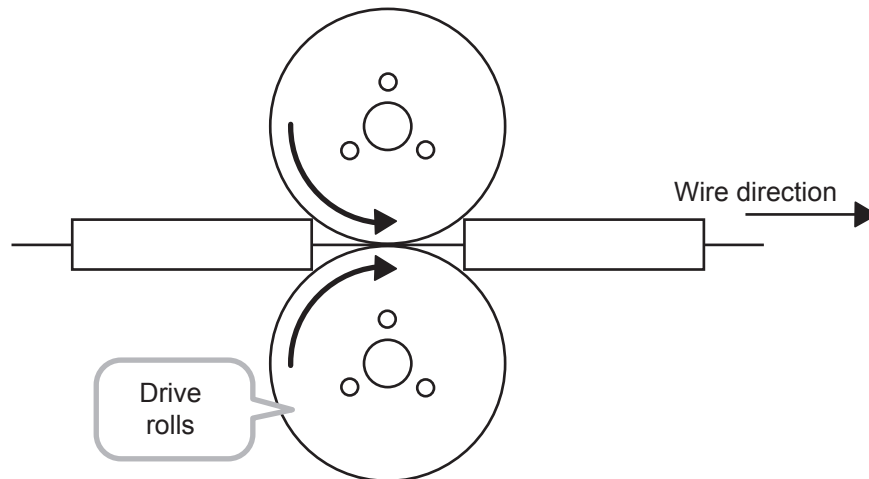


Fig 7.7 – Two roller feeder

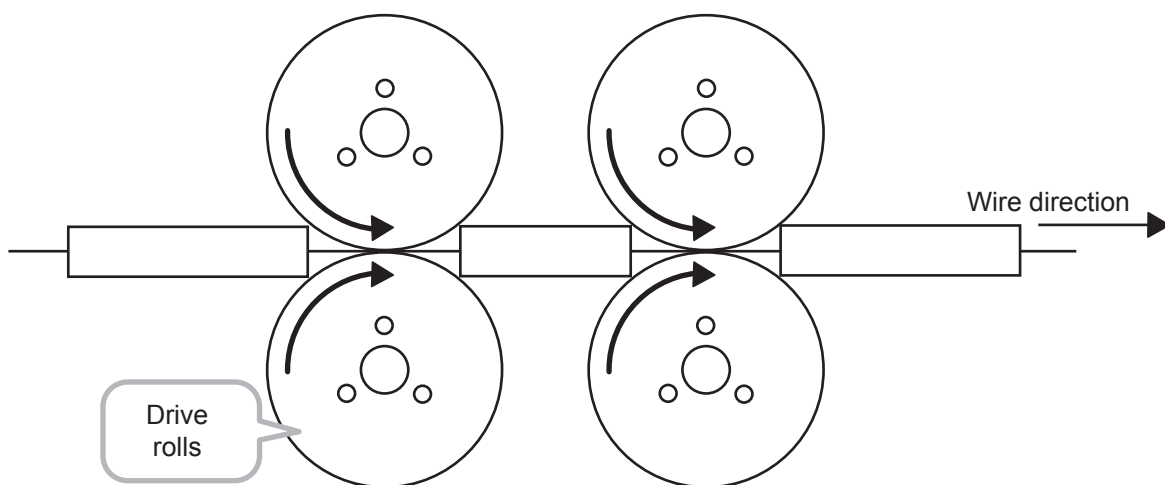


Fig 7.8 – Four roller feeder

The cross sectional shape of the rollers used with any particular wire feeder, for any particular application, varies according to the manufacturer.



Common configurations/sections of drive rolls and their uses include the following.

Drive roll	Type	Application
	flat top roll/'V' bottom roll (three point universal system)	used for general purpose feeding of hard wires such as steel and stainless steel
	flat top roll/'U' bottom roll (contour system – the rolls must suit wire size)	used mainly for aluminium wires. The 'U' profile reduces deformation of the soft wire
	top and bottom rolls have serrated 'V' grooves (knurled)	used for cored wires and large diameter solid wires

Fig 7.9 – Drive rolls



This list is not exhaustive, but these are in most common use.



Wire conduit (liner)

The liner is used to guide the wire through the gun cable to the handpiece, and through to the contact tip. The liner is made of spiral steel wound-wire for feeding hard wires such as carbon and stainless steels, and of Teflon®, for feeding aluminium wire. To ensure reliable wire feeding, it is imperative that the liner is cut to the correct length, and properly fitted in the gun cable and kept free of dust. Additionally, the gun cable should be kept as straight as possible when in use.

Contact tip

The contact tip serves two functions:

- to guide the wire to the arc
- to transfer welding current to the wire.

The contact tip is a most important component of the welding torch. It is here that the filler wire is energised or 'picks-up' the welding current. It is usually made from copper and is, via the gas diffuser and torch body, directly attached to the power lead. Contact tips are matched to each wire size. It is important that the contact tip is maintained in a clean condition, free from spatter on the end, and with a smooth internal bore. Worn contact tips reduce the efficiency with which current is transferred to the wire, and contribute to uneven wire feeding. They should be replaced when worn.

Metal transfer

With most of the commonly used welding processes, the operator has little control over the way metal is transferred across the arc. With GMAW the operator can select and control the type of metal transfer. This is done essentially by selecting the arc voltage, although wire diameter and shielding gas also influence metal transfer.

The metal transfer mode determines the characteristics of the GMAW process. The operator must select the most appropriate mode of transfer and set the machine accordingly, prior to commencing welding.

Apart from the pulsed transfer mode, which requires sophisticated power sources, the welding operator can select from three transfer modes, which are:

- dip (or short arc) transfer
- globular transfer
- spray transfer.

Dip transfer

Dip transfer is also known as 'short arc' transfer (short for short circuiting arc). In the dip transfer mode, low current and voltage settings are used. The low voltage employed is easily overcome by electrical resistance across the arc, preventing continuous current flow as arc length increases.

When welding commences, the tip of the electrode wire contacts the plate and a short circuit occurs. This results in a rapid temperature rise in the wire (caused by the short circuit current flowing through to the work piece) and the end of the electrode wire is melted off. An arc is immediately formed between the tip of the wire and the weld pool. This arc maintains the electrical circuit for a short time until the electrical resistance across the increasing arc gap causes the arc to be extinguished.



The electrode wire continues to feed, and the tip once again dips into the pool and the cycle is repeated. This sequence of events is repeated at a frequency of up to 200 times per second. It produces sufficient heat for fusion, and to keep the weld pool fluid.

This method of transfer is suitable for positional welding due to rapid freezing of the weld pool, and has the advantage that the heat input to the work piece is kept to a minimum. This limits distortion and enables thin sheet material to be welded. However, on thicker material, the low heat input tends to result in a lack of fusion defects if care is not taken with machine adjustment and welding technique.

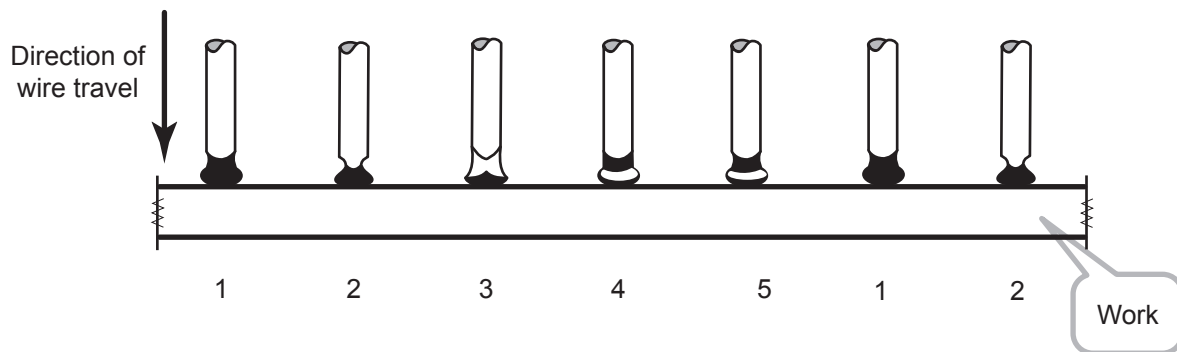


Fig 7.10 – Schematic diagram of short arc transfer

1. Trigger depressed – wire starts to feed.
2. Wire contacts the work piece – heats up due to electrical resistance and starts to melt.
3. Wire melts off and an arc is established.
4. Arc length increases as the end of the wire melts slightly.
5. Arcing ceases due to the low arc voltage being unable to overcome the electrical resistance across the arc gap.
6. Wire is fed into the weld pool which has been created and the cycle begins again.

The following are features of dip transfer:

- low currents are used
- low heat input
- low penetration
- moderate spatter
- low deposition rate
- relatively cold weld pool
- ideal for thin materials
- used for positional welding
- tends to result in lack of fusion defects – particularly when plate thickness exceeds 5 mm.



Globular transfer

Globular transfer occurs at current levels between those used for dip and spray transfer. Voltages are high enough to ensure a constant arc, but amperage is set below the threshold current that produces spray transfer. The result is that the wire melts in the arc, and a molten globule forms on the end of the wire. As melting continues, the size of the globule grows until its own weight causes detachment of the droplet due to gravitational forces. This droplet detachment is erratic and, along with arc forces repelling the droplet away from the wire, high spatter levels result. Droplet size is considerably larger than the wire diameter.

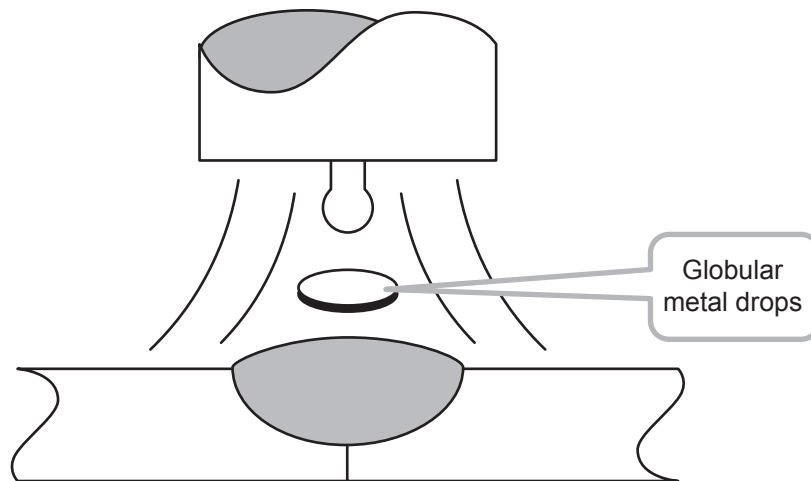


Fig 7.11 – Globular transfer

The following are features of globular transfer:

- moderate amperages are used
- low/moderate penetration
- moderate/high spatter levels
- coarse appearance
- metal droplets are detached by gravitational forces
- largely unsuitable for positional welding
- occurs even at high amperages when the shielding gas contains in excess of 23% CO₂.

Spray transfer

Unlike dip transfer, where the low arc voltage used precludes the use of a continuous arc, spray transfer employs an arc which burns continuously. To achieve this, the arc voltage, when welding steel, must be above approximately 23V (depending on wire size and shielding gas composition).

Additionally, the amperage used must be above the 'threshold current'. The threshold current is the current above which tiny droplets are pinched off and projected axially across the arc gap. Below the threshold current, droplet detachment is brought about by the molten droplet of wire growing in size until it is heavy enough to be detached by gravitational forces.

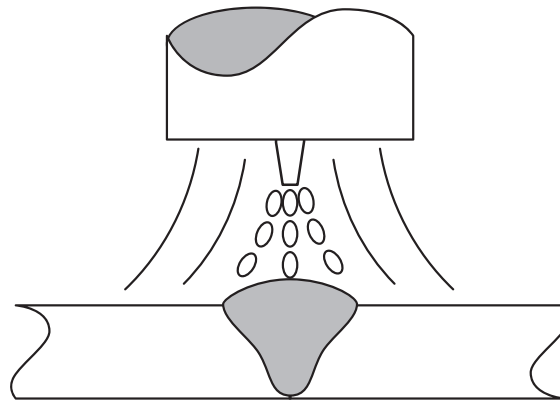


Fig 7.12 – Spray transfer

Spray transfer offers greatly increased deposition rates compared to dip transfer, produces minimal spatter, and doesn't result in the lack of fusion defects sometimes associated with dip transfer. Due to the hot, fluid weld pool associated with spray transfer, it is only suitable for use on plates above approximately 5 mm thick, and in the downhand (flat) position.

The following are features of spray transfer:

- high currents are used
- high heat input
- moderate/deep penetration
- high deposition rates
- low spatter
- good appearance
- fluid weld pool
- unsuitable for positional welding
- requires a shielding gas with high argon content.

The following chart (Fig 7.13) shows the amperage and voltage ranges for the above-mentioned transfer modes.

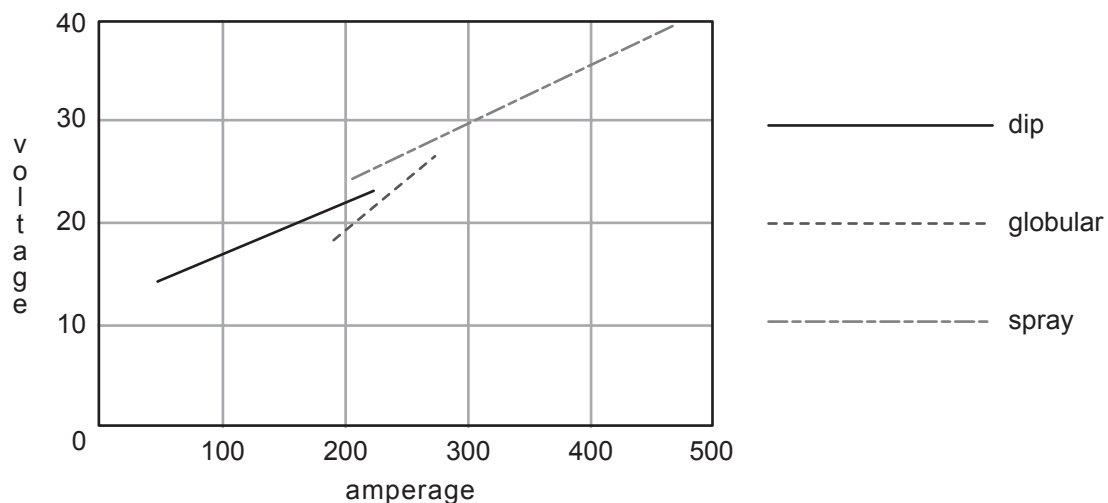


Fig 7.13 – Volt AMP ranges for gas metal arc welding



Pulsed current

Pulsed current may be available on some GMAW equipment. The welding current is set to fluctuate between a high current level for fusion and a low solidification or background current level; both of which are adjustable, as is the time for which each current level is effective. The number of pulses can be varied from ten per second down to about one per second.

Pulsed current is particularly useful for welding very thin materials, providing good penetration during the high cycle with cooling of the molten pool during the low cycle. In effect, pulsed current produces a series of spot welds, penetration is good, distortion is minimised, and control is improved for difficult welding situations involving thin materials and positional welds.

A number of machine manufacturers are providing a droplet transfer option. In this mode the variable related to background current, pulse frequency and pulse current are controlled to provide a cool/heat cycle that produces sufficient current and voltage to melt off a droplet of wire at each pulse cycle. Refer to Fig 7.14 and 7.15.

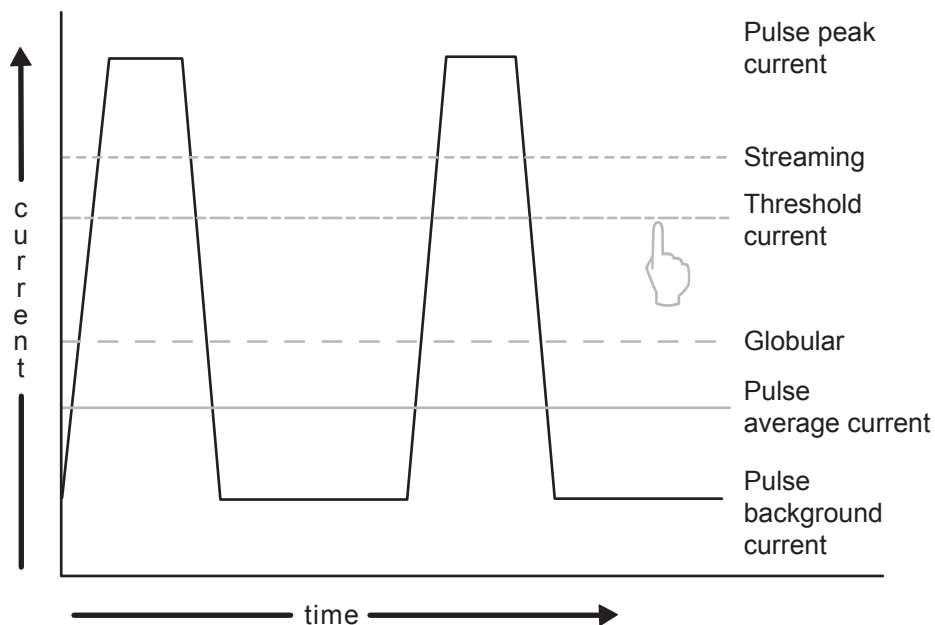


Fig 7.14 – Pulsed current terms

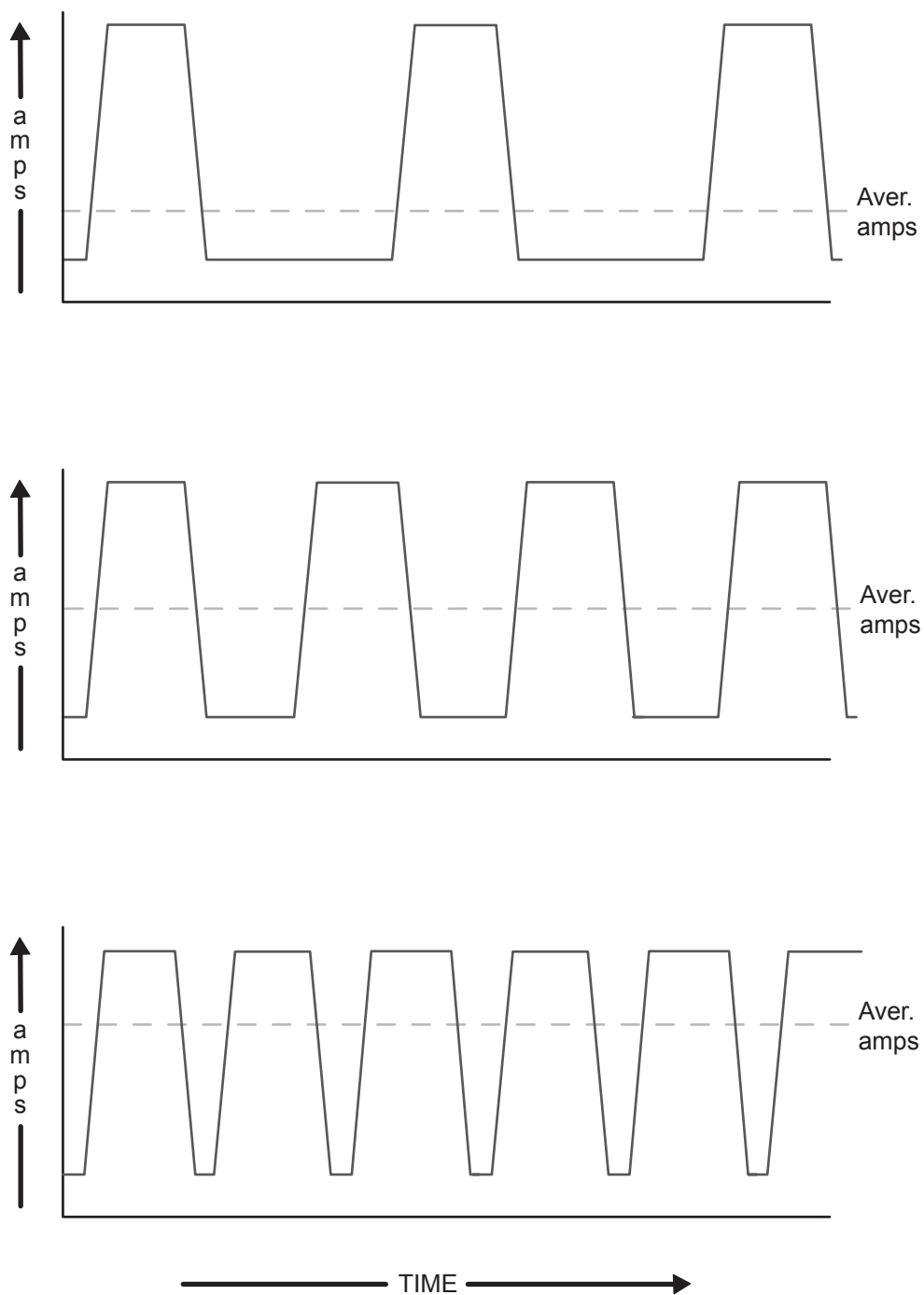


Fig 7.15 – Increasing pulse rate increases average amperage



Classification of consumables

There are many different types of solid and flux-cored electrode wires commercially available. They are classified to a particular standard, which makes it possible to identify and select the most suitable type of wire for a job. It is important to understand classification systems and the information they represent.

Consumable classification systems list a number of essential features about the consumable. For example, consumables are classified in construction, filler metal composition, shielding method, mechanical strength of the weld deposit and so on.

The two systems in this text specify features of solid and/or flux-cored wire electrodes.

Solid wire electrodes classification system

Australian Standard® AS/NZS 2717.1 Welding – Electrodes – Gas metal arc – Part 1: Ferritic steel electrodes.

This Standard classifies solid wire electrodes under three groups of elements separated by hyphens. Each group consists of a letter(s) and number(s).

Example:

ES2-GMp-W502H

Group 1 (ES2)

The first group of letters denotes a solid electrode, and indicates the chemical composition of the wire. **ES** stands for 'electrode solid'. After ES, a number indicates the chemical composition of the wire. From the chart below you can see that a wire **ES2** contains 0.07% carbon, and 0.9 to 1.4% manganese.

Chemical composition chart

Classification	Carbon (%)	Manganese (%)	Silicon (%)
ES2	0.07	0.9–1.40	0.40–0.70
ES3	0.06–0.15	0.9–1.40	0.45–0.70
ES4	0.07–0.15	1.00–1.50	0.60–0.85
ES5	0.07–0.19	0.90–1.40	0.30–0.60
ES6	0.07–0.15	1.40–1.85	0.80–1.15
ES7	0.07–0.15	1.50–2.00	0.50–0.80

Based on AS/NZS 2717.1: 1996 – Table 2.2 (www.saiglobal.com)



Electrodes can also contain very small additions of copper, titanium, zirconium and aluminium.



Group 2 (GMp)

The second group consists of **G** for gas shielded and then two letters that indicate the type of shielding gas used during qualification tests and the welding current required.

G – gas shielding which is then followed by one of the following:

- C** = shielded with carbon dioxide (CO₂)
- M** = shielding with a mixture of gases
- I** = shielded with an inert gas
- p** = positive electrode.

For example, **GMp** indicates that the wire is to be shielded by use of mixed gas with positive electrode.

Group 3 (W502H)

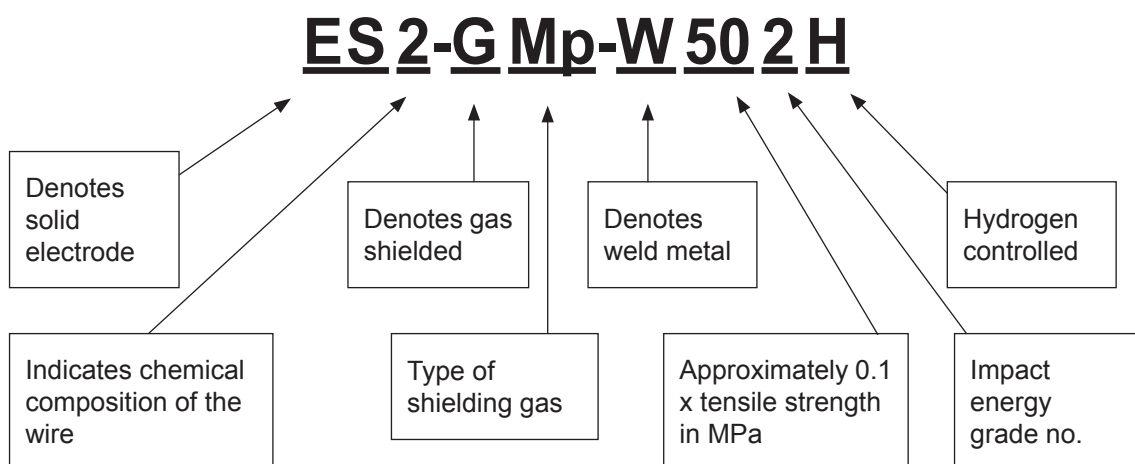
The third group involves a letter **W** followed by a three-digit number. **W** stands for weld metal. The first two digits refer to the minimum strength of the deposited weld, which is measured in megapascals. The third digit refers to the minimum impact value. The letter **H** generally completes the classification which indicates that the process is hydrogen controlled.

W – weld metal properties:

- 50** = 500 MPa strength
- 2** = degree of impact test
- H** = hydrogen controlled.

For example, **W502H** indicates the weld strength is 500 MPa and low in hydrogen.

An example of the full classification system is shown below.





Here are some examples of the system.

ES-GMp-W502H

A plain carbon steel wire electrode.

The chemical composition can be found in the chart on the previous page. When deposited with an Ar/CO₂ gas shield, the weld metal will have a minimum tensile strength of 500 MPa and an impact value 60 J at 0 °C. The weld is hydrogen-controlled.



Term	Definition
tensile strength	measures the maximum force required to pull material to the point where it breaks

ES4-GCp-W503H

A plain carbon steel wire electrode.

The chemical composition can be found in the chart on the previous page. When deposited with CO₂ shielding gas, the weld metal will have a minimum tensile strength of 500 MPa and an impact value of 60 J at 0 °C. The weld is hydrogen-controlled.

Filler wires for the welding of steels are de-oxidised with manganese and silicon, and are generally copper coated (nickel is sometimes used). The copper coating of the wire serves three purposes:

- prevents corrosion of the wire
- improves current pickup
- improves feeding characteristics.

Common wire sizes for GMAW of steels is as follows.

0.6 mm 0.8 mm	Generally used for sheet metal and other light applications
0.9 mm 1.0 mm 1.2 mm	General purpose GMAW
1.6 mm	Welding of heavy plates



Gas metal arc welding variables

The variables affecting the GMAW process are:

- wire speed/amperage
- arc voltage
- travel speed
- electrical stick-out
- torch angle
- shielding gases and flow rate.

Wire speed/amperage

Wire speed and amperage are controlled by the same potentiometer on a GMAW plant. Consequently, these variables cannot be adjusted independently of each other.

As amperage is increased, the current density in the wire increases and the melt-off rate of the wire increases. Amperage is the most important factor when determining heat input into the metal being welded. Increasing wire speed/amperage control will:

- increase the wire feed speed
- increase amperage
- increase deposition rate
- increase penetration
- increase heat input
- for a given travel speed, increase the size of the weld bead.

Decreasing wire speed will have the opposite effect.

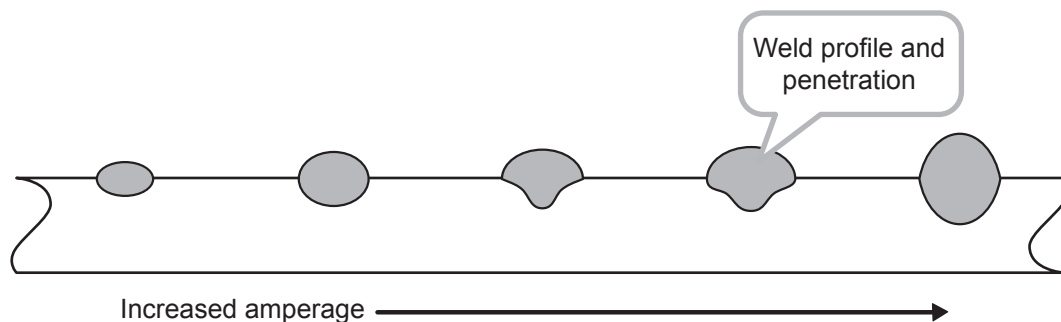


Fig 7.16 – Effect of amperage



Arc voltage

Arc voltage determines the mode of metal transfer when GMA welding. At low arc voltages, resistance across the arc causes extinguishment of the arc, which results in dip transfer. Higher arc voltages are enough to maintain the arc by overcoming the electrical resistance. As the arc voltage is increased, arc length is increased. This enables more wire to be melted off without 'stubbing' as sometimes occurs when high wire feed speeds and low arc voltages are used. Increased arc length also increases the width of the weld bead.

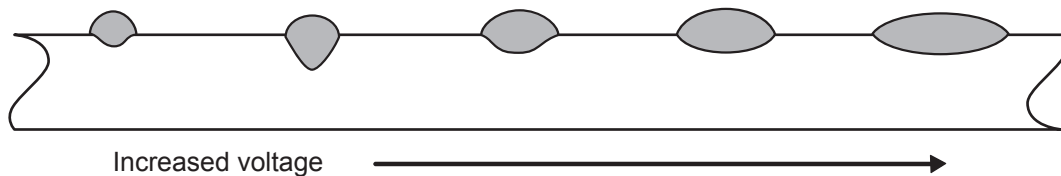


Fig 7.17 – Effect of arc voltage

It can be seen therefore, that if arc voltage is increased without changing the wire speed or travel speed, the arc gap is increased, resulting in a wider, flatter bead.

Travel speed

As travel speed is reduced, the weld bead becomes more convex due to a greater deposition of filler wire. Heat input is increased due to the arc remaining above any particular point for a greater period of time.

The opposite is achieved when travel speed is increased.

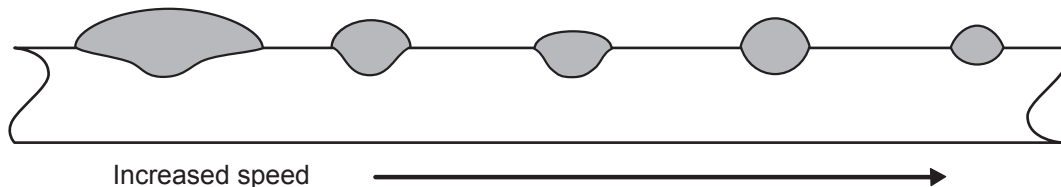


Fig 7.18 – Effect of travel rate

Electrical stick-out

When discussing GMAW, two types of stick-out are referred to:

- visible stick-out – the distance that the electrode protrudes beyond the gas nozzle
- electrical stick-out – the distance that the electrode protrudes from the contact tip.

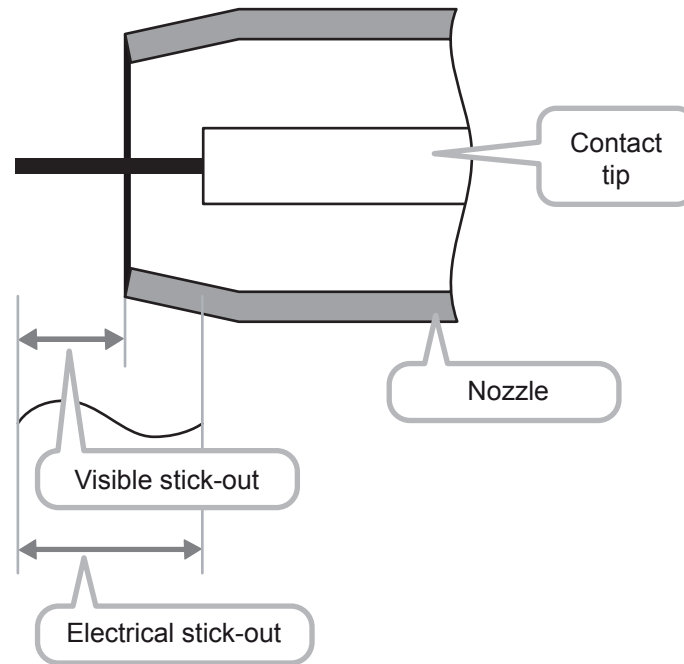


Fig 7.19 – Stick-out length

Visible stick-out has little effect upon welding conditions except that, if excessive, shielding efficiency will be reduced. However, electrical stick-out is an important consideration. Welding current is transferred to the wire via the contact tip. The wire between the end of the contact tip and the arc offers electrical resistance. As the electrical stick-out is increased so is the electrical resistance (Fig 7.20).

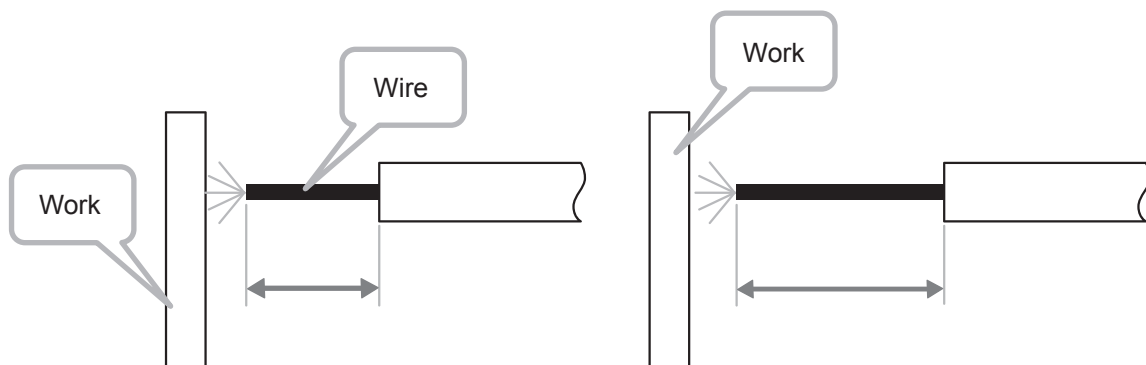


Fig 7.20 – Increased resistance due to increased electrical stick-out

The effect of this increased resistance is:

- reduced amperage
- reduced penetration
- reduced heat input
- higher deposition rate.

The increased deposition rate is brought about by:

- preheating of the wire
- the wire feed rate.



As the increased electrical resistance due to the increase in electrical stick-out preheats the wire, it tends to melt off sooner. This has the effect of increasing the arc length, which in turn tends to increase arc voltage – because of the power source characteristics (constant voltage) the current reduces and thus compensates. If the drive motor speed is now increased there will be an increase in wire deposition rates.

Torch angle

As with any welding process, the angle of approach must be adjusted to distribute the weld metal evenly in the joint (Fig 7.21).

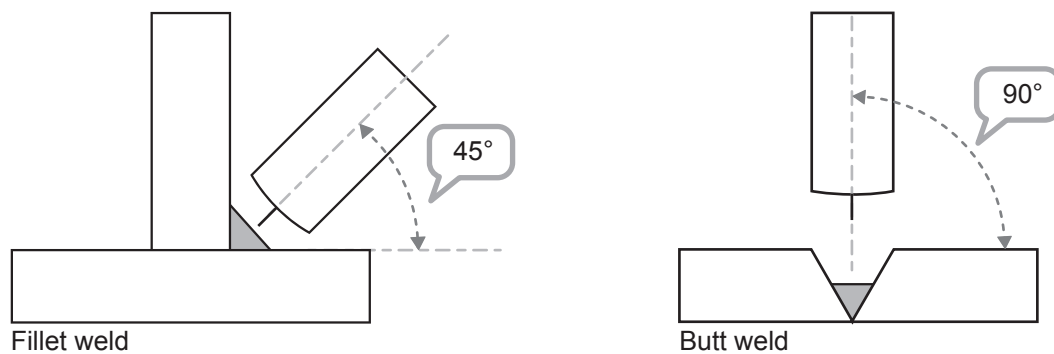


Fig 7.21 – Angle of approach

Angle of travel

The angle of the gun is maintained such that it is 'pushed' in the direction of travel (Figure 7.22).

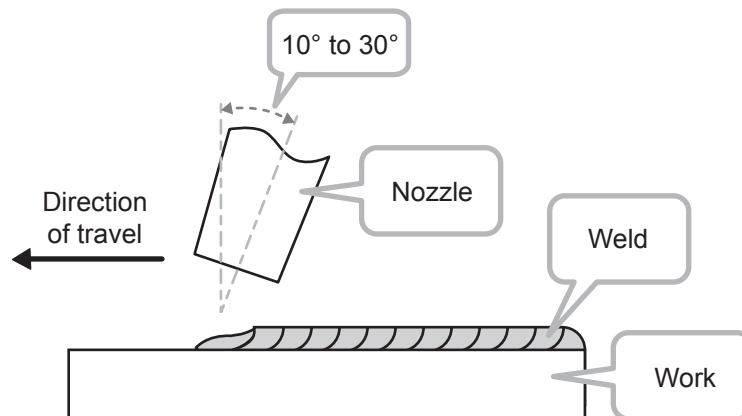


Fig 7.22 – Angle of travel

The exception to this is when making heavy welds in spray transfer where the gun is 'dragged'. This is done to direct shielding gas over the solidifying/cooling weld metal, which remains hot for an extended period of time.

The operator determines the actual angle of travel used, by seeking the best compromise between good visibility and efficient shielding.

As the torch angle is lowered shielding efficiency is reduced due to the Venturi effect, which draws air into the gas shield.

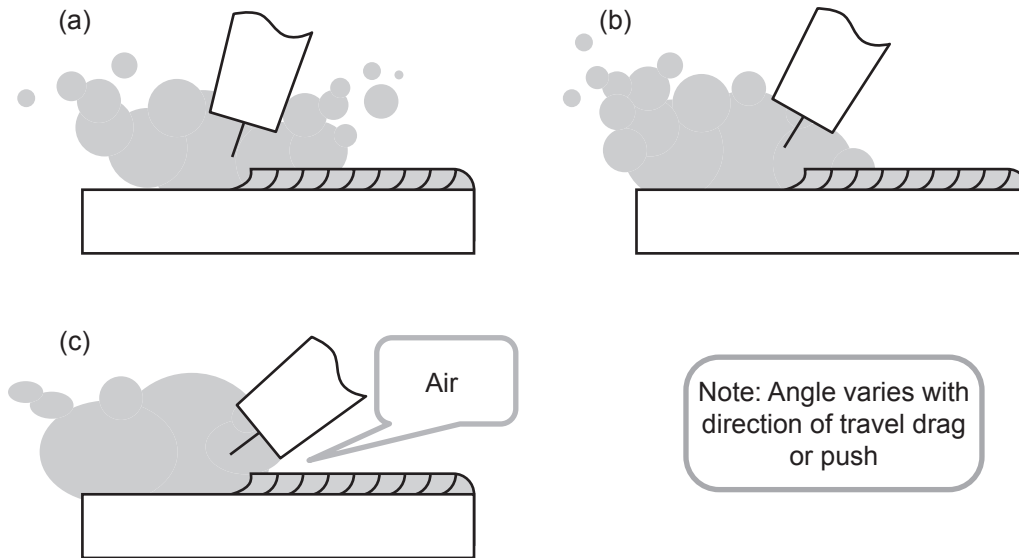


Fig 7.23 – Nozzle angle

(a) correct (b) incorrect (c) incorrect

Shielding gases

In Australia GMAW was also commonly known as ‘MIG welding’ (metal inert gas). This is in fact misleading, as it suggests that the shielding gas is inert. All GMAW of carbon and low-alloy steels employ the use of an active shielding gas, ie there is a reaction between the shielding gas and the metal droplets as they travel across the arc. Inert shielding gasses are used for welding stainless steels and non-ferrous metals. To achieve the desired arc stability when welding carbon and low-alloy steels, some oxidising action is required in the arc. This can be achieved in one of two ways:

- using CO₂ (carbon dioxide) as a shielding gas
- using Ar (argon) as the base with the addition of CO₂ and/or O₂ (oxygen).



Term	Definition
inert	refers to unmoving or unchanging. Having only a limited ability to react chemically; chemically inactive
non-ferrous	the term given to metal that does not contain iron



(weld) bead	the metal that has been deposited in the weld joint, after it has cooled off
-------------	--

Carbon dioxide

CO₂ when used as a shielding gas, produces a highly reactive arc. CO₂ has the following welding arc characteristics:

- deep penetration
- high spatter levels
- high deposition rates
- high heat input
- true spray transfer cannot be achieved.

CO₂ is best suited to the making of welds using dip transfer. The additional heat of CO₂ helps to overcome the tendency towards lack of fusion, and increases deposition rates. CO₂ tends to produce convex bead shapes and high spatter levels.

Argon

Argon is a true inert gas, which by itself cannot be used to weld carbon and low-alloy steels. When used by itself to weld non-ferrous metals, it produces an arc which, when compared to CO₂, has the following characteristics:

- smooth arc
- lower penetration
- lower heat input
- lower spatter
- improved bead shape
- promotes spray transfer.

Gas mixtures

Gas mixtures for welding steel employ the use of argon as a base, with the addition of differing levels of CO₂ and/or O₂ to achieve desirable arc characteristics.

The greater the O₂/CO₂ addition, the more the arc characteristics align to the characteristics of CO₂. The lower the addition of CO₂/O₂ the more the arc aligns toward the characteristics produced by argon shielding gas.

Shielding gas	Chemical behaviour	Effect/uses
Argon	inert	For welding all metals except carbon and low alloy steels
CO ₂	oxidising	Produces high spatter and deep penetration. Used with de-oxidised wire on carbon steels



Argon/CO ₂	oxidising	For welding carbon and low-alloy steels. Produces low spatter and moderate penetration
Argon/CO ₂ /O ₂	oxidising	Additional oxygen increases penetration. Used with de-oxidised wire to weld carbon and low-alloy steels

Each gas company will supply mixtures of their own formulation. However, as a rough guide for welding carbon and low-alloy steels, uses for mixtures approximating the following compositions are:

- CO₂ – dip transfer, particularly on thicker plates
- Ar + 25% CO₂ – general use in dip transfer
- Ar + 15% CO₂ – multi-purpose for dip and spray transfer
- Ar + 5% CO₂ – for spray transfer.

The ionising effect of the shielding gas influences bead shape as well as the amount of penetration obtained. The effect of shielding gas upon bead shape can be seen in the following graphic (Fig 7.24).

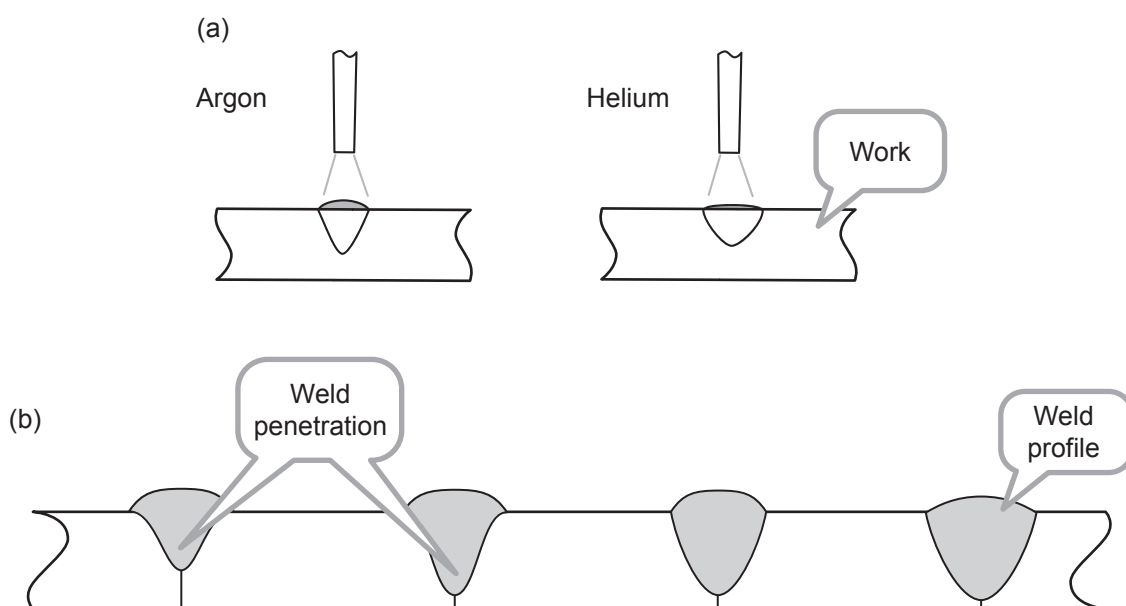


Fig 7.24 – (a) Effect of a change from argon to helium and (b) Effect of various shielding gases on bead shape



Term	Definition
ionising	a process in which an atom or molecule loses or gains electrons, acquiring an electric charge or changing an existing charge



Flow rates

Flow rates for CO₂ should be set at 16–18 L/min. Flow rates for Ar/CO₂ mixtures should be set at 12–14 L/min.

Gas flow rates should be set so as to provide adequate shielding.

Recommended rate of flow for Argon / CO₂ mixtures = 12–14 L/min.

Recommended rate of flow for CO₂ mixtures = 16–18 L/min.

It should be kept in mind that excessively high flow rates cause turbulence and increase the Venturi effect when torch angles are too low.

Other machine controls

Spot timer

Allows the weld time to be preset as a means of making consistent weld sizes for spot welding. The timer is activated when the gun trigger is depressed.

Burnback control

Enables wire to feed for a small amount of time after current flow is terminated when the gun trigger is released. This can be adjusted to prevent the wire fusing to the contact tip, or stop it sticking to the weld pool when welding is terminated.

Spool brake

The wire spool carrier employs a braking device to prevent over-run of the wire due to the inertia of the spool of wire. It should be adjusted to provide enough braking to prevent over-run, but with no unnecessary drag which would cause slippage of the wire at the drive rollers.



Photographed with permission of Lincoln Electric Co. (Aust) Pty Ltd

Fig 7.25 – Typical wire feeder



Joint design for gas metal arc welding

Pre-qualified joint preparation for GMAW of steel structures can be found in Australian Standard® AS/NZS 1554.1 Structural steel welding. It can be seen that joint design is similar to that used for MMAW butt welds in steels but with the following variations.

- Included angles of butt welds are reduced by ten degrees. This is because the thinner electrode and lack of flux provides easier access to the root of the joint.
- The root face for butt welds is decreased when dip transfer is used due to the fact that penetration is limited, and increased when spray transfer is used as a means of preventing burn through.



Term	Definition
burn through	a localised collapse of the molten pool due to melt through

Gas metal arc welding defects

Apart from slag inclusions, all the common weld defects that occur with other processes may occur with GMAW. Defects such as porosity and lack of fusion can be a particular problem with GMAW.

The defects commonly encountered in GMAW are:

- porosity
- cold lap/lack of fusion
- lack of root penetration
- excessive penetration
- contour defects
- undercut
- weld cracking
- excessive spatter
- stray arcing.

Porosity

Defined as a pore or group of gas pores in the weld metal. Porosity may be conveniently differentiated according to size and distribution. A number of different terms are used related to size. These are:

- gas pore – a cavity (usually spherical) formed by entrapped gas during the solidification of molten metal
- wormhole – an elongated or tubular cavity in the weld metal caused by entrapped gas being forced away from the solidifying weld metal
- cluster – a group of pores in close proximity to each other.



As is the case with other welding processes, porosity may be caused by moisture, or surface contaminants on the plate. With GMAW, by far the greatest cause of porosity is due to inadequate gas shielding. This may be due to:

- flow rate set too low
- flow rate set too high
- no gas flow at all
- excessive wind or air movement at the gun
- contaminated shielding gas
- stick-out length too long
- gun angle too low.

Lack of fusion

Defined as portions of the weld deposit which do not fuse to the surface of the metal or the edge of the joint. With GMAW, lack of fusion is commonly referred to as 'cold lapping' as it usually takes the form of lack of sidewall fusion over an extensive part of the joint.

Cold lapping is common when welding in the dip transfer mode – particularly when the plate thickness exceeds 5 mm. Welding downhill, or with high wire speed and low arc voltage settings, further increases the risk of occurrence. Plates that are dirty or heavily scaled further exacerbate the problem.

Cold lapping does not generally occur when welding in the spray transfer mode. To minimise the likelihood of cold lapping, one or more of the following should be employed:

- weld in the spray transfer mode
- clean plates
- if in doubt, set the arc voltage slightly higher
- set enough amperage to ensure sufficient heat for fusion
- keep the electrical stickout short
- use CO₂ shielding gas or a mixed gas high in CO₂.

Lack of root penetration

Defined as the failure of the weld metal to completely fill the root of the joint.

Root runs in butt welds are normally made in the dip transfer mode except for those in heavy plate, in which case spray transfer would be used. The dip transfer mode is inherently 'cold', employing low amperages and voltages. This means that root penetration is limited in this mode.

The solution to overcoming lack of root fusion is to use thinner root faces on butt welds than would be the case with other processes – typically in the range of ½ mm to 1 mm.

In fillet welds, the solution is to use comparatively high amperage settings when in the dip transfer mode. Additionally, CO₂ or a gas mixture high in CO₂ will help.



Excessive penetration

Defined as excess weld metal protruding through the root of a butt weld. This defect normally only occurs on thin (sheet) materials or when the spray mode of transfer is used. Adjustment of wire speed and arc voltage will usually overcome this problem with relative ease.

Another form of this defect is electrode wire protruding through the root of the butt in the form of 'spikes' or 'icicles'. This is caused when arcing to the root face of the butt weld momentarily ceases, a small amount of wire penetrates the butt, and the arc is re-established when the wire contacts the parent metal.



The solution to this problem is to limit the width of the root gap and/or increase the arc voltage, which results in a wider spread of the arc so that arcing to one or both sides of the weld is always present.

Contour defects

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

Travel speed and torch angle adjustments may fix many of these problems. The GMAW operator can also control the weld profile by adjusting the arc voltage.

Excessive convexity may be remedied by increasing the arc voltage, and beads which are too wide or too concave may be remedied by decreasing the arc voltage.

Undercut

Defined as a groove or channel in the parent metal, occurring continuously or intermittently along the toes or edge of a weld.

Undercut is not a common problem in GMAW, however, it is likely to be encountered in two situations.

1. When fillet welding in spray transfer – This is normally caused by setting the arc voltage too high, causing a long arc length which results in undercutting of the toe of the weld of the vertical plate. To remedy this, set a smooth spray transfer mode using the lowest arc voltage that will facilitate this. This solution is quite simple and it is good practice for all welds in spray transfer.
2. Vertical-up welds – Solid wires are largely unsuitable for making stringer beads in the vertical-up position. Convex beads with some undercut generally result. When a weave technique is used, a bead that is convex in the middle, with undercut toes may result. The solution is to:
 - o reduce the arc voltage
 - o reduce the overall heat of the welding
 - o pause longer at the toes.



Cracking

Defined as discontinuities produced either by the tearing of metal in the plastic condition (hot cracks) or by fracturing when cold (cold cracks). Hot cracks are common in materials with high co-efficients of expansion, and/or which suffer from hot shortness. Hot cracking occurs at elevated temperatures soon after solidification. This mode of cracking is common in aluminium and stainless steel. Cold cracking is most common in hardenable materials, particularly when cooling rates are rapid. Cracking is considered to be a serious defect and rarely is any amount of cracking tolerated.

Cracks may also be described depending on how, when and where they occur, for example 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 longitudinal cracks and crater cracks being the most common examples.
- 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 from 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, propagate from the crater and lead to failure of the weldment.

Cracking in GMA welds is not generally a major problem due to the following factors.

- GMAW is a 'low-hydrogen' process.
- Hollow craters are not usually a characteristic of GMA welds.
- The inherent low heat input is ideal for stainless steels and other metals which are prone to hot cracking.

Stray arcing

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

Stray arcing is not a major problem associated with GMAW as the electrode is usually only live when the gun trigger is depressed. Care should be taken that the gun is not put down with the weight resting on the trigger, and also that arcing does not occur between the job and the work return lead connection.

Excessive spatter

Defined as the metal particles expelled onto the surface of the parent metal or weld, during welding, and not forming part of the weld.

This usually occurs due to one of the following factors:

- shielding gas or plate contaminated with moisture
- high levels of CO₂ or O₂ in the shielding gas
- excessive arc voltage in the dip transfer mode
- welding in the globular transfer mode.



Spatter is not usually present in the spray transfer mode.

Trouble shooting/equipment malfunction

Compared to the manual welding processes, GMAW requires higher levels of care and maintenance. Major sources of frustration are the problems associated with the feeding of the electrode wire.

This is a particular problem when welding with aluminium wire, feeding wire through long gun cables, or when using a gun cable that has been poorly maintained.

Equipment malfunctions with GMAW fall into two main categories; which are:

- electrical
- mechanical.

The main problems with regard to electrical malfunctions and their likely causes areas follows.

Problem	Likely cause	Solution
No power at machine	Mains switch off Machine switched off Blown fuse	Check switches and fuses If intact, call an electrician
Mains power on but no welding power	Trigger switch not working Wire feeder not connected	Check if trigger is working, and whether wire feeder will operate and wire will feed
Wire feeds, but no arc	Work return not connected Blown fuse	Check work return Check fuses



Mechanical problems manifest themselves in the form of wire feeding problems. Common wire feeding problems and their likely causes are as follows.

Problem	Likely cause	Solution
No wire feed at all	Spool brake excessively tight No friction at drive rolls Wire jammed at drive rolls or in gun cable	Check tension on spool brake Check drive rolls and adjust as necessary Check guide tubes Check wire conduit
Uneven wire feed	Dirty or damaged liner Slippage at drive rolls Liner cut too short Kinks in gun cable Insufficient roll pressure Wire distorted due to excessive roll pressure Contact tip worn or dirty Spool brake excessively tight	Clean or replace Increase pressure Replace Keep as straight as possible Tighten drive rolls Misalignment of drive rolls Damaged liner Inspect and replace Check tension on spool brake
Spool overrun	Spool brake too loose	Tighten
Wire fused to contact tip	Excessive arc voltage Excessive burnback time Intermittent wire feed	Reduce arc voltage Reduce burnback time See above

GMAW equipment requires a regular inspection and maintenance schedule.

- Contact tips should be inspected at least daily.
- Liners, and drive rolls, and spool brake should be inspected weekly.
- Gas and electrical connections should be inspected monthly.

Feeding aluminium wire presents additional problems. It is essential that all sources of friction upon the wire be minimised. Recommendations are:

- reduce spool braking
- use a Teflon® liner
- ensure the correct liner is used
- keep the gun cable as straight as possible
- avoid small diameter wire if possible
- fit a straighter gooseneck to the gun
- pay particular attention to drive roll pressure
- use good quality wire.



Additionally, a welding machine with the following features is highly recommended:

- a push/pull gun
- a four-roll wire feeder ('U' shaped bottom groove) and late-top roll
- a soft-start feature.



Term	Definition
Teflon®	Teflon® is the brand name of a polymer compound. A micro porous laminate on various nylon fabrics forming a protective layer

Activity

Carry out the following in your workshop.

- Identify safe working practices and protective equipment in the workshop.
- Locate a suitable GMAW plant.
- **With the mains power switch OFF**, set up the GMAW plant (start by checking the electrical cable connections to the wire feed unit, work lead and hand piece).
- Check the appropriate general purpose wire is fitted correctly into the wire feed unit.
- Remove the gas nozzle and check to see if the correct contact tip is fitted and the nozzle and tip are clean.
- Refit gas nozzle to give correct electrode stick-out.
- Ask your lecturer to help you to set up the shielding gas flow at 12–14 L/min and in setting the voltage and wire feed rate for dip transfer mode.
- Strike an arc between the electrode and a practice piece of material.
- With your lecturer's assistance, produce welds using dip transfer, globular transfer and spray arc on the practice material.

Refer to Australian Standard® AS/NZS 2717.1 Welding – Electrodes – Gas metal arc – Ferritic steel electrodes, for a full understanding of the classification system for solid wire.





Chapter 8 – Flux-cored arc welding (FCAW)

Introduction

The introduction of flux-cored wires (creating the newer and closely related process of flux-cored arc welding) extended the range of work carried out by hand-held semi-automatic welding. Flux-cored welding brought with it the advantages of greater penetration, higher welding speeds, site welding capability, and the ability for it to be applied to a variety of plate thicknesses.

In this chapter you will look at the following.

- Principles
 - advantages
 - limitations
- Equipment
- Techniques for gas-shielded flux-cored arc welding
 - electrode stick-out
 - direction of travel
 - position and angle of torch
 - self-shielding flux-cored arc welding
 - advantages of self-shielding FCAW
 - limitations of self-shielding FCAW
 - techniques of self-shielding FCAW
 - electrode stick-out
 - electrode angles
 - vertical welding
 - Welding procedures for FCAW
 - Effects of the operating variables with FCAW
 - polarity
 - arc voltage
 - current (wire feed speed)
 - travel speed
 - electrode stick-out
 - electrodes for flux-cored arc welding
 - classification of flux-cored wire electrodes
 - safety recommendations with FCAW



- Flux-cored arc welding faults
 - cracking
 - porosity
 - slag inclusions
 - lack of fusion/lack of penetration
 - excessive penetration
 - contour defects
 - undercut
 - excessive spatter
 - stray arcing.

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

Principles

As the name implies, the flux-cored arc welding process employs an electrode which is essentially a formed steel sheath in which is contained a core of flux. The electrode has been described as a 'stick' electrode turned inside out and made into a continuous wire.

There are two distinct types of FCAW welding.

- Self-shielding FCAW, in which all of the shielding is provided by the decomposition of the flux core. Self-shielding wire has the advantage that it is suitable for use in windy conditions and is therefore ideally suited to site work. Further to this, no shielding gas system is required.
- Gas-shielded FCAW, which requires additional shielding gas. Gas-shielded wires have the disadvantage of requiring a shielding gas system, but they produce lower fume levels.

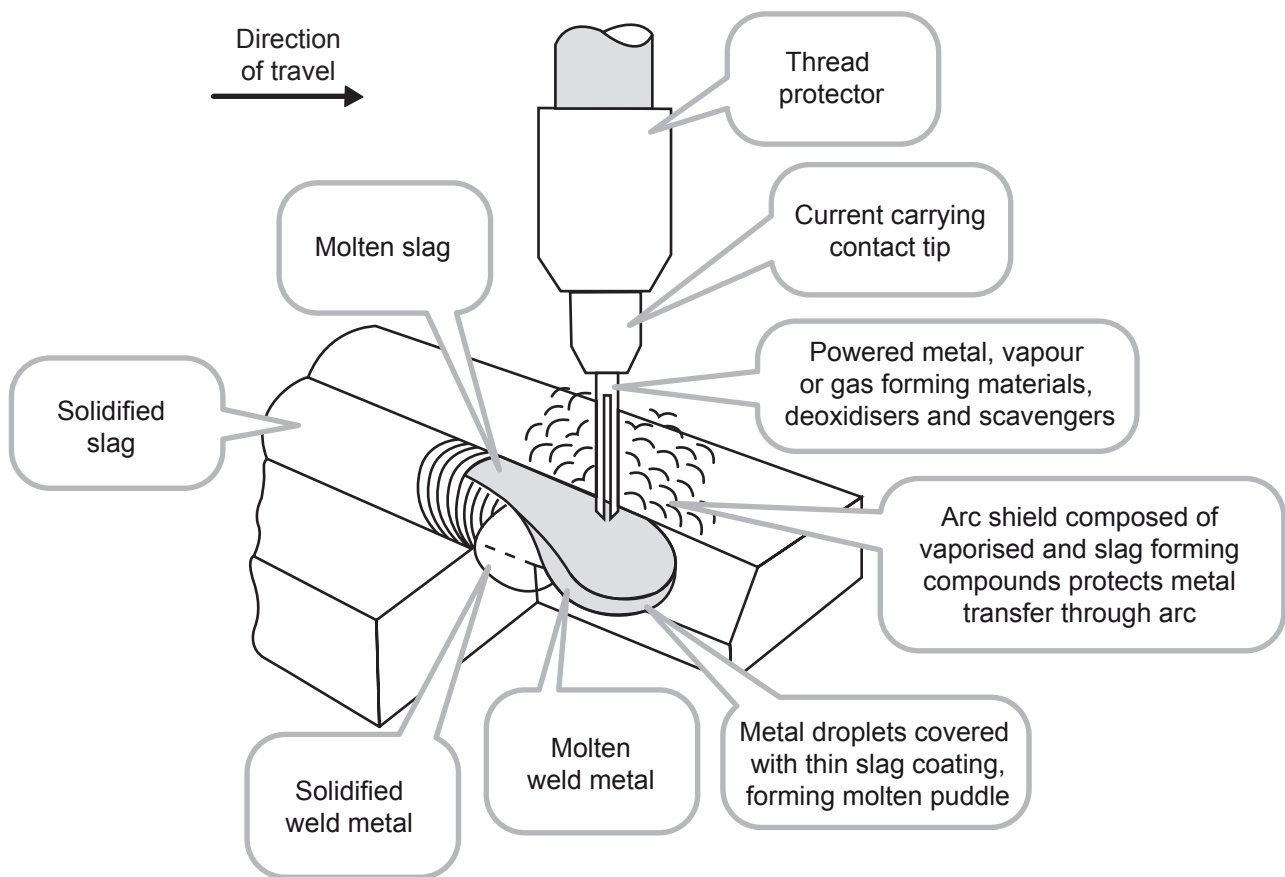


Fig 8.1 – Flux-cored arc welding

A major advantage of FCAW compared to GMAW is that the higher current densities used means that the mode of metal transfer across the arc is **always spray transfer**. The advantages of this are:

- higher deposition rates
- deeper penetration
- excellent fusion to the base metal.

The down side of this is:

- higher emission of UV radiation
- higher fume levels
- more heat is generated.

The flux core serves as a medium to introduce de-oxidants and alloy elements into the weld. The flux is low in hydrogen and the process is therefore suitable for welding hardenable steels and other carbon and low-alloy steels.

Due to the limitations of the manufacturing technology available at the time, early flux-cored wires were produced by applying the flux to a strip of metal, and then forming it into a tube. Wires smaller than about 2 mm to 2.4 mm diameter could not be produced by this method. This meant that, when low welding currents were required, the current density in the wire was relatively low and the metal transfer across the arc was relatively coarse and rough.



Currently, flux-cored wires are produced in a number of configurations designed to improve burn-off, as shown in Fig 8.2. They are also being manufactured by filling a tube with flux, and drawing the wire to produce a seamless electrode in sizes as low as 0.9 mm in diameter. This is a major advantage in that even though welding current used may be low, the current density is high enough to ensure ideal transfer characteristics across the range.

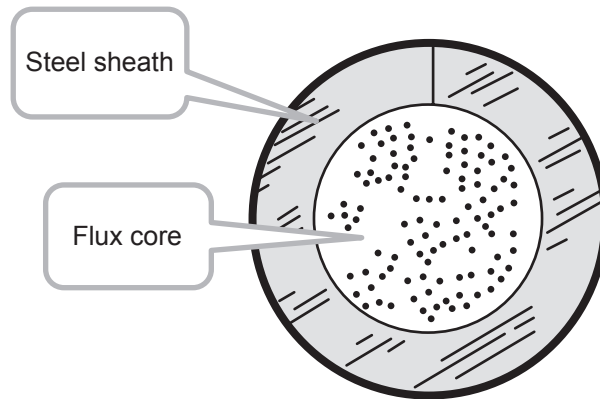


Fig 8.2 – Flux-cored wire

Advantages

Penetration – Compared with iron powder electrodes for MMAW, the depth of penetration is much greater. This makes it possible to reduce the fillet leg length without decreasing the strength of the weld (Fig 8.3).

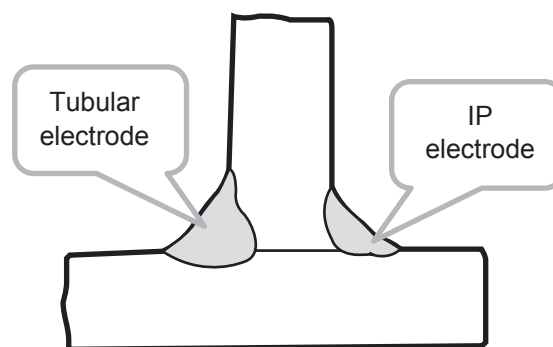


Fig 8.3 – Comparison of penetration

Deposition rate – Compared with manual metal arc electrodes, the deposition rate is very high.

Slag detachability – Providing that the operating conditions are correct, the slag is virtually self-detaching. In a deep groove, the slag is easily removed when the weld has cooled.



Appearance – Providing the operating conditions are correct the weld appearance is bright and neatly rippled with a good ‘wash’ into the parent metal at the toes. Fillet welds tend to be mitred or slightly concave rather than convex.

Weld quality – The weld deposit is low in hydrogen content and has good mechanical properties. Sound radiographic quality welds can be achieved.

Low spatter – Assuming the correct operating conditions have been selected, spatter should be minimal.

Visibility – Because of its high deposition and high penetration characteristics, gas-shielded flux-cored arc welding is often compared with submerged arc welding, which can offer similar advantages. With the FCAW process, however, the operator can see the arc and be in a position to allow for variations in the joint fit-up.

Limitations

- **Limited applications** – The range of FCAW consumable currently available are limited to ferrous-based alloys such as steel. Constant development means there is potential for a much greater range of materials that may be welded with FCAW in the future.
- **Loss of gas shielding** – The gas-shielded FCAW is only suitable for sheltered conditions, away from any wind that may interfere with the gas shielding. For this reason the process is not usually suitable for outdoor work, unless adequate steps are taken to screen the arc from the wind. Loss of gas shielding can cause severe porosity in the weld. Self-shielding wires do not suffer from this problem.
- **Operator fatigue** – With the smaller diameter of positional wires, operator fatigue is no greater than that experienced with GMAW. However, when used as a high deposition process, the welding gun and cables must be robust enough to withstand the heat generated and are usually rather heavy. This, together with the hot conditions, makes operator fatigue a significant factor. This problem can be overcome by mechanising the process.
- **Fumes** – Many FCAW wires (particularly self-shielding wires) emit a substantial volume of fumes which add to the discomfort of the operator. Special precautions may be required to eliminate these fumes, such as the use of fume extractor nozzles fitted to the gun. In confined spaces, fume extraction units will be needed to remove fumes from the work area into filter banks or outside the workshop.

Equipment

The equipment required is essentially the same as that used for GMAW however the component parts may be heavier duty. Electrode positive is generally required for gas assisted wires whilst most of the self-shielding wires use electrode negative.

A constant voltage DC power source is generally used, however there are some newer wire feeders that incorporate a wire feed-rate compensating circuit and these will operate successfully on constant current power supplies.

The wire feed unit used for GMA welding can usually be adapted for FCAW. The wire reel holder may need to be changed to carry the spool of flux core wire which is usually supplied in 30 kg reels. The wire drive rolls may be serrated or have a 15° ‘V’ groove. Care must be taken to minimise the pressure on the feed rolls so that the wire is not squeezed out of round.



The welding gun preferred is the pistol type where the wire is kept straight as it passes through. Goose necked guns with a small radius bend tend to create a 'drag' on the wire thus giving rise to wire feed problems.

Due to the high amperages employed, heat radiation is intense and therefore the welding torch is sometimes fitted with a heat shield at the handle.

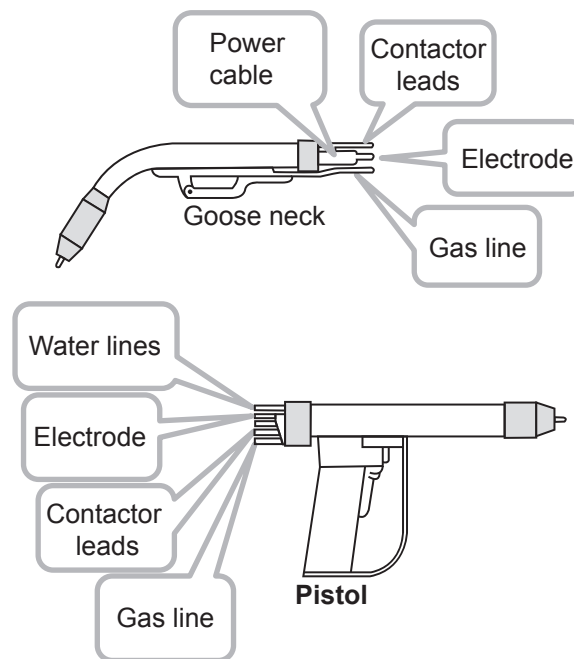


Fig 8.4 – FCAW equipment and pistol and goose necked guns

The welding cable and return lead must be of sufficient size to carry the high currents without overheating.

Techniques for gas-shielded flux-cored arc welding

A welding operator with a reasonable degree of skill in MMA or GMA welding can readily adapt to gas-shielded FCAW, however, a few factors need attention.

Electrode stick-out

Recommended stick-out lengths must be adhered to – they tend to be greater than the stick-out lengths used with GMAW. Stick-out is the length of the wire from the end of the contact tip to the surface of the work piece. A shorter stick-out could result in a poorly shaped weld due to an increase in amps and a decrease in voltage. A longer stick-out could give rise to excessive spatter and porosity in the weld due to poor gas shielding when using gas-shielded wires.

Direction of travel

The direction of travel (whether pushing the torch or dragging it) is usually a matter of personal preference on the part of the operator. However, where the work is to be of a particularly high quality, the backhand or drag method is regarded as superior.



Position and angle of torch

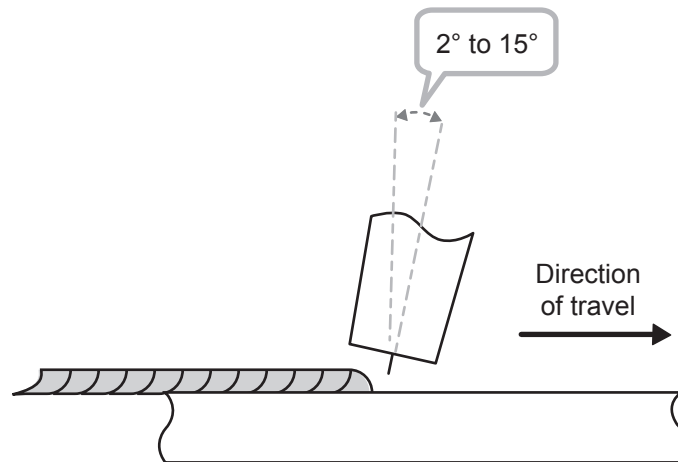


Fig 8.5 – Angle of torch to direction of travel

As already mentioned, it is preferable to push the arc with gas assisted wires and most self-shielded wires should be dragged (although not always essential). Fig 8.5 shows the recommended angle of the torch in relation to direction of travel.

In the flat position, the torch is angled at 90° to the plate (Fig 8.6).

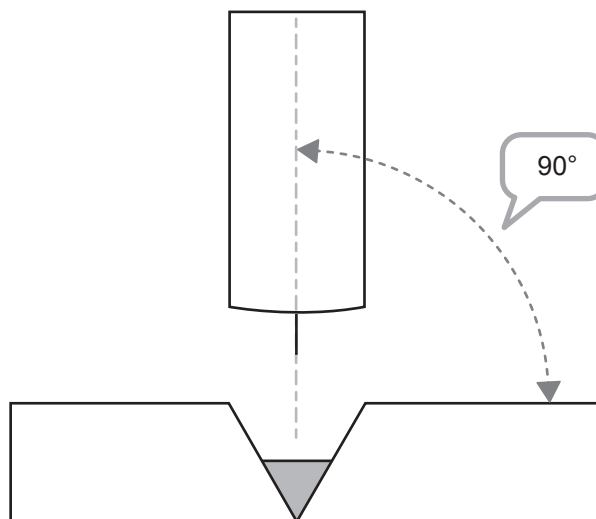


Fig 8.6 – Position of torch for flat butt weld

Self-shielding flux-cored arc welding

This is probably best regarded as a semi-automatic version of the manual metal arc process. Like MMAW, the flux-cored wire generates sufficient vaporised gases around the arc to completely protect it from the atmosphere.



Advantages of self-shielding flux-cored arc welding

- No external shielding gas or flux is required, therefore the process can easily be used outdoors even in draughty conditions.
- All positional wires, hard facing and stainless steel wires are available.
- Deposition rates are high when compared with MMA welding.
- Slag is easily detached except where tacks have been made with cellulose or rutile electrodes.
- The weld deposit is low in hydrogen and resists cracking in many crack-sensitive applications.
- Poor fit-ups (gaps) can be handled easily by increasing wire stick-out.

Limitations of self-shielding flux-cored arc welding

- Penetration is not as great as the gas-shielded FCAW process. It is more akin to that achieved with MMA low hydrogen electrodes.
- Slag removal is difficult when welding over tacks or a previous weld made with cellulose or general purpose electrodes. The use of low-silicon cellulose electrodes or certain low-hydrogen electrodes can overcome this problem.
- Fumes can also be a problem and the precautions outlined previously for gas-shielded FCAW may be necessary.

Techniques of self-shielding flux-cored arc welding

Welding techniques are similar to those employed with hydrogen-controlled MMAW electrodes, however, a few additional factors should be considered.

Electrode stick-out

For all positional self-shielding electrode wires, the recommended electrode stick-out is usually 18–20 mm. If no gas nozzle is used with these wires, the electrode stick-out is visible from the contact tip to the work (Fig 8.7). Even though no gas shielding is employed, a nozzle is commonly used to give the operator the feel of ‘normal’ electrical stick-out.

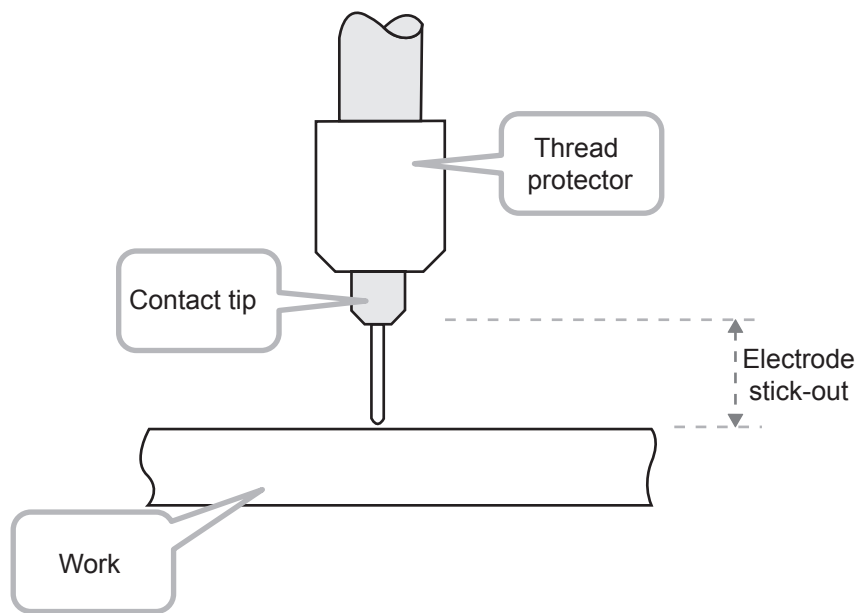


Fig 8.7 – Electrode stick-out is visible stick-out

Some self-shielding electrode wires are designed to give high deposition rates in the downhand positions by employing long electrical stick-out (Fig 8.8).

A long electrical stick-out is used to increase the deposition rate by pre-heating the wire before it is melted at the arc. The recommended electrical stick-out varies, depending on the type and size of wire and the wire manufacturer's recommendations. To assist the operator in maintaining the correct electrical stick-out for these wires, the welding gun can be fitted with a nozzle incorporating an insulated extension guide.

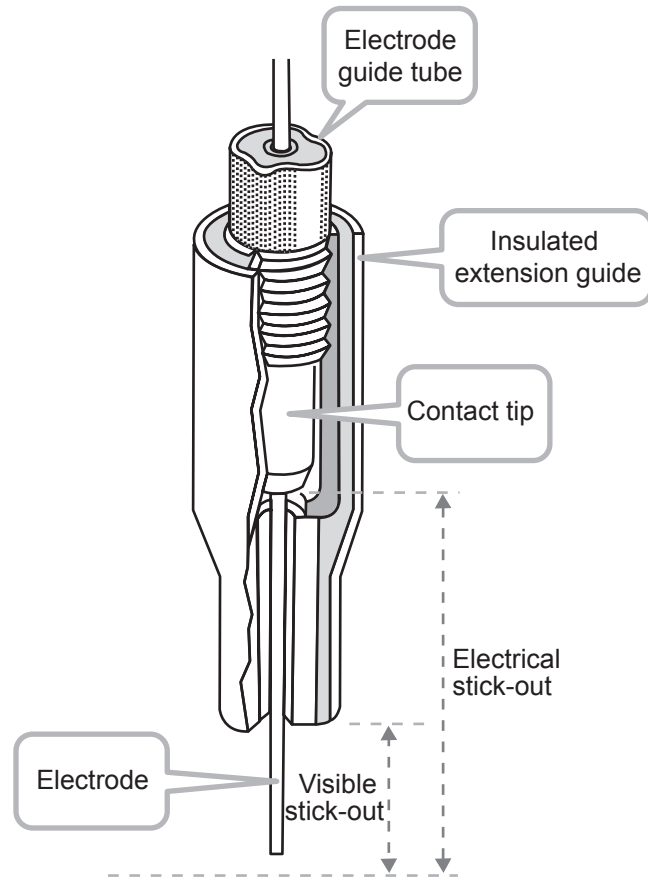


Fig 8.8 – Insulated extension guide nozzle for electrical stick-out

Electrode angles

When welding with self-shielding flux-cored wires, the electrode angles are much the same as for MMAW electrodes, as shown in Fig 8.9.

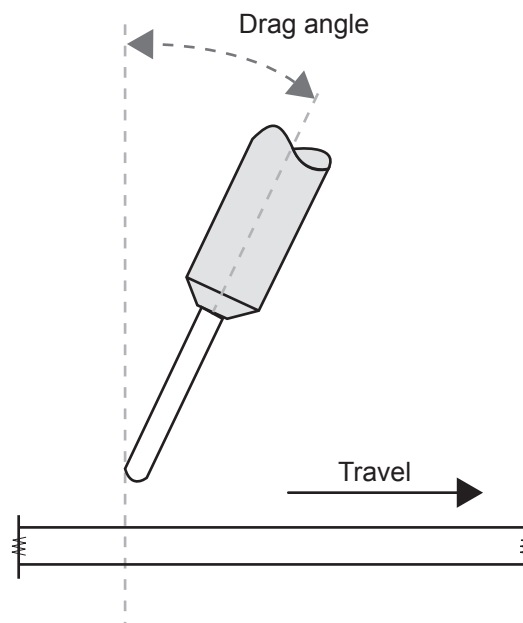


Fig 8.9 – Self-shielding wires are dragged similarly to MMAW electrodes



For horizontal/vertical welds the wire is pointed directly into the root of the joint at an approach of 40° (Fig 8.10).

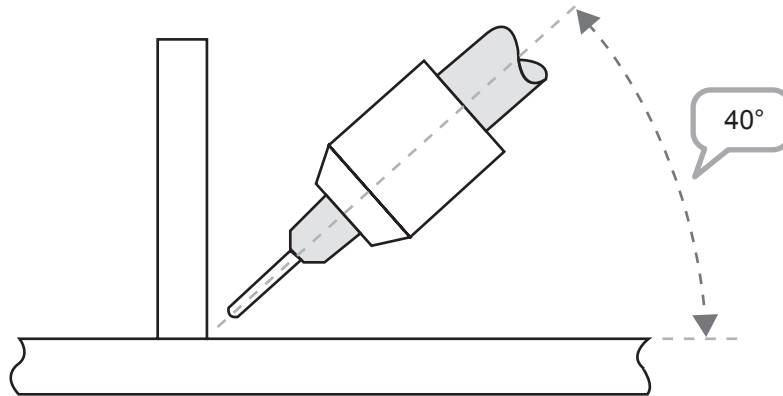


Fig 8.10 – Recommended electrode angle for horizontal/vertical fillet weld

Vertical welding

Most all-positional self-shielding wires can be used vertical-down or vertical-up. Vertical-down is usually preferred for welds in thinner sections or for the first pass in a butt weld. The gun is tilted to a drag angle of 10° – 15° from the horizontal so that the arc force helps hold the molten metal in the joint (Fig 8.11).

Techniques for welding vertical-up are the same as for low-hydrogen MMAW electrodes. Vertical-up welding is recommended for welds in thick sections. The first pass in a vertical-up fillet or butt is best made using a triangular weave technique and subsequent passes are made with a side-to-side weave.

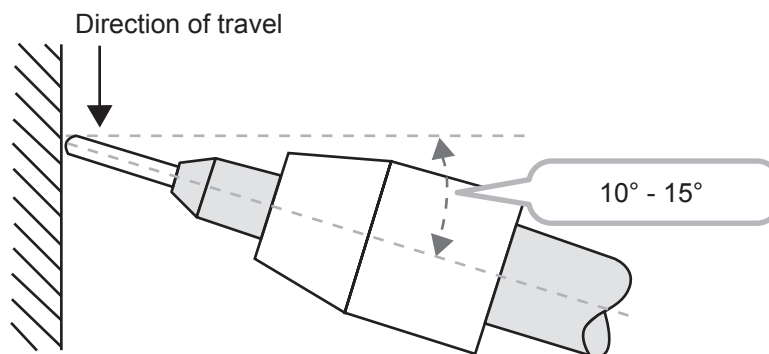


Fig 8.11 – Electrode angle for welding vertical-down

Welding procedures for flux-cored arc welding

There is a wide variety of flux-cored electrode wires for both the gas-shielded and self-shielding processes. Each wire has its own set of optimum operating conditions and procedures and therefore it is best to consult the wire manufacturer's table to obtain the recommended welding procedure for a particular wire. However, the following effects of the operating variables associated with the FCAW process may help to refine the set procedures.



Effects of the operating variables with flux-cored arc welding

With FCAW there are five major operating variables, which are:

- polarity
- arc voltage
- current (wire feed speed)
- travel speed
- electrode stick-out.

Polarity

Whereas all solid wires for GMAW run on DC +ve, some flux-cored wires are designed to run on negative polarity.

Arc voltage

If the other variables are held constant, arc voltage variations have the following effects.

- Higher arc voltage gives a wider and flatter bead shape.
- Excessive arc voltage can cause porosity.
- Low voltage causes a convex, ropey bead shape.
- Extremely low voltage will cause the electrode wire to stub on the parent metal.

The arc voltage should be set according to the wire manufacturer's recommendations and, if necessary, be fine-tuned to give the desired bead shape.



Term	Definition
ammeter	an instrument that measures electric current in amperes

Current (wire feed speed)

In setting critical procedures, wire feed speed is a better measure than the welding current. The wire feed speed is constant whereas the current reading at the ammeter tends to fluctuate.

If the other variables are held constant, current variations have the following major effects:

- increasing the current increases penetration and deposition rate
- excessive current produces convex, ropey bead shapes
- current that is too low gives a large droplet transfer and may give porosity.

As the current is increased or decreased, the arc voltage must be increased or decreased to maintain the proper bead shape. The correct current range should be obtained from the wire manufacturer's tables.



Travel speed

If the other variables are held constant, travel speed variations have the following effects.

- A too high travel speed increases the convexity of the bead and causes uneven edges.
- A too slow travel speed results in slag interference, possible slag inclusions and a rough uneven bead shape.

Electrode stick-out

If the other variables are held constant, variations in stick-out have the following effects.

- Increasing stick-out decreases the welding current.
- Decreasing stick-out increases the welding current.
- With self-shielding wires the stick-out can be increased to reduce the penetration thereby allowing poor fit-ups to be bridged.
- Decreasing stick-out can lead to spatter build-up on the contact tip or overheating of the contact tip.

Electrodes for flux-cored arc welding

Early electrode wires developed for gas-shielded flux-cored arc welding used a basic type flux with low-hydrogen content and required electrode positive polarity. This type of flux-cored wire electrode is still popular.

More recent developments have led to the availability of electrode wires with a rutile flux suitable for more general purpose work. Many of these rutile flux-cored wires perform better with electrode negative polarity.

Virtually all flux-cored wires, whether gas shielded or gasless, require a constant voltage power source. However, there are a few types which can operate satisfactorily with constant current power sources.

Due to this range of variables stated, it became necessary to provide a system of classification for flux-cored electrode wires, an outline of which follows.

Classification of flux-cored wire electrodes

There are many different types of solid and flux-cored electrode wires commercially available. They are classified to a particular standard, which makes it possible to identify and select the most suitable type of wire for a job. It is important to understand classification systems and the information they represent.

Consumable classification systems list a number of essential features about the consumable. For example, consumables are classified by construction, filler metal composition, shielding method, mechanical strength of the weld deposit and so on.

AS/NZS 18276 and 17632 classifies flux-cored electrodes under three groups of symbols separated by hyphens. Each group consists of a number of letters or letters and numbers.

eg ETD - GCp – W503H



First group – construction and recommended welding position (ETD)

The first group of letters denotes a tubular electrode, and indicates the following.

E	=	electrode
T	=	tubular construction
D	=	horizontal fillet or flat position
P	=	any position
S	=	single run (if applicable)

Second group – shielding requirements and current type (GCp)

The second group consists of **G** for gas shielded and then two letters that indicate the type of shielding gas used during qualification tests and the welding current required.

G = gas shielding which is then followed by one of the following.

C	=	shielded with carbon dioxide (CO ₂)
M	=	shielding with a mixture of gases
N	=	no shielding required
p	=	d.c. constant potential, electrode positive
n	=	d.c. constant potential, electrode negative
a	=	a.c.

For example, **Nn** indicates that the wire is self shielded with negative electrode.

Third group – properties of the weld metal

The third group involves a letter **W** followed by a three-digit number. **W** stands for weld metal. The first two digits refer to the minimum strength of the deposited weld, which is measured in megapascals. The third digit refers to the minimum impact value. The letter **H** generally completes the classification which indicates that the process is hydrogen-controlled.

W	=	weld metal properties:
50	=	500 MPa strength
3	=	degree of impact test
H	=	hydrogen-controlled





From the reference chart in the code, this electrode will meet an expected impact value of 47 joules at -20 °C.

Symbol	Temperature for minimum average impact energy of 47 J ^{a,b} or J ^c
Z ^a	no requirements
A ^b of Y ^c	+ 20
0	0
2	-20
3	-30
4	-40
5	-50
^a Only the symbol Z is used for electrodes for the single-run technique. ^b Classification by yield strength and 47 J impact energy. ^c Classification by tensile strength and impact energy.	

Based on AS/NZS 17632: 2006 – Table 3 (www.saiglobal.com)

Due to earlier problems related to flux-cored wires achieving satisfactory impact values in the completed welds, further information is sometimes added to the final group of numbers. For example, an electrode is classified in the following way.

AS/18276 and 17632 ETDS – GM/Cp – W503A CM1 H₁₀

A = classified in the as-weld condition or **P** = classified after post-weld heat treatment

CM = carbon manganese or **K** = killed (double deoxidised)

H₅ diffusible hydrogen content of deposited weld metal < 5 ml/100 g of weld

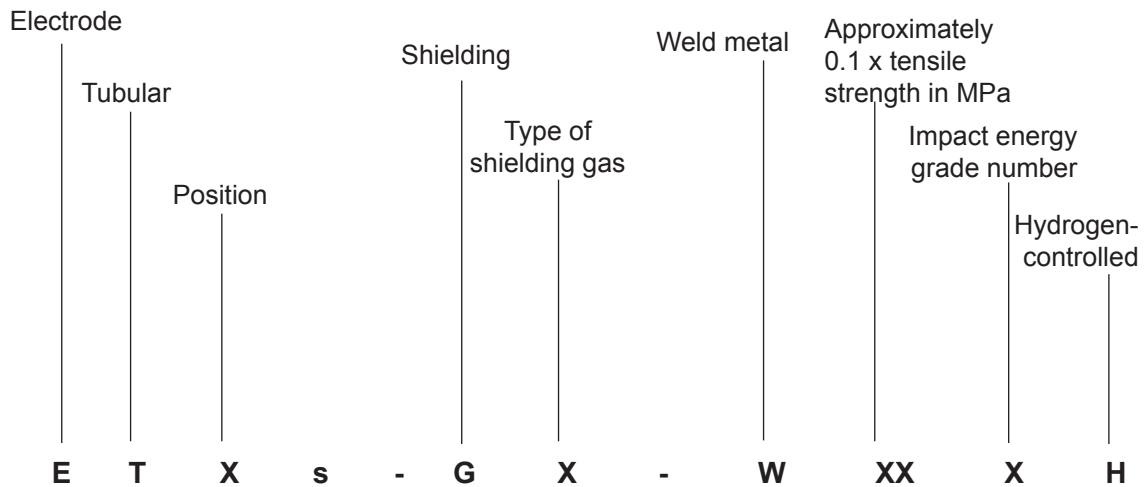
H₁₀ diffusible hydrogen content of deposited weld metal < 10 mL/100 g of weld

H₁₅ diffusible hydrogen content of deposited weld metal < 15 ml/100 g of weld

For example, this weld deposit would be carbon manganese alloy of 500 MPa, minimum strength in the as-welded state and contain 10 mL of hydrogen per 100 g of weld.



An example of the full classification system is shown below.



The classification system consists of three groups, separated by a hyphen. Each group consists of a letter or letters and figures. To assist with the above explanation the symbols X1, X2, X etc are used to represent the variables.

Example 1

Fluxed-cored electrode
Metal-Cor 2

AS/NZS 18276 and 17632
ETD – Mp – W502 (H)

- E = Electrode
- T = Tubular
- D = Downhand
- M = Mixed gas
- p = DC constant voltage electrode positive
- W = Weld metal
- 50 = 500 MPa minimum tensile strength
- 2 = Charpy v-notch impact test 47 J at 0 °C
- H = Hydrogen-controlled

Example 2

Fluxed-cored electrode
Lincoln innershield NR211

AS/NZS 18276 and 17632
ETP – Nn – W500

- E = Electrode
- T = Tubular
- P = Any position
- N = No external shielding (self-shielding)
- n = DC constant voltage electrode negative
- W = Weld metal
- 50 = 500 MPa minimum tensile strength
- 0 = Charpy v-notch impact test not required



Safety recommendations with flux-cored arc welding

The following recommendations apply to FCAW.

- Due to the greater arc intensity, particularly with the gas-shielded FCAW process, a welding lens one to two shades darker than for MMAW should be used.
- A heat shield fitted to the torch handle is desirable to protect the operator's hand from radiated heat. Reflective backed leather gloves are also recommended.
- Additional care should be taken regarding clothing and protective leathers. Dark woollen clothing is most desirable, and leather gloves, apron, jacket and spats should be worn.
- Attention should be given to ensuring adequate ventilation. If natural ventilation is inadequate, exhaust fans and respirators should be used.

Flux-cored arc welding faults

The defects commonly encountered in FCAW 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.

Crater cracks occur when the weld solidifies from 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, propagate from the crater and lead to failure of the weld.

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



Porosity

Porosity in FCA welds may 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 voltage or current has been used. The shielding gas may not be the correct type to suit the wire. The gas flow may be set incorrectly or be affected by wind. Too long an arc length may have been used.

Slag inclusions

Slag inclusions are not generally a problem in FCA due to the high heat input. If they do occur in FCAW they can occur at the weld root, between weld runs, or on the weld surface. They may occur as a result of low voltage or amperage, or poor electrode manipulation. Slag inclusions can occur when incorrect joint preparations are used, or when material is dirty or contaminated.

Lack of fusion/lack of root penetration

With FCAW, lack of fusion or lack of root penetration is not normally a problem but may be caused by working with incorrect joint configuration, low amperage, working on dirty or contaminated material or using the wrong electrode angles or travel rate.

Excessive penetration

Excess weld metal protruding through the root of a butt weld may occur in FCAW 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 using the correct electrode, voltage, amperage, travel speed and electrode angle adjustments may solve many of the problems.

Undercut

Undercut in FCAW 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 FCAW and may be caused by excessive voltage or amperage, too long an arc length, wrong electrode angles, or wrong travel rate.

Excessive spatter

Spatter is a normal part of welding and FCAW does not normally produce excessive spatter.

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 usually a major problem associated with the FCAW 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 into a stressed situation.

Activity

- Identify safe working practices and protective equipment in the workshop.
- Locate a suitable gas shielded FCAW plant.
- **With the mains power switch OFF**, set up the FCAW welding plant (start by checking the electrical cable connections to the wire feed unit, work lead and hand piece).
- Check the appropriate flux-cored wire is fitted into the wire feed unit.
- Remove the gas nozzle and check to see if the correct contact tip is fitted and that the nozzle and tip are clean.
- Refit the gas nozzle to give correct electrode stick-out.
- Ask your lecturer to help you set up the shielding gas flow at 12–14 L/min and in setting the correct voltage and wire feed rate.
- Strike an arc between the electrode and a practice piece of material.
- With your lecturer's assistance, produce welds on a practice piece of material.

Your lecturer should also be able to demonstrate the equipment and set up required for self-shielding wires.

Refer to Australian Standard®:

- AS/NZS ISO 17632:2006 (in part) Welding consumables – Tubular cored electrodes for gas shielded and non-gas shielded metal arc welding of non-alloy and fine grain steels – Classification (ISO 17632:2004, MOD).
- AS/NZS ISO 17634:2006 (in part) Welding consumables – Tubular cored electrodes for gas shielded metal arc welding of creep-resisting steels – Classification (ISO 17634:2004, MOD).
- AS/NZS ISO 18276:2006 (in part) Welding consumables – Tubular cored electrodes for gas shielded and non-gas shielded metal arc welding of high-strength steels – Classification (ISO 18276:2005, MOD).





Chapter 9 – Submerged arc and electro-slag welding processes (SAW)

Introduction

The principles of submerged arc and electro-slag welding processes are similar, to the extent that they are ideally suited to joints in very heavy materials. Both processes make use of a continuously fed filler wire and a granular flux. Deposition rates are high and weld quality is excellent, providing very economical welded joints.

The basic difference between the two processes is that submerged arc is applied to joints in the flat position, and electro-slag to joints in the vertical position.

In this chapter you will look at the following.

- Submerged arc welding
 - principles
 - the process
 - limitations of the process
 - Metals weldable
 - process advantages
 - process limitations
 - power source
 - current selection: alternating current or direct current
 - control box/head unit
 - submerged arc welding consumables classification
- Variables
 - the effects of welding variables
 - arc voltage
 - wire feed control (amperage)
 - travel rate
 - flux
 - process requirements
 - weld backing
 - causes of cracking



- Electro-slag welding
 - preparation
 - copper mould
 - flux
 - wires
 - power source
 - metallurgical aspects
 - summary
 - advantages
 - limitations.

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

Submerged arc welding

Principles

Submerged arc welding is defined as the process where the heat required for welding by an electric arc (or arcs) is created between a bare metal electrode (or electrodes) and the work piece. The weld area is completely shielded by a blanket of finely crushed mineral composition (flux) making the arc invisible; hence the term 'submerged arc' (see Fig 9.1). The flux, when cold, is a non-conductor of electricity but in the molten state is highly conductive.



Term	Definition
conductor	a material that permits the easy flow of electricity
electrode	an electrically conductive structure which transfers electrons to or from reactant atoms or molecules

During the welding operation, the flux in the vicinity of the arc fuses and forms an airtight slag to protect the molten metal from oxygen and nitrogen in the atmosphere and to slow down the cooling rate. As welding progresses there is no visible arc and a complete absence of spatter. The fused flux is easily removed when cool and the unfused flux is recovered for re-use.

The process was developed primarily for the production of high quality butt welds at increased welding rates. The operation is carried out by a unit which moves at a controlled speed along the joint to be welded. For circumferential joints, the work piece is rotated beneath a stationary welding head.

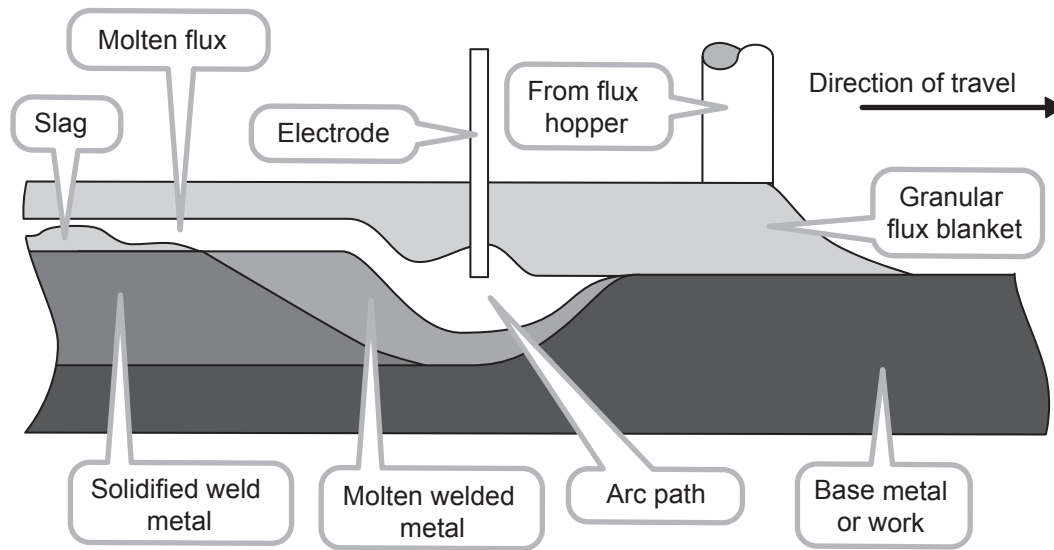


Fig 9.1 – Submerged arc welding

The process

Although the process is particularly suited to welding heavy plate, (plate 75 mm thick has been welded in one pass) with smaller filler rod and low amperages, it can be used successfully on material as light as 2.6 mm. Usually high welding currents can be used on heavy sections – in some cases as high as 4000 amps. This allows faster weld deposits to be made with very deep penetration. Plates up to 12.5 mm thick can be welded without edge preparation. On thicker plate a relatively small preparation is used permitting the use of smaller amounts of deposited metal.

Submerged arc welding has been carried out using two or three wires simultaneously, with welding speeds as high as 2.5 metres per minute. It can also be used manually, which makes the process flexible for repetition work where complicated shapes make fixturing too difficult. Submerged arc welding is a fast and economical method of welding when large diameter rod and high amperage are used. Absence of spatter and easy slag removal facilitates post cleaning. Completed welds are of a high quality with uniform appearance. Travel speed is predetermined and arc length is adjusted automatically eliminating human errors which often occur with manual arc welding processes.



Term	Definition
alloy	a mixture of two or more metals



Limitations of the process

Major limitations of submerged arc welding are the inability to cope with positional welding and the almost exclusive use on mild and low-alloy, high strength steels.

The high heat input, slow cooling cycle can be a problem when welding quenched and tempered steels. The heat input limitations of the steel being used must be strictly adhered to when using submerged arc welding. This may require the making of multipass welds where a single pass weld would be acceptable in mild steel. In some cases, the economics may be reduced to the point where flux-cored arc welding or some other process should be considered.

In semi-automatic submerged arc welding, the inability to see the arc and puddle can be a disadvantage in reaching the root of a groove weld and properly filling or sizing.

Metals weldable

- Low and medium carbon steels.
- Low alloy, high strength steels.
- Quenched and tempered steels.
- Many types of stainless steels.
- Copper and nickel alloys have been welded experimentally.

Process advantages

- High quality of the weld metal (ie good mechanical properties).
- Extremely high deposition rate and speed due to high current densities (ie amps to wire ratio).
- Uniform bead appearance with no spatter.
- Little or no fumes.
- No visible arc flash.
- Easily automated for high operator factor.
- Multiple electrodes can be used (ie tandem or twin arcs).
- Deep penetration can be attained.
- Penetration can be closely controlled.
- Thick joints can be welded in one pass.
- Less distortion compared to other processes.
- Flux blanket prevents any rapid escape of heat.
- Small preparations only are required, hence there is a minimum of filler metal required per metre of joint.

Process limitations

- High initial cost of equipment.
- Not usually suited for jobs requiring only short runs.
- The process is intolerant to such factors as poor fit-up, dirt.

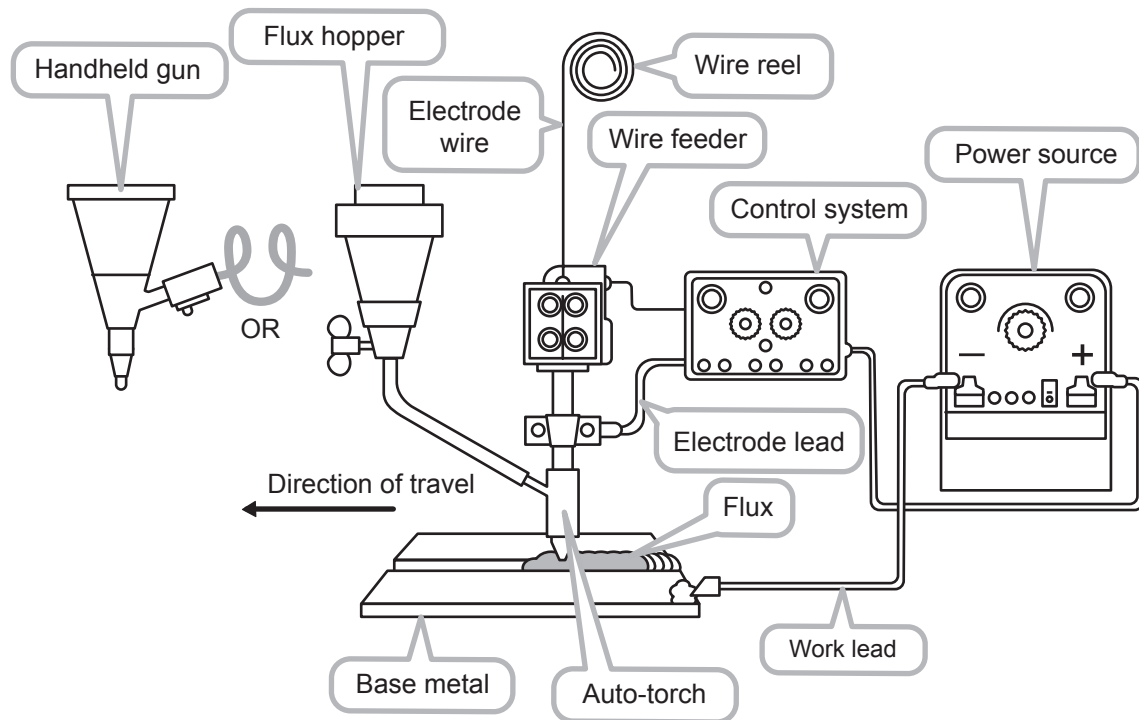


Fig 9.2 –Submerged arc welding equipment

Power source

The power source for submerged arc welding can be either constant voltage or constant current type. Constant voltage is often used with small wire sizes where the self-adjusting arc properties are most useful. Constant current type power sources are generally used on larger wires and these require feedback circuits that change the wire feed rate to compensate for any arc length or wire burn off variations.

Machines can be either generator or transformer – rectifier power sources, with the latter being the most common. These machines range in capacity from 300 amperes to 1500 amperes and must be rated for a 100% duty cycle. They may also be connected in parallel to provide extra power for high-current applications. Both AC or DC current can be used. Multiple electrode systems require specialised types of circuits especially when AC is employed.

Current selection: alternating current or direct current

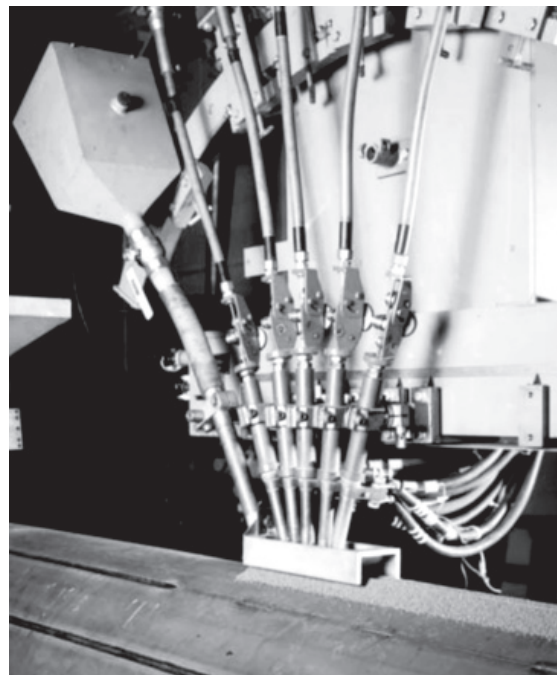
The differences in arcing and operating characteristics obtained from AC and DC welding supply with the submerged arc welding process has a slight bearing upon the suitability for a particular application. Generally, the majority of applications can be carried out equally effectively using AC or DC, but there are definite advantages at the extremities of the application range.

When selecting the most suitable welding supply, direct current gives the operator greater control over bead shape and penetration. Direct current electrode negative has a slight advantage in regard to deposition rate (this is the reverse of GMAW), whilst electrode positive has a slight advantage where deep penetration is required. Light gauge applications up to 3 mm are best carried out with DC current. Weld starting is more positive with DC and the arc is more stable at the lower currents with increased travel speeds possible.



Square-edge and prepared-edge butt welds, and standing and positioned fillet welds from 5 mm and upwards, may be carried out with either type of power supply with equal results. However, arc blow or magnetic disturbance may cause deposit deformation when welding inside circular vessels with a DC supply.

Arc blow is more likely to occur at higher currents with DC, especially on applications such as heavy wall thickness circular vessels of comparatively small dimensions, and also geometrically complex weldments.



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Fig 9.3 – Twin/tandem arc

Multiple electrode techniques such as twin arc (side-by-side) or tandem arc (where one automatic welding head follows another in a common molten pool) are used for higher productivity rates. Where more than one power supply is used, one of the electrodes is connected to an AC welding supply to cancel any magnetic effects and help arc stability. Both electrodes can be operated from an AC welding supply, but higher welding speeds are possible with an AC/DC combination.

Control box/head unit

The head unit consists of a control box that provides adjustment for the arc voltage, amperage and travel rate. It may have additional functions such as wire inch, start, stop and crater fill. The welding head also houses a large reel of wire that is lightly covered with copper to improve its transport and electrical properties, a wire straightener and a wire feed unit. A flux feed hopper and delivery system is also provided to deposit the dry, finely divided, free-flowing flux automatically along the weld joint. The unit may also have a travel motor that can allow the unit to travel at a predetermined speed (forward or reverse) along a weld joint. It may also have arc length and seam tracking adjustments.



Photographs reproduced with permission of Lincoln Electric (Aust) Pty Ltd

Fig 9.4 – Head unit

Submerged arc welding consumables classification

There are many different types of electrode wires commercially available. They are classified to a particular standard, which makes it possible to identify and select the most suitable type of wire for a job. It is important to understand classification systems and the information they represent.

Consumable classification systems list a number of essential features about the consumable, for example, consumables are classified according to filler metal composition, flux method, weld deposit and so on.

Australian Standard® AS 1858.1 Electrodes and fluxes for submerged-arc welding – Carbon steels and carbon-manganese steels classifies solid wire electrodes under three groups of elements separated by hyphens. Each group consists of a letter(s) and number(s).

Example

EL12K - FMM – W504

Group 1 (EL12K)

The first group of letters denotes a solid electrode, and indicates the following.

- E** = electrode
- L** = low manganese content:
 - L** (low)
 - M** (medium)
 - H** (high)



12 = a number indicating percentage of carbon:

12 (0.12%)

8 (0.8%)

13 (0.13%)

14 (0.14%)

K = killed (double de-oxidised)

Group 2 (FMM)

The second group consists of **F** for flux shield and then two letters that indicate the type of flux and contribution to weld metal

F – flux shield which is then followed by one of the following.

M = multi run

S = single run

B = basic flux

G = general flux

M = increase in manganese

M (little or no increase)

L (moderate)

H (high)

Group 3 (W504)

The third group involves a letter **W** followed by a three-digit number. **W** stands for weld metal. The first two digits refer to the minimum strength of the deposited weld, which is measured in megapascals. The third digit refers to the minimum impact value.

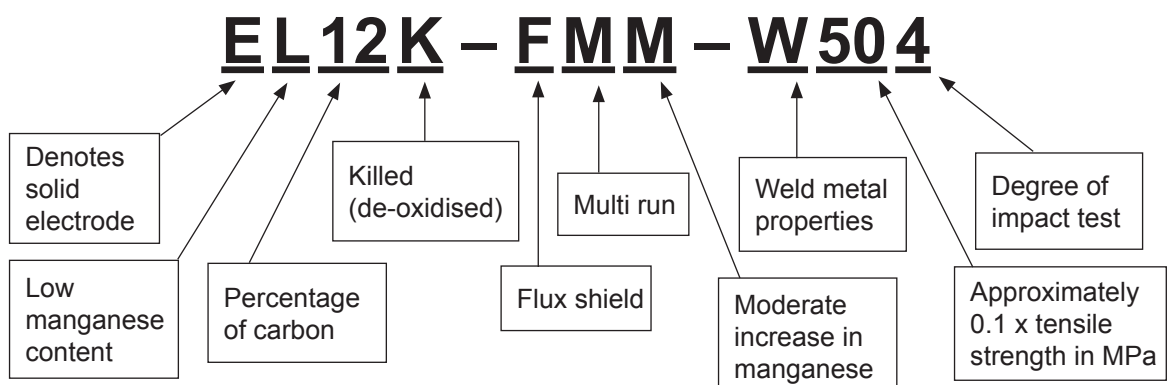
W – weld metal properties.

50 = 500 MPa strength

4 = degree of impact test

For example, **W502H** indicates the weld strength is 500 Mpa and low in hydrogen.

An example of the full classification system is shown below.





Variables

The effect of welding variables

The major variables that affect the weld involve heat input (including the arc voltage), the welding current, and the travel speed. The quality of the finished weld depends almost entirely upon their proper selection and control.

The variables, in the approximate order of importance, which must be set and maintained during welding are voltage, the current, weld speed, and width/depth of flux.

Arc voltage

As the arc voltage is reduced, so the tip of the welding wires will operate at a lower level, giving a narrower weld with deeper penetration than a higher arc voltage would give under the same current and speed condition. With high arc voltage, the wire tip operates at a high level, allowing the metal to spread out, giving a wider weld with less penetration. It also allows the fusing of slightly more flux than in the former case.

An extremely low arc voltage for a given current setting, with the tip of the welding wire operating at a lower level (which could be well below the surface of plate), will cause the molten deposited metal to be forced up around the sides and the rear of the crater. The resultant bead will be rough, irregular, and comparatively high and narrow, with visible gas holes sometimes occurring in the crater. With an excessively high arc voltage under the same current conditions, the tip of the welding wire being rather high above the plate surface will mean that the covering flux will tend to extinguish the arc. The resultant bead will again tend to be rough and irregular, but in this case comparatively flat and wide.

Mechanical adjustments may be necessary to keep the process in the line of weld and to maintain a uniform stick-out length of wire.

Wire feed control (amperage)

This may be either constant feed or voltage control.

Constant feed control maintains the wire speed by means of some form of governor. This control is often used with constant potential power sources. The desired arc length (or arc voltage) is selected by setting the constant voltage power source output voltage at a suitable value.

Voltage controlled, wire feed motors are used for constant current. The control used may be a 'series control', which is essentially an electric motor that is highly responsive to arc voltage variations, or it could be an electronic device which senses arc voltage variations and promotes motor response to these changes as they occur.

If for any short period of time the current melts-off filler wire at a faster rate than it is being fed, the distance between the wire and the work will increase as will the arc voltage. This increase in arc voltage speeds up the wire speed motor and restores the wire tip-work relationship as previously established.

With either control system, the most critical variables; arc voltage and arc current, are maintained at constant levels.

Typically, any increase in wire feed rate will increase amperage, penetration, and deposition rate.



Travel rate

Weld size and shape are affected by travel speed. Any increase in travel speed will reduce weld size and produce a narrower weld bead. Penetration is also affected by travel speed, an increase over normal settings will give a proportionate decrease in depth of penetration.

Flux

Submerged arc welding flux shields the arc, and the molten weld metal, from the harmful effect of atmospheric oxygen and nitrogen. The flux contains de-oxidisers and scavengers which help to remove impurities from the molten weld metal. Flux also provides a means of introducing alloys into the weld metal. As the molten flux cools to a glassy slag, it forms a covering that protects the surface of the weld.

The non-melted portion of the flux does not change its form, its properties are not affected, and it can be recovered and re-used. The flux that does melt forming the slag covering must be removed from the weld bead. This is easily done after the weld has cooled and in many cases will actually peel without requiring special effort for removal. In groove welds, the solidified slag may have to be removed by a chipping hammer.

Fluxes are available in various types similar to MMAW, namely rutile, acid, or basic types and these are formulated for specific applications and for specific types of weld deposits. Due to a large part of the flux interacting with the molten weld pool, another method is often used to differentiate between various types of submerged arc fluxes.

- A neutral flux has no effect on the finished weld, in spite of any variable change.
- Active fluxes contain elements such as manganese and/or silicon and these can be picked up in the arc and thus contribute to the weld metal properties. The flux/wire combination must be carefully selected and is often critical in predicting weld metal properties.
- Submerged arc fluxes are also available in different particle sizes and methods of manufacturing.

Process requirements

The successful application of the process of submerged arc welding depends on the following.

- Welding conditions and preparation to suit the work. Correct voltage, welding current and travel rate create the necessary bead width, weld contour and penetration. The joint often contains more of the base metal, 50–70% than applied filler metal and hence the composition of the base metal plays an important part in this process. Base metal composition and thickness go hand in hand in determining the mechanical properties of the joint.
- Correct selection of welding wire and flux combination to suit the base metal to be welded. The manganese wire and flux contribution should be matched and the depth of flux covering applied should be no greater than is required to obtain a quiet action and an absence of porosity in the finished weld. If too deep a layer is used, the rough and uneven surface which results is due to the entrapment of gases generated during the welding process, and which cannot escape through the thick layer of flux.

Too shallow a flux results in porosity and 'open-arc' occurring.



Term	Definition
porosity	the state or property of being porous (having pores, easily penetrated)

- Plate surface preparation other than joint preparation. It is important that no foreign material is picked up during flux reclamation and to prevent this, a suitable width of plate on either side of the joint is cleared prior to welding. It is essential that the plate and joint surfaces are clean and dry. Oil, grease, paint and other gas producing materials remaining in the joint area cause porosity. Even a crayon mark on the joint surface can ruin an otherwise good weld.
- Heat treatment prior to, during and after welding has been completed. Calculation of pre-heat temperatures and the requirements of post-weld heat treatment is extremely important. For most plain carbon and alloy steels, only pre-heat is needed, if any treatment is required at all.

Weld backing

Due to the large volume of molten metal which remains fluid for a length of time, it is essential to provide support to contain the weld until it solidifies.

Methods used are:

- non-fusible backing – for example, copper backing strip
- weld backing – the most widely used method of applying support.

Some further points to consider on weld backing are as follows.

- In a 'root backed' joint, the root face is thick enough to support the incompletely penetrated first pass of weld. It is most important that the joint edges are tightly butted.
- Manual welds are sometimes used as backing when it is not convenient to use other backing methods because of inaccessibility, poor joint preparation or fitting, or difficulty in positioning the job.
- The manual weld may become part of the complete joint or it may be removed and replaced.
- E4112 and E4113 electrodes are not recommended as backing welds, as they tend to cause porosity in the finished weld.
- Fusible metallic backing which the weld penetrates into and fuses with the backing material either temporarily or permanently becomes part of the weld.
- Preparation is provided to aid weld penetration and control the amount of weld reinforcement. Preparation is usually provided in accordance with the quality of the weld metal required in the finished weld.
- The root face should be thick enough for the weld to fuse down into, but not through the nose of the joint. Sufficient thickness of nose must be provided to absorb the heat of the molten metal in the joint area.



Causes of cracking

The principal causes of cracking when submerged arc welding are as follows.

Result	Cause
Rigidity	Cause by thick plates or reinforced/braced structures.
Low ambient temperatures and fast cooling rates	Causes an increase in quench rates that might be detrimental on susceptible material.
Steels of low weldability	High alloy content, high carbon equivalent or large mass can all contribute to poor weldability.
Polarity	If cracking is due to plate composition, electrode positive polarity is recommended. The 20–30% better burn-off will help to build up an adequate cross section of weld with a proper convex bead which resists cracking.
Manual first pass weld backing	Use only recommended hydrogen controlled electrode types for this function.
Bead shape and dimensions	Particularly the ratio between the width and depth of deposit.
Internal shrinkage	To prevent internal shrinkage cracking, the bead surface must be flat to slightly convex and the width of the weld must not be greater than penetration depth.
Electrode stick-out	This determines the burn-off rate. A high burn-off rate gives less penetration and weld dilution and reduces cracking but bead shape is hard to control.
Bead shape	Particularly below the plate surface. What is termed 'hat-shaped beads' provide stress rises due to their below plate cross-section and could lead to cracking where fatigue loading is possible.



All operating factors are important, and with adequate supervision, submerged arc welding will provide the most consistent and trouble-free welding of all production processes.





Electro-slag welding

The electro-slag process was first developed for vertical welding of tank seams on site. The process potential for single pass welds on heavy materials in the vertical position was soon realised. Unique features of the process are the absence of an arc, because once the molten pool is established, welding heat is developed by resistance heating as the current passes through the molten slag. Preparation of plate edges is minimised, since square oxy-cut edges can safely be welded, but the advantages of this feature are limited to some extent by the need to provide substantial clamping arrangements to secure the parts during welding. The slag has no metallurgical function because very limited amounts of flux are used compared with other processes; its function is to develop and distribute welding heat and to protect the molten pool of weld metal.

In the electro-slag process, the guide and contact tube for the continuously fed electrode wire is mounted just above the weld pool and mechanically raised as the weld progresses. An adaptation of this process employs a continuous guide from top to bottom of the weld, passing down the centre of the joint, and this process is referred to as 'consumable guide welding', because the guide is melted into the weld pool as it rises. The advantage of a consumable guide is that it can be set up before welding commences, including the wire feed mechanism which remains static, and joints which change direction and slope away from the vertical can be better catered for.

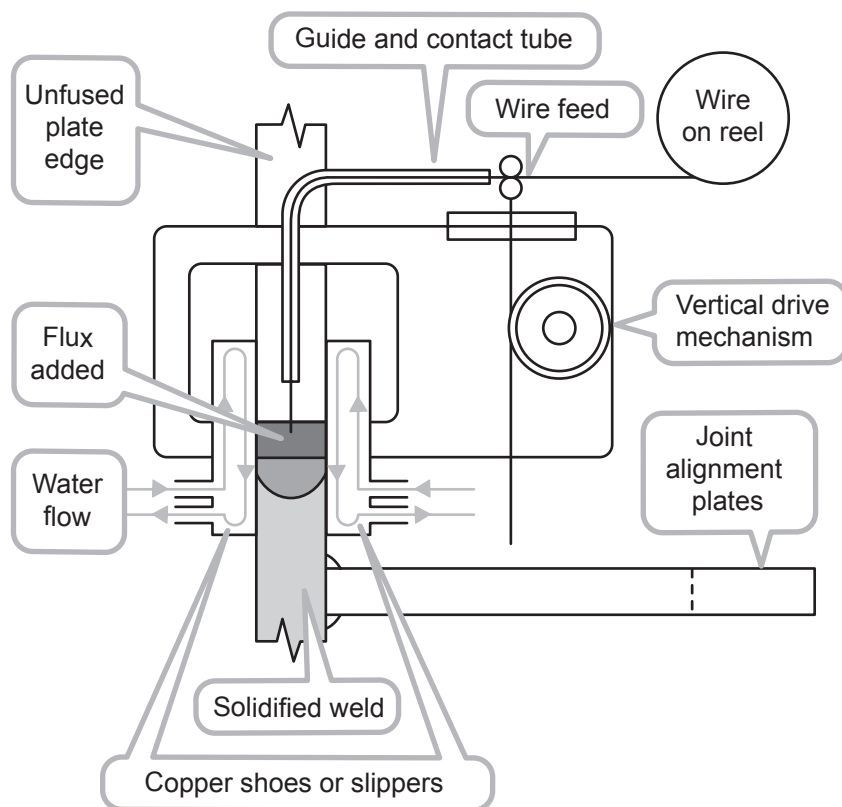


Fig 9.5 – Electro-slag arrangement



Preparation

A gap between square plate edges of between 25 mm and 50 mm depends on the thickness of the material. The gap is often set to increase from bottom to top in order to cope with the considerable contraction forces as the weld progresses. 'Strong-backs' or shaped plates are usually welded on to hold joint plates in position and maintain good alignment across the face of the joint.

These strong backs must be cut out to provide free passage for the copper strips and the vertical drive gear (see Fig 9.6).

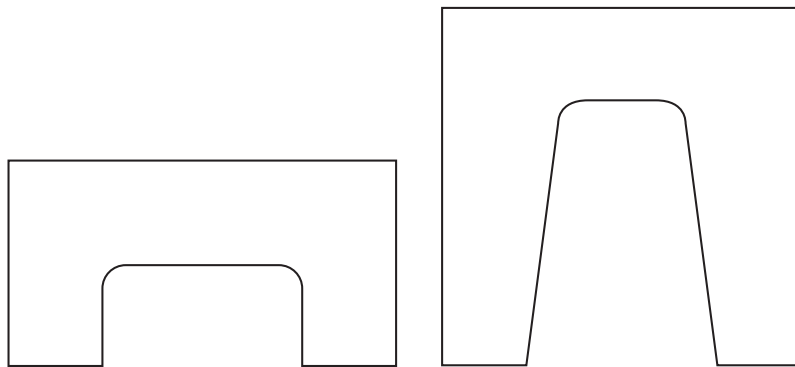


Fig 9.6 – Strong backs to secure joint for welding

Preparation also requires the provision of 'run-on' and 'run-off' plates at the beginning and end of joints. These short extensions of joint plates, approximately 75 mm, allow full size and strength welds to be maintained throughout. They can be seen on the drawing of the consumable guide arrangement in Fig 9.7.

Copper moulds

Copper moulds, or shoes, retain the molten metal and slag and are moved forward as the weld proceeds. Copper is a good conductor of heat and the moulds tend to cool the weld quickly. The moulds are water cooled internally and form a solidified flux coating against the weld face which also serves to protect the copper. Reinforcement of the weld is created by the shape of the moulds. They are held in close contact with the joint faces to prevent leakage from the molten pool, and are moved upwards as welding progresses. The molten metal solidifies and becomes self-supporting before the bottom of the mould moves forward. An alternative to continuously moving shoes is the stepping of moulds as indicated in Fig 9.7.

Flux

Flux is similar to submerged arc fluxes but has additional amounts of:

- calcium fluoride – to prevent arcing
- manganese and aluminium silicates – to raise boiling point
- fluorspar and magnesia – to improve conductivity and ionisation.

Flux is added as necessary to compensate for losses, and the level of molten slag is maintained between 38 mm and 50 mm. Molten slag which is too deep may trap gas or slag, and if too shallow may allow metal to run out or cause unstable current flow.

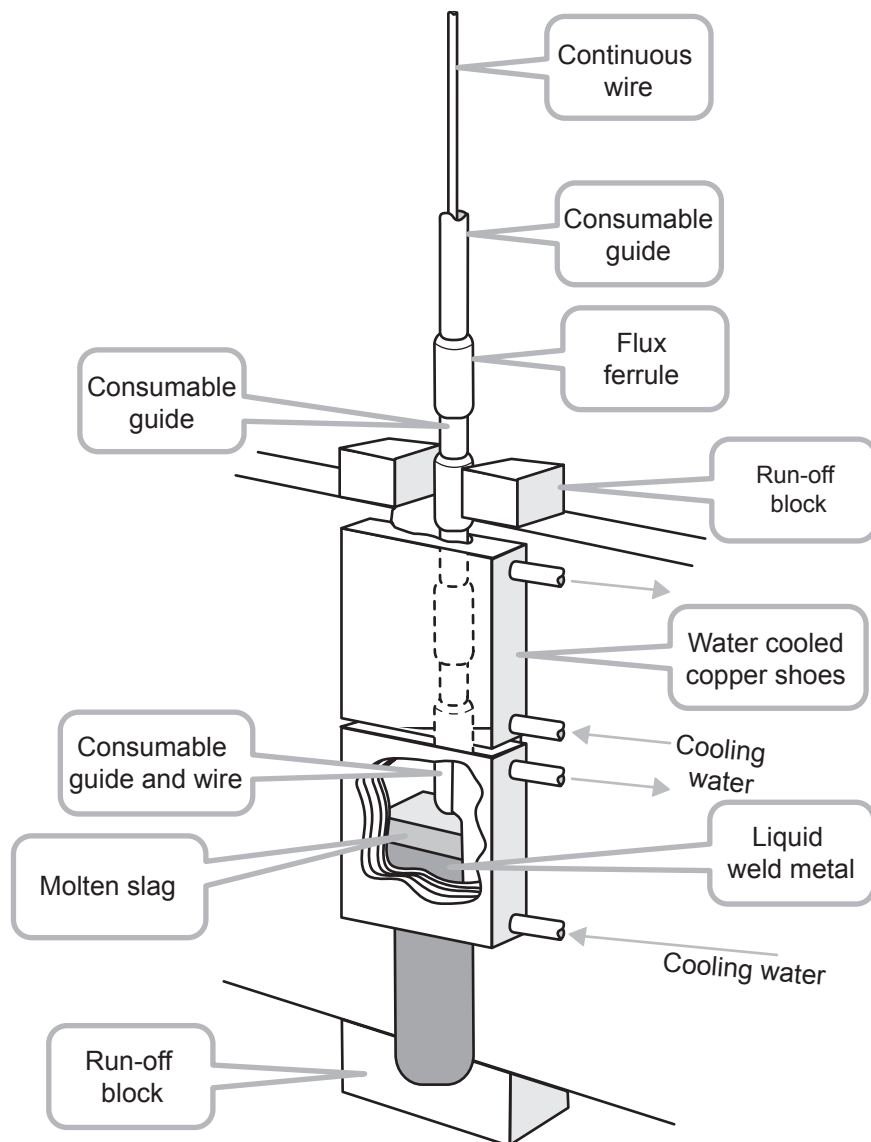


Fig 9.7 – Electro-slag process

Wires

Standard wires are used, as in submerged arc welding, but since flux cannot be used to add elements to the weld, these must be added via the wires, and/or the consumable guide when it is used, and wire oscillation can be arranged to ensure even heat and metal distribution.

The molten slag maintains a temperature between 1700 °C and 2400 °C, which melts the filter wire and the plate edges. The actual melting point of flux is much lower than the melting point of steel, which is designed to prevent slag being trapped. The molten slag must not be allowed to boil.



Power source

Ordinary arc welding transformers or generators can be used. Constant potential machines give better control of weld conditions than constant current machines. Alternating or direct current can be used, but alternating is preferred. Welding current is relatively high, depending on the size of joint and the number and size of electrodes; for example, three wire feeds may require 3000 amps at 40 to 55 volts.

Metallurgical aspects

Owing to prolonged heating and slow solidification, the welds produced have a very coarse grain structure and a wide HAZ, often returning low impact values. However, normalising can give the necessary grain refinement and a resulting improvement in mechanical properties.



Term	Definition
HAZ (heat affected zone)	the part of a metal that is not melted during cutting, brazing, or welding, but its microstructure and physical properties are altered by these processes

Summary

Advantages

- Single pass only required.
- Square edge preparation.
- No arc and little heat given off.
- Excellent on heavy material.
- No angular distortion.
- More metal is deposited per unit of electrical power than other processes.
- Flux consumption is very low compared to submerged arc welding.

Limitations

- High cost of equipment.
- Can only weld vertical.
- Setting up may be difficult – strongbacks must be used.
- Heat treatment is often required.



Activity

Carry out the following in your workshop.

- Identify safe working practices and protective equipment in the workshop.
- Locate a suitable submerged arc welding (SAW) plant.
- **With the mains power switch OFF**, set up the SAW plant (start by checking the electrical cable connections to the wire feed unit, work lead and handpiece).
- Check the appropriate wire is fitted into the wire feed unit.
- Remove the flux distribution nozzle and check to see that the correct contact tip is fitted.
- Set up the correct electrical stick-out and flux height as the nozzle is refitted.
- Ask your lecturer to help you set up a typical voltage, welding current and travel rate. Your lecturer should be able to also demonstrate the equipment.
- With your lecturer's assistance, produce practice welds on practice material.

Conduct three test welds.

1. Try variations in arc voltage while keeping all other parameters constant.
2. Alter amperage while keeping all other parameters constant
3. Alter travel rate, while keeping all other parameters constant.

Refer to Australian Standard® AS 1858 – Electrodes and fluxes for submerged-arc welding – Carbon steels and carbon-manganese steels.



Appendix

Metals and fabrication competency mapping

Arc welding 1

Book title	Chapter title	Comp code	Competency title	Full = ✓ Partial = ★
Arc welding Vol 1	1. 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	★





Appendix – Competency mapping

Book title	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	★



Book title	Chapter title	Comp code	Competency title	Full = ✓ Partial = ★
	5. Manual metal arc welding	MEM 5.12C	Perform routine manual metal arc welding	★
		MEM 5.15C	Weld using manual metal arc welding	★
		MEM 5.16	Perform advanced welding manual metal arc welding	★
	6. Gas tungsten arc welding	MEM 5.49B	Perform routine gas tungsten arc welding	★
		MEM 5.19C	Weld using gas tungsten arc welding	★
	7. Gas 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	★
	8. Flux-cored arc welding	MEM 5.47B	Weld using flux-cored arc welding	★
	9. Sub-arc and electro-slag welding processes	MEM 5.23C	Weld using submerged arc welding	★



Arc welding 1

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.

ARC WELDING 1

Basic Arc Welding Information Book

DESCRIPTION

This resource supports learners to develop the basic underpinning skills and knowledge relating to a number of competency units used in the Engineering Tradesperson learning pathway, with a particular focus on introductory level arc welding.

Topics covered include the following.

- Arc welding safety
- Electricity and welding machines
- Weld preparation and workmanship
- Air-arc gouging
- Manual metal arc welding (MMAW)
- Gas tungsten arc welding (GTAW)
- Gas metal arc welding (GMAW)
- Flux-cored arc welding (FCAW)
- Submerged arc and electro-slag welding processes (SAW)

The book is divided into separate chapters, each containing workshop-based activities that will provide opportunities for practice before assessment.

A comprehensive mapping guide is included, to show where the content in this resource aligns with the relevant competencies.

EDITION

2007

CATEGORY

Metals & Engineering

TRAINING PACKAGE

- MEM05



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and **Workforce Development**

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