INTRODUCTION TO WELDING

Gas and Thermal Processes

www.vetinfonet.dtwd.wa.gov.au
ENG092

Introduction to Welding
Gas and Thermal Processes

Learning Resource
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# Contents

<table>
<thead>
<tr>
<th>Chapter 1</th>
<th>Oxygen-fuel gas plant safety</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2</td>
<td>Oxygen-acetylene and propane equipment</td>
<td>9</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Flame heating</td>
<td>37</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Oxy fuel gas welding</td>
<td>49</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Oxy-flame cutting</td>
<td>75</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Oxy-flame gouging</td>
<td>105</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Plasma cutting</td>
<td>115</td>
</tr>
<tr>
<td>Appendix</td>
<td>Competency mapping</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 1 – Oxygen-fuel gas plant safety

Introduction

Gas welding has been around for many years and when it is carried out by a skilled operator, it can be useful in welding a wide range of materials. It has, however, been largely superseded by more modern welding methods yet it remains a desirable base skill for welding and associated trades.

Gas welding process overview

Oxygen and acetylene together in a flame provide the heat necessary to melt most metals. This combined with a neutral welding atmosphere and suitable filler material allows a skilled operator to weld most metals. Other fuel gases such as LPG or propane produce a reactive secondary flame that interferes with the molten metal, making them unsuitable for welding. These and other fuel gases are suitable for heating and cutting purposes.

In this chapter you will look at the following.

- Personal safety for oxygen-fuel gas plant use, including:
  - what you should wear when using an oxygen-fuel gas plant
  - personal safety for oxygen-fuel gas plant operators
  - ventilation
  - fire prevention
  - eye protection
  - safety when oxygen-fuel gas cutting and welding.
Personal safety for oxygen-fuel gas plant use

What you should wear when using an oxygen-fuel gas plant

It is important that you always wear the proper safety clothing when you are working with any oxy-fuel gas equipment or electrical welding equipment.

For general fabrication or welding, or when working near machinery or on scaffolding, it is essential that you wear heavy-duty clothes which do not have lots of pockets or loose material which can easily get caught up in moving parts or equipment.

Loose-fitting shirts or old baggy windcheaters with floppy sleeves could put your life in danger. It is important to make sure that the trousers you wear do not have cuffs as these have been the cause of many a trip to hospital because of fire and burns. In some factories, cuffs have even collected explosive or poisonous dust.

It is better to wear short sleeves rather than rolled-up sleeves. However, if you are engaged in gas cutting or electric welding operations, long sleeves should be worn with the recommended protective clothing. Remove wristwatches and rings as these too can get caught up in the machinery.

Do not wear old worn shoes or boots. Loose laces and ragged soles or heels can cause serious falls. Wear sound, sturdy, safe shoes or safety boots.

Remember that if the job requires special protective clothing, you must wear it, even if it causes you a bit of inconvenience. It could save you from death or from serious injury.

Unrestrained hair hanging down has been the cause of many scalping accidents. Always wear a hat, a beret or a hairnet when working near moving machinery.

The operator should wear:

- a long-sleeved cotton shirt (non-flammable)
- sleeves rolled down and buttoned
- hard-wearing trousers without cuffs (fire resistant)
- sturdy leather shoes or work boots (spark resistant, steel toe cap)
- an apron (leather)
- gloves (leather)
- spats (leather)
- caps (non-flammable)
- a leather cape or jacket
- eye protection
- ear protection.
Personal safety for oxygen-fuel gas plant operators

1. Be neat and clean about your work. Avoid tripping or falling.
2. Keep equipment in good condition in order to avoid fire and explosions.
3. Wear eye protection at all times and goggles when using a blowpipe. These will protect your eyes from sparks, flying slag and the strong light and harmful rays that come from the flame. They will also help you to see your work better.
4. Wear the proper gloves, apron, shoes and any other protective clothing provided in order to minimise the risk of burns.
5. Watch out for sparks as they could land on your sleeves, cuffs and in pockets.
6. Never use oxygen as compressed air.
7. Never use matches to light a blowpipe – use a flint lighter or a pilot light.
8. Move all flammable material at least 10 metres away from the area in which you are welding or cutting.
9. Keep flame, sparks and hot metal away from cylinders and tubing.
10. When you are working on a metal which gives off poisonous fumes, always use the correct fume extraction system.
11. Never use a blowpipe when you are working on scaffolding or staging suspended by a manila rope.
Ventilation

The oxygen-fuel gas flame produces both carbon monoxide and carbon dioxide as a result of the combustion process. Carbon monoxide can cause drowsiness, loss of consciousness and even death. Carbon dioxide displaces oxygen and can lead to asphyxia and death.

Many materials give off irritating and/or toxic fumes when heated, for example, cadmium, zinc and lead. For this reason, gas welding and flame cutting fumes should be avoided. Remember that cutting or welding on toxic materials should be avoided as much as possible. If these operations must be carried out, an exhaust type ventilation system should be used particularly if the fumes are excessive or if natural ventilation is inadequate. In extreme cases, a suitable respirator should be worn.
Fire prevention

Any flame is a source of potential ignition for a fire or explosion. In order to reduce the risk, the following steps should be taken.

- Clear the immediate work area of rubbish. Flammable material should not be allowed to accumulate near welding and flame cutting operations – it should be at least 10 metres away. Oily, greasy or paint-stained rags should be placed in special fire-retardant bins.

- Store all flammable liquids and explosives in isolated areas and do not cut or weld anywhere near them. Use only non-sparking tools to open containers which hold these materials.

- Do not perform any welding or cutting operations on any container that has previously held flammable materials. It is important that you think about the area in which you are cutting and welding. Cutting and gouging can produce high velocity particles which can travel long distances (in some cases up to 10 metres). Hot particles falling from a high workstation can travel further than you might think, as illustrated in Fig 1.3.

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

Fig 1.3 – Typical travel distances for hot or molten metal particles in cutting or welding
Eye protection

Welding, heating and cutting flames give off infra-red and ultraviolet rays. Although the rays are not as concentrated as those of the arc, they have a similar damaging effect on the eyes over a long period of time.

In any metal fabrication or welding workshop, the minimum general requirement is that clear safety glasses (not sunglasses) must be worn at all times. These must be approved to Australian Standard® AS 1336:1997.

As with arc welding, oxy-welding processes require that operators protect their eyes from damage caused by rays, sparks and flying scale.

When using an oxygen-fuel gas process to perform welding or cutting, the operator must wear proper goggles or a full face shield fitted with at least a shade five (5) lens filter. The correct type and shade of lens must be used at all times.

<table>
<thead>
<tr>
<th>Description of operation</th>
<th>Type of work</th>
<th>Shade No. AS/NZS 1338.1:1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>• flame descaling, silver brazing, fusing welding zinc die cast, braze welding light</td>
<td>light cutting</td>
<td>4</td>
</tr>
<tr>
<td>gauge copper pipe and steel sheet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• fusion welding of copper and its alloys, nickel and alloys, medium thickness steel</td>
<td>general, most common shade</td>
<td>5</td>
</tr>
<tr>
<td>plate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• braze welding of heavy steel, cold cast iron, hard facing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• fusion welding heavy steel, heavy and hot cast iron</td>
<td>heavy work</td>
<td>6</td>
</tr>
<tr>
<td>• braze welding hot cast iron and cast steel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For more detailed current information refer to the current version of AS/NZS1338.1:1992 for gas welding.

Based on AS/NZS 1338.1: 1992 – Table A1 (www.saiglobal.com)

Table 1.1 – Types and shades of lens
Safety in oxygen-fuel gas cutting and welding

Clear the welding area

Be careful of other people

Do not use heat on any container that may have contained fuel

Keep hoses clear of the floor.
Wear gloves

Mark work that is hot

Fig 1.4 – Safety in oxy-acetylene welding
Activity

Identify safe working practices and protective equipment in the workshop. Refer to the following Internet site for additional information and case studies.

www.safetyline.wa.gov.au
Chapter 2 – Oxygen-acetylene and propane equipment

Introduction

As mentioned in Chapter 1, the oxygen and acetylene flame has been used in gas welding and cutting for many years. There are, however, other fuel gases such as propane which, when combined with either air or pure oxygen, may be used for heating and cutting purposes only.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>oxygen</td>
<td>a colourless, odourless gas – the most abundant chemical element – which forms compounds with most others</td>
</tr>
<tr>
<td>acetylene</td>
<td>a hydrocarbon gas used in welding and flame cutting operations – it generates high heat when used with gaseous oxygen under pressure</td>
</tr>
</tbody>
</table>

In this chapter you will look at the following.

- Cylinders
- Gases – oxygen, acetylene and liquefied petroleum gas (LPG)
- Supply of gases
- Bulk storage
- Cylinder safety and handling
- The gas regulator
- Hoses
- Fittings
- Blowpipes
- Nozzles and tips
- Setting up of gas welding and cutting equipment.

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

Oxygen cylinders
An oxygen cylinder is a hollow container with thick walls sufficiently strong enough to withstand very high pressures and to which a valve and regulator are attached.

Oxygen gas is compressed and forced into the cylinder to produce a pressure to a maximum of 17 500 kPa, at 15 °C. One size cylinder (G) will hold in excess of 8.9 m³ (8900 litres) of gas under pressure, but if water filled this container it would only take 47 litres. Oxygen is squeezed into the container under pressure and therefore oxygen cylinders can be very dangerous. Bursting discs are fitted to these containers to vent off excessive pressure. Oxygen cylinders are painted black and have right-hand threads.

Acetylene cylinders
An acetylene cylinder is very different from an oxygen cylinder. The walls do not need to be very strong as there is no high pressure involved.

The cylinder is not hollow because acetylene is extremely unstable when compressed in a free area. The cylinder is filled with porous material saturated with liquid acetone. The porous material is used to break up the area inside the cylinder into many holes capable of absorbing the acetone, (in a similar manner to a sponge absorbing water). The cylinder is filled with acetylene gas which is absorbed by the soluble acetone (acetone can absorb many times its own volume of acetylene). The gas is dissolved into the acetone inside the cylinder at a pressure of approximately 1550 kPa at 15 °C. The porous material in the cylinder prevents large areas of gas forming and limits explosions to the size of the microscopic pore.
When acetylene is forced into the cylinder it is absorbed by the acetone and because heat is produced the container is sprayed with water to keep the temperature low. This also assists the absorption of the gas. Fusible plugs, (that melt at 100 °C) are fitted to the cylinder to vent off acetylene should overheating occur.

As acetylene is drawn from the cylinder a reaction occurs – similar to the opening of a soft drink bottle, and gas comes bubbling out as the pressure is reduced. When the acetylene cylinder valve is opened, the pressure in the cylinder falls and gas comes away from the acetone. If the flow out of the cylinder is too great the gas will not have time to separate out from the acetone, and instead liquid acetone will flow from the cylinder.

For this reason the discharge rate of acetylene is one-seventh the volume of a full cylinder per hour, eg if a cylinder containing 7000 litres is used the maximum draw-off in any one hour would be 1000 litres. Long jobs or continuous work would have several cylinders joined together with a manifold.

Acetone can also be discharged from a cylinder if it is laying on its side, so always store and operate acetylene cylinders in an upright position. Acetylene cylinders are claret coloured and have left-hand threads.

The passing of liquid acetone into welding or cutting equipment is extremely dangerous as it will continue to liberate acetylene and pressures may become excessive, it also reduces the flame temperature and therefore increases the cost of carrying out the work.

**Liquid petroleum gas cylinders (LPG)**

LPG cylinders are hollow containers with walls strong enough to withstand the pressure of LP gas in liquid form. This is essential as the storage of LP gas in liquid form only occupies 1/270th of the space it would as a gas.

The pressure in the container depends upon the type of gas and temperature, for example, propane gas pressure varies from 650 kPa at 25 °C to 1180 kPa at 38 °C.

When the pressure is released, by opening the valve, some of the remaining liquid vaporises. This is why the cylinder gets cold as heat is required to make up the pressure again.

LPG cylinders are fitted with a pressure relief valve to vent off gas, should any overheating occur. Liquid petroleum cylinders are painted aluminium and have left-hand threads.
Gases – Oxygen, acetylene, and liquefied petroleum gas (LPG)

Oxygen and fuel gas combined

At the end of the nineteenth century a discovery was made which was to have a big effect on the metal fabrication industry. The flame produced by burning acetylene with oxygen was hotter than any previously known. The flame was quickly adapted to heat and weld metal.

Today this system is widely used in welding and cutting operations where oxygen and acetylene (or other fuel gases) are used.

Table 2.1 sets out the flame temperatures of various fuel gases. From this it can be seen that it is the hottest of all flames in commercial use.

<table>
<thead>
<tr>
<th>Fuel gas</th>
<th>Maximum flame with air °C</th>
<th>Temperature with oxygen °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>acetylene</td>
<td>2630</td>
<td>3130</td>
</tr>
<tr>
<td>hydrogen</td>
<td>2210</td>
<td>2660</td>
</tr>
<tr>
<td>coal gas</td>
<td>1920</td>
<td>2450</td>
</tr>
<tr>
<td>propane</td>
<td>1925</td>
<td>2700</td>
</tr>
</tbody>
</table>

**Table 2.1 – Fuel gases – temperatures**

Oxygen

Oxygen is a colourless, odourless, tasteless gas. Oxygen itself does not burn, but supports combustion. Oxygen is used in cutting and welding to make the fuel gases used burn hotter, and to oxidise metal during flame cutting.

- **chemical symbol**: $\text{O}_2$
- **can be liquefied at**: minus 183°C
- **density**
  - gas at 150 °C and 100 kPa: 1.337 kg/m³
  - liquid at boiling point (B.pt): 1.141 kg/L

**Oxygen production**

The air around us consists of 1/5th oxygen, the remainder being mainly nitrogen, with some carbon dioxide, water vapour and traces of other rare gases.

Oxygen is compressed and distilled from the air and between each compression stage, the heat generated is extracted in coolers, resulting in a fall in temperature of the air. This process continues until the air liquefies.
The liquid air is then distilled to separate the nitrogen from the oxygen. Nitrogen vapour forms at the top of the distillation tower and is allowed to boil off. The oxygen, still in liquid form, collects at the base of the tower. This oxygen is virtually pure and is drawn off and contained under pressure in large storage vessels. The oxygen is then distributed either in cylinders as a compressed gas, or in insulated containers in liquid form.

**Acetylene**

Acetylene is composed of carbon and hydrogen (C₂H₂). Acetylene is a colourless gas with a distinctive odour and is readily soluble in acetone.

Acetylene is popular fuel gas for cutting and welding as it produces a hotter flame than any other fuel gas.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical symbol</td>
<td>C₂H₂</td>
</tr>
<tr>
<td>Density at 0 °C and 1 atm</td>
<td>1.1709 kg/m³</td>
</tr>
<tr>
<td>Solubility of acetylene in acetone</td>
<td>300:1 by volume 175 kPa at 15 °C</td>
</tr>
</tbody>
</table>
Flammability

Acetylene burns in air with a yellow, hot, smoky flame. The ignition temperature of acetylene (335 °C) is much lower than the majority of other fuel gases.

Acetylene, when mixed with air, has a very wide flammable and explosive range (from about 3% acetylene and 97% air to 81% acetylene and 19% air). When submitted to a pressure exceeding 175 kPa, acetylene becomes unstable; if subjected to a slight shock, friction or heat, it is likely to explode with great violence. Consequently, the maximum safe working pressure for acetylene is 100 kPa.

Acetylene production

In contrast to oxygen production, impure acetylene is relatively easy to make but because of its unstable nature stringent safety precautions must be maintained.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>slaked lime</td>
<td>calcium hydroxide, a white alkaline powder derived from the action of water on calcium oxide</td>
</tr>
</tbody>
</table>

Acetylene gas is produced by feeding solid calcium carbide into water. Acetylene is given off as a gas, and slaked lime remains with the water as sludge.

\[
\text{CaC}_2 + 2\text{H}_2\text{O} = \text{C}_2\text{H}_2 + \text{Ca(OH)}_2
\]

Calcium carbide + water = acetylene + slaked lime.

The acetylene gas given off is washed in water, purified, dried and passed into an acetylene compressor.

A characteristic of acetylene is its effect on copper. When acetylene and copper come into contact a highly explosive compound (copper acetylide) is formed on the surface of the copper. This compound may cause an explosion if subjected to heat, friction or a sharp blow. For this reason copper tubing should never be used to join welding hoses – use approved type joiners.
Liquefied petroleum gas (LPG)

LPG is a term applied to the gas products of petroleum refining, (usually propane, butane or a mixture of these gases), and sold under such trade names as Handigas®, Kleenheat®, Porta-Gas®. LP gas is a fuel gas, i.e., it can be burned as a source of heat, as can acetylene and hydrogen. Like these gases, it can be used with oxygen for flame cutting, brazing and heating.

The LP gas from the refinery is first cleaned and dried, then compressed, cooled and liquefied. A particularly useful feature of LP gas is that it liquefies at a comparatively low pressure. This means the gas can be readily transferred into a cylinder, stored and transported as a liquid. LP gas has no smell so an odorant is added to aid detection of leaking gas. LP gas is heavier than air and tends to collect in hollows thus becoming a possible source of fire or explosion.

Propane (C₃H₈) is the most commonly used LP gas in the welding industry because of its low cost, convenience in handling, relatively high discharge rate and other unique properties. It is a particularly clean fuel and burns without the carbon or soot deposits of other fuels. It is also very stable and equipment using it is much less prone to backfiring and flashbacks experienced when using other fuel gases.

LP flame temperatures reach 1925 °C using air and 2700 °C using oxygen. LP is difficult to light and set compared to acetylene and so more skill is needed to control it.
Propane

<table>
<thead>
<tr>
<th>chemical symbol</th>
<th>C₃H₈</th>
</tr>
</thead>
<tbody>
<tr>
<td>density:</td>
<td></td>
</tr>
<tr>
<td>• gas at 0 °C and 1 atm</td>
<td>1.97 kg/m³</td>
</tr>
<tr>
<td>• liquid at 21 °C, saturation pressure</td>
<td>0.500 kg/L</td>
</tr>
</tbody>
</table>

Supply of gases
Industrial gases are usually supplied in steel cylinders or in bulk to suit the requirements of industry. Manufacturers deliver the many types of gas to industry using road, air and sea transport.

Acetylene is always supplied and transported in cylinders.

Transport and storage of oxygen as a gas
Where smaller quantities of oxygen are required or portability is essential, oxygen is delivered to the user in gaseous form – compressed into steel cylinders (Fig 2.4).

The most common size of cylinder in use in Australia contains 8 m³ of oxygen at a pressure of approximately 15,000 kPa.
Bulk storage

Bulk supplies or the use of manifold units is advantageous when large amounts of gas are used. The bulk supply may be in the form of cylinders grouped in stationary packs or mobile trailer units (Fig 2.5).

A manifold set consists of a series of cylinders, usually compressed oxygen and acetylene, connected in a bank. The gas flow is controlled by a master regulator which allows the gas to reticulate to a number of convenient points in the workshop (Fig 2.6).
As a liquid in an insulated tanker

This method is used where large quantities of oxygen are involved. The liquid oxygen is stored, at the place where it is to be used, in a vacuum insulated container and evaporated off as a gas when required. The gas is then distributed to points of usage by means of a pipeline.

Cylinders have the advantage that the gas can be stored indefinitely without loss. Their principal disadvantage is the fact that owing to the heavy construction materials used to withstand high pressure, the weight of gas contained is only a small proportion of the gross weight, eg about one-eighth in the case of oxygen.

With the high initial cost of cylinders and the great weight of metal which has to be carried, transport of gases in cylinders is expensive. By transporting oxygen as a liquid in insulated tankers, the vessel only weighs about half as much as the liquid oxygen contained, which results in a considerable saving in transport cost.
Nitrogen, LP gas, and argon also lend themselves ideally to bulk storage in liquid form (Fig 2.7).

Fig 2.7 – Storage of gas as a liquid
Chapter 2 – Oxygen-acetylene and propane equipment

Cylinder safety and handling

General safety

1. Keep all empty or full cylinders separated, eg fuel gas, oxidising gas, inert gas in locked secure storage areas. These must be away from radiators, furnaces, other sources of heat and electrical circuits, and from direct sun.

2. Close valves of empty cylinders to keep water or contamination out.

3. Never tamper with or alter cylinder numbers, marking or colour coding.

4. Never try to refill a cylinder or try to mix gases in a cylinder.

5. Never use a cylinder or its contents for other than its intended purpose.

6. Keep oil, grease and all hydrocarbons away from cylinders. Keep them clean!

7. Make sure cylinders are upright and secure, and protect cylinder valves from bumps, falls, falling objects and the weather.

8. Never allow anyone to strike an arc or tap any electric arc against any cylinder.

9. Never draw oxygen or acetylene from cylinders except through properly attached pressure regulators.

10. If valves cannot be opened by hand, do not use a hammer or wrench, and notify the supplier.

11. Never use cylinders as supports or rollers.

12. Always remove regulators before moving cylinders, and make sure valves are tightly closed before removing regulator.

13. Open all cylinder valves slowly.

14. Never open a cylinder valve more than 1½ (one and a half) turns.

Oxygen cylinders

1. Always call oxygen ‘oxygen’ not ‘air’.

2. Never use oxygen in pneumatic tools, oil preheating burners, blowing out pipes or tanks, or anywhere as a substitute for compressed air or other gases.

3. Any hydrocarbon, for example oil, paint, grease, forms an explosive compound when subjected to oxygen under pressure. Never use oil on oxygen-fuel gas equipment.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>pneumatic</td>
<td>referring to compressed air</td>
</tr>
</tbody>
</table>
Acetylene cylinders

1. Always call acetylene ‘acetylene’ not ‘gas’.
2. Always keep acetylene cylinders upright when in use to avoid loss of acetone.
3. If an acetylene cylinder valve leaks from or around the spindle, close the valve and tighten the glands. If this fails or if the fusible plug is leaking, remove the cylinder to the open air, far away from possible sources of ignition. Tag the cylinder properly to explain the trouble and notify the supplier immediately.
4. If the acetylene cylinder is on fire or seriously heated, either accidentally or through severe flashbacks:
   a) shut valve off (if possible)
   b) take the cylinder into the open air (if possible)
   c) cool with copious supply of water (if possible).

If an acetylene cylinder is on fire, and cooling is being applied, allow the fire to burn. Call the fire authorities and evacuate all personnel. (Any gas leak that cannot be shut off is more dangerous because there is a high risk of explosion).

Cylinder colours

<table>
<thead>
<tr>
<th>Type of gas</th>
<th>Colour of cylinders</th>
<th>Used for</th>
</tr>
</thead>
<tbody>
<tr>
<td>acetylene</td>
<td>claret or crimson</td>
<td>cutting, welding and heating in general.</td>
</tr>
<tr>
<td>argon</td>
<td>peacock blue</td>
<td>gas tungsten arc welding (GTAW) gas metal welding (GMAW)</td>
</tr>
<tr>
<td>carbon dioxide with 5% or more argon</td>
<td>peacock blue with French grey neck</td>
<td>GMAW steel welding</td>
</tr>
<tr>
<td>carbon dioxide</td>
<td>French grey (green grey)</td>
<td>GMAW steel welding</td>
</tr>
<tr>
<td>LPG</td>
<td>aluminium</td>
<td>cutting and heating</td>
</tr>
<tr>
<td>hydrogen</td>
<td>signal red</td>
<td>cutting under water</td>
</tr>
<tr>
<td>oxygen</td>
<td>black</td>
<td>cutting, welding and heating</td>
</tr>
<tr>
<td>nitrogen</td>
<td>dark admiralty grey</td>
<td>powder cutting - plasma cutting</td>
</tr>
<tr>
<td>helium</td>
<td>middle brown</td>
<td>GMAW aluminium welding</td>
</tr>
</tbody>
</table>

Table 2.2 – Colour code for identification of industrial compressed gas cylinders
Labels are attached to the shoulder of the cylinder as illustrated below (Fig 2.8). The properties of the gas contained in cylinders can be determined by the colour of the identification label:

- **red** – flammable gas
- **yellow** – oxidising gas
- **green** – inert gas
- **red and white** – poisonous gas

A cylinder without a label should not be used but returned to the supplier and a replacement cylinder obtained.
The gas regulator

Before oxygen or dissolved acetylene can be used in the various blowpipes and attachments, it is necessary to use a pressure reducing valve between each cylinder and the blowpipe. This device is known as a gas regulator and is a precision instrument. It must be sensitive in operation, yet robust enough to withstand wear and tear.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>blowpipe</td>
<td>a device consisting of a tube and valves used for regulating the flow of oxygen and gases required for welding, cutting and other similar operations</td>
</tr>
</tbody>
</table>

Functions of regulators:

- to display the cylinder pressure (contents) and working output pressure
- to reduce the pressure of the gas from the cylinder to a safe pressure that can be used at the blowpipe
- to adjust the output pressure to suit different blowpipe sizes and types
- to automatically maintain a constant pressure and flow, free from fluctuation, despite the drop in cylinder pressure that occurs as the cylinder contents are consumed.

All regulators are designed to fulfill these requirements, and each type is suitable only for the gas for which it is intended.

Regulator operation

With the cylinder valve open and the tee screw loose, the regulator seat is held hard against the high pressure orifice.

Screwing in the tee screw compresses a spring, which in turn deflects a diaphragm and this action opens the regulator seat. This allows gas to flow into the regulator body and hoses.

This gas flow will continue until pressure within the regulator is sufficient to force the diaphragm back against the pressure of the spring, closing the valve and cutting off the flow of gas.

Pressure within the regulator is now stable and indicated by the low pressure gauge.

If the gas is then drawn off through the regulator outlet to operate a blowpipe, a slight drop occurs in the gas pressure within the regulator, the spring deflects the diaphragm, again opening the valve – and the flow of gas from the cylinder is resumed. This will continue until the blowpipe valves are closed.

The output pressure is dependent on the pressure applied to the spring by means of the tee screw.
**Chapter 2 – Oxygen-acetylene and propane equipment**

### Term Definition

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>creep</td>
<td>creep is the development of additional pressure over time creating excess pressure in the regulator and hoses. Creep is most prevalent in regulators with damaged seats and valves</td>
</tr>
</tbody>
</table>

**Maintenance of regulators**

**Filters:** Regulators have metal filters located in the bullnose end of the inlet. This protects the regulator by preventing particles from clogging the passages or damaging the seat, thus helping to eliminate the cause of creep.

**Regulator seats:** If the seat is damaged, the seat must be replaced. Excessive creep is the main indication of a damaged seat. Damaged regulators should be referred to the manufacturer for repairs.

---

Regulators may be:
- single stage – for general workshop use
- two stage – for heavy duty cutting or thermic lancing.
Fig 2.9 – Oxygen regulator

Fig 2.10 – Acetylene regulator
Chapter 2 – Oxygen-acetylene and propane equipment

Hoses (tubing)

Hoses are generally constructed of synthetic rubber and reinforcing material, and are designed to withstand high pressures, while providing flexibility to give the operator freedom of movement.

Oxygen hoses are black and the fittings at each end of the hose have right-hand threads. Fuel gas hoses are red or maroon and the fittings have left-hand threads.

One of the major problems in selecting the proper bore dimensions for rubber hose is that a pressure drop occurs when gas flows through the hose over any distance. For instance, if you introduce gas at, say, 700 kPa at the inlet of the hose, friction losses cause the pressure at the outlet end to be much less. Pressure reduction will occur in hose lengths over 3.5 m and allowances must be made for this. A 10 mm bore hose should be used for all large flow applications and where extra long lengths are required.

Hoses are available in the following sizes: 5 mm, 8 mm, 10 mm, and 13 mm.

Constant attention should be given to hoses and their connections because old hoses and poorly fitting connections are a potential source of danger. After lengthy use, hoses may become cracked due to rough handling, or the rubber perishes and the nipples become worn. Hence it is wise to renew the hoses as required to prevent fires or explosions due to oxygen or acetylene leaking from the equipment.

Fittings

Use only approved fittings for any connection between hoses to regulators and the blowpipe. (RH thread oxygen, LH thread for fuel gas) (Fig 2.11).

Copper tubing should not be used to repair or join acetylene hoses, for copper and acetylene combine to form a compound known as copper acetylide. This is an explosive compound which may be detonated by friction, a spark or a blow. Nor should friction, or insulated tape, be used to bind the hose in an effort to stop leaks, the gas will still force its way out no matter how tightly the tape is bound.
**Blowpipes**

The blowpipe is the device which regulates the flow of oxygen and the fuel gas. Tubing attached to the regulators is connected to the blowpipe by the inlet connections that are situated at one end of the blowpipe (left hand thread for acetylene, right hand thread for oxygen). Two valves control the amount of gas that enters the blowpipe and they are conveniently placed near the inlet connections (see Fig 2.12).

![Blowpipe Image](BOC Limited © 2006)

**Fig 2.12 – Typical welding blowpipe, mixer and welding tip**

The mixing chamber where the gases are mixed must be correctly designed to ensure that the two gases such as oxygen and acetylene are completely mixed in their correct proportions. Fuel gases such as acetylene, are highly flammable and burn very rapidly, and the mixer design has to make allowance for this fact.

If the flame velocity is reduced, backfires and flashbacks may occur and the flame may enter the barrel and travel almost instantaneously back to the supply source.

The mixer design must be such as to extinguish this flame and thus prevent the flame from travelling past this point. This is done by breaking up the fuel gas passage into a series of small ports which are sufficiently small in diameter to quench any flame.

**Cutting attachment and cutting blowpipes**

Most small workshops use a combination welding and cutting blowpipe (Fig 2.13). To change from one operation to the other it is only necessary to unscrew the welding attachment from the barrel of the blowpipe and replace it with the cutting or heating attachment.

![Cutting Attachment Image](BOC Limited © 2006)

**Fig 2.13 – Cutting attachment**
Where thicknesses greater than 50 mm are to be cut it is advisable to use a heavy-duty cutting blowpipe which is a complete unit that has larger gas lines for better gas flow and is longer to allow the operator to get away from the heat (Fig 2.14).

Fig 2.14– Heavy-duty blowpipe
Nozzles and tips

Nozzles (for cutting) and tips (for welding) are stamped for easy identification. The markings indicate the type and size of nozzle and special process identification.

Nozzle type

The first part of the type number gives the form of nozzle connection. The 30 series nozzles are a screw-in with a threaded inlet connection. The 40 series nozzles are the taper seat type (Fig 2.15).

The second part of the type number indicates the fuel gas used. If the type number ends in a ‘1’ the nozzle is used with acetylene shows a type 41 nozzle (Fig 2.15); this indicates a taper seat nozzle for use with acetylene.

A type 44 nozzle (Fig 2.15) is a tapered nozzle, for LPG. The LT type nozzle (Fig 2.15) is for acetylene gas.

Fig 2.15 (a), (b) and (c) – Cutting nozzle identification showing various types
Gas number identification
1. Acetylene
2. Low pressure acetylene
3. Coal gas
4. LP gas
5. Hydrogen

Size of nozzle
The hole size number is stamped underneath the type number. The size number is in tenths of a millimetre, e.g., a size 12 nozzle has a main bore diameter of 1.2 mm. Sizes for nozzles are 6, 8, 12, 15, 20, 24, 32, 40, 48, and 64. Most common sizes for welding tips are 8, 10, 15, 20, 26, 32, and 38.

Special nozzles
Nozzles other than standard, are identified by two letters after the size number.

DG    Deep gouging
TH    Heating tip
DS    Deseaming
PW    Power washing
FW    Flame washing
RC    Rivet cutting
GB    Gouging bent
RW    Rivet washing
GS    Gouging straight
SM    Sheet metal
HS    Hi-speed cutting
UW    Underwater

Care and maintenance of nozzles and tips
Good consistent cutting and welding can be expected only where the welding tip or cutting nozzle is kept in perfect condition (assuming that the other conditions are observed).

A blocked heating orifice produces an irregular flame and a clogged cutting orifice results in a distorted cutting stream, both tend to mar the surface of the cut.

The orifice should have parallel sides throughout and exit at a square face. Use the correct size tip drill or reamer and use it as a probe to gently remove any obstructions, do not twist the cleaners otherwise the orifices will be damaged (bellmouthing). The nozzle face should be flat and clean and this can be accomplished by using fine emery cloth. The nozzle is held vertically and is rubbed across the emery cloth with long regular strokes, turning the nozzle through 90 degrees after a few strokes.
The tip or nozzle should then be checked by fitting it to a blowpipe and igniting the flame. A welding tip should have a clean well defined flame, and the cutting oxygen stream of a cutting nozzle should be clearly defined as a long dark parallel sided zone, when viewed from two different positions at 90 degrees to each other.

Type 40 nozzles are so designed that the seats cannot easily be damaged if dropped. Before fitting, ensure that the taper seats are clean and unscored. When fitting, tighten the nut firmly.

**Setting up of gas welding and cutting equipment**

1. Make sure your equipment, hands and gloves are clean and free from oil and grease. (As this substance combined with oxygen under pressure creates an explosive mixture).

2. Stand and secure the oxygen and acetylene cylinders in a vertical position (preferably in a specially designed truck or trolley where oil cannot drip onto them and where they cannot be knocked by falling or moving objects).

3. Inspect the cylinder valve for damage or any foreign substances such as oil or grease.

4. Before connecting regulators to their respective cylinders, crack open each cylinder valve (i.e., sharply open and close the cylinder valve) allowing the escaping gas to blow out any foreign matter which may damage seats or clog orifices.

5. Attach the regulators, flashback arrestors and hoses to their respective cylinders. The acetylene regulator and hoses are colour coded and have left-hand threads, and the oxygen regulator and hoses are black with a right-hand connection.

In making the connections use the correct spanner as supplied for the purpose, do not use excessive force.

6. Make certain that the regulator’s pressure adjusting knobs (tee screws) are released.

7. Open each cylinder valve slowly so the pressure gauge hand moves up gradually ensuring that the high pressure gas does not strain the gauge mechanism.

8. Attach the other end of the oxygen tubing to the blowpipe oxygen valve marked ‘0’. Repeat the procedure with the acetylene tubing, with the blowpipe acetylene valve being marked ‘F’.

9. See that the blowpipe valves are closed. Select the correct nozzle for the job, and fit it to the head of the cutting blowpipe, making sure the nozzle is seated correctly. Set the appropriate pressures.
Testing for leaks

After you have connected the welding plant to the cylinders go through the following test procedure:

1. Shut off blowpipe gas valves.
2. Open the cylinder valves and set the regulators to show approximately 75 kPa on the delivery gauge.
3. Close the cylinder valves.
4. Watch the cylinder pressure gauges. If any decrease in pressure occurs, there is a leak in the system. If no pressure drop is seen, then there are no leaks up to the blowpipe valves.
5. Locate any leaks using a clean paint brush, a bucket of water and a cake of soft or liquid soap to make a soapy-water mixture (do not use a flame!).

Adjusting pressures

Acetylene should be set to maximum of 100 kPa with the blowpipe acetylene valve open approximately one-quarter of a turn.

When a welding tip is attached the same pressure of 100 kPa should also be set, with the blowpipe oxygen valve open approximately one-quarter of a turn.

When a cutting attachment is fitted to a multipurpose blowpipe, the handpiece oxygen valve should be kept fully open at all times. Oxygen flow is then controlled via the preheat oxygen valve, and the cutting lever of the cutting attachment.

Oxygen should be set to the appropriate pressure with the cutting lever fully depressed. Use the recommended pressure charts as a guide. Excessive pressures are wasteful, as they prevent you doing your best work. Incorrect pressure may also cause backfires or flashbacks, and can be very dangerous.

Lighting up

1. Open the acetylene valve and ignite the gas with a flint lighter or pilot, until the acetylene flame burns at the nozzle without excessive black smoke and sooting.

2. Open the blowpipe oxygen valve until the flame resolves itself into two visible sections; that nearest the nozzle being white and ragged, and the other bluish and feathery. Continue to open the oxygen valve until the inner flame cone becomes clearly defined.

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<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>sooting</td>
<td>the action of carbon dust formed by incomplete combustion</td>
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</table>
3. Adjust so that the pre-heating flame remains neutral when the cutting oxygen lever is depressed (if using a cutting attachment).

4. Final flame adjustment. Neutral pre-heat flames of full size are the most suitable.

**Closing down**

1. Close the blowpipe acetylene valve.
2. Close the blowpipe oxygen valve.

This is enough for temporary halts, but when closing down finally, in addition to closing the valves at the blowpipe, you must also:

3. close both cylinder valves
4. open the oxygen blowpipe valve and allow the oxygen to drain out
5. close the blowpipe oxygen valve when both gauges on the oxygen regulator have fallen to zero
6. release the oxygen regulator tee screw
7. repeat all this with the acetylene valves and regulator
8. remove regulators, hoses and blowpipe from cylinders and store in a safe place (optional).

---

**Note**

This procedure must be performed separately for each gas supply to avoid cross contamination of gases.

**Backfires and flashbacks**

**Backfire**

A **backfire** is a momentary extinguishment or momentary burning back of the flame into the blowpipe tip or nozzle, i.e., the flame goes out with a loud snap or pop followed by re-ignition from the flame or heat of the work.

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**Glossary**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>backfire</td>
<td>caused by a malfunction or poor handling of the equipment which extinguishes the flame, sounding off with a loud snap or pop</td>
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</tbody>
</table>
A backfire may be caused by:
- touching the tip against the work
- particles entering the tip and obstructing the gas flow
- using incorrect gas pressures – in particular pressures too low
- a loose tip or mixer
- overheating the tip or nozzle (indicated by a rapid series of backfires)
- flame too small for tip size.

Sometimes the trouble will clear itself immediately, and if the work is hot enough, the blowpipe will relight automatically. If this does not happen:
- close the blowpipe valves immediately
- check your gas pressures
- check your equipment for loose or damaged parts
- cool tip or nozzle.

After a backfire check that gas flow is clean, e.g. flame at blowpipe tip should burn without contamination in flame.

Flashback
A flashback is the burning back of the flame into the blowpipe, or the ignition of an explosive mixture in one of the gas lines.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>flashback</td>
<td>a flame burning back to the source of the flammable material. As it burns a distinctive shrill, hissing sound is heard</td>
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</tbody>
</table>
A flashback occurs very fast (at the speed of light) and usually it goes no further than the first safety device which is the mixing chamber. Here it burns with a distinctive shrill hissing sound and produces rapid heating of the blowpipe. Rarely does the flashback burn into the tubing and reach the regulator.

The occurrence of a flashback indicates that something is radically wrong with the equipment or your handling of it. The danger of a flashback can be eliminated by being able to recognise what it is, what caused it and knowing what action to take.

1. Close the blowpipe oxygen valve at once. This removes one of the three parts required to maintain a fire (fuel, oxygen, ignition).
2. Close the blowpipe fuel gas valve.
3. Wait to be sure the flame in the blowpipe has burnt out.
4. If the flashback enters the rubber tubing, close the cylinder valves immediately.
5. Check your equipment for:
   - incorrect gas pressures
   - distorted or loose tips
   - distorted or loose mixer seats
   - kinked tubing
   - clogged tip or nozzle
   - overheated tip or blowpipe.
6. Repair or replace any part damaged by the flashback (e.g., damaged mixer or burnt tubing).

The possibility of a flashback reaching the regulators has been reduced in modern equipment by the provision of a number of safety devices.

The mixer contains small orifices to trap any flame front, and the blowpipe contains spring-assisted non-return seats.

Current regulations require a flashback arrestor to be fitted at both the blowpipe and cylinder ends of hoses. These units should extinguish any flashback, thus eliminating any danger to the cylinders and/or operator.
Activity

Proceed to the workshop and identify the various gas cylinders, equipment and accessories.
Chapter 3 – Flame heating

Introduction

The use of a fuel gas and oxygen is a convenient and efficient method of heating material or raising the temperature of material for additional operations such as forming or bending, because the equipment is portable and easy to use, making it ideal for site or workshop applications. The controlled high heat intensity can result in the saving of time and labour over more traditional heating methods using coke or oil.

Flame heating can be used to:

- dry wet plates prior to welding
- preheat plates prior to welding
- carry out heat treatment operations
- make metals more malleable for forging or bending
- descale – to remove surface oxides from steel sections and plates
- contraheat as a means of cambering or straightening steel sections.

In this chapter you will look at the following.

- Oxygen and acetylene
- Contraheating
- Advantages of the process
- Principles of flame straightening
- Cooling procedure
- Application to plates
- Precautions to be observed.

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

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>cambering</td>
<td>the process of arching slightly, to bend or curve upwards in the middle</td>
</tr>
<tr>
<td>endothermic reaction</td>
<td>absorbs heat during manufacturing process</td>
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</tbody>
</table>
Oxygen and acetylene

As previously mentioned the combination of oxygen and acetylene produces the hottest flame known to man because the acetylene breaks down and releases the heat used to make it an (endothermic reaction), in addition to the normal heat produced by combustion of any fuel and oxygen. The oxy-acetylene flame is the most commonly used combination for heating and bending operations because of its intense flame concentration and high temperature.

When used with a neutral flame, the process has no effect on the material because of its protective envelope. However, it is possible to overheat the material and burn off the elements the material is made up from. Overheated material will also oxidise while it is still hot, when the protective flame envelope is removed.

A carburising flame (excess acetylene) will add carbon to the surface of heated material while an oxidising flame (excess oxygen) will help the heated material to actually burn or produce a thick oxide layer on the surface.

The table below compares the flame temperatures between oxygen and acetylene and oxygen and LPG fuel gases.

<table>
<thead>
<tr>
<th>Fuel gas</th>
<th>Maximum flame with air °C</th>
<th>Temperature with oxygen °C</th>
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</thead>
<tbody>
<tr>
<td>acetylene</td>
<td>2630</td>
<td>3130</td>
</tr>
<tr>
<td>propane</td>
<td>1925</td>
<td>2700</td>
</tr>
</tbody>
</table>

Table 1 – Fuel gases – Temperatures

Heating tips are fitted to standard oxy-acetylene plants and require no expensive outlay.

The following diagram shows a selection of heating tips available for use with acetylene and LPG, when used as a fuel gas with oxygen.

Fig 3.1 – Typical heating tips
It should be noted that many heating tips draw large volumes of gas. In many cases, it is easy to exceed the maximum draw-off rate of 15% of the nominal cylinder contents per hour for acetylene. In such cases, cylinders will need to be manifolded to provide the flow rates required.

**Contraheating**

Although contraheating can be used for correction of distortion, it is more commonly used for two other industrial applications:

- flame straightening of steel sections
- cambering of steel sections.

In many instances, a skilful operator with the help of an oxy-acetylene plant and some simple mechanical aids can perform the same operation as large and costly bending/pressing machines. Fig 3.2 shows an example of the amount of movement that can be obtained with the use of the flame bending technique.

![Fig 3.2 – Two beams that were fabricated in the normal manner, and then cambered, by the controlled use of the oxy-acetylene flame](image)
Advantages of the process

- The portability of the oxy-acetylene flame means that the work may be carried out on site. Thus heavy, bulky objects do not need to be returned to the workshop for pressing.
- Many objects are just too large, or complex to make mechanical methods an economic proposition, thus leaving oxy-acetylene heating the only suitable alternative.
- The oxy-acetylene flame can be directed into inaccessible locations that might otherwise require dismantling or removal of the section.
- Low equipment cost and simple operation.

Principles of flame straightening

A complete understanding of the principles involved in the use of the oxy-acetylene flame for bending, or straightening structural steel, is required before the process can be applied successfully. Lack of understanding of these principles can lead to damage and distortion of the metal; particularly by the incorrect application of heat, and/or overheating.

The process of bending, or straightening structural steel sections, is based on controlling the resulting expansion and contraction of the metal due to the application of intense localised heating and cooling. It must be noted that a high temperature is not required for the process. The temperature should not exceed 600 °C. What is needed is rapid heat input, and therefore large heating blowpipes are generally required.

Whenever heat is applied to a metal it will expand and then contract back to its original shape when it cools. In the contraheating process intense heat is applied to a local area and the surrounding cold metal acts to resist expansion. Therefore, most expansion will occur in the direction of least resistance which is cross sectional thickness. On cooling however, contraction will occur equally in all directions resulting in the heated area becoming slightly shorter. This can be used to produce noticeable movement at the ends of structural members, particularly in the case of long narrow sections. If the above principles are thoroughly understood, with experience, an operator will develop an understanding of exactly where and how much heat is required to bend a member the desired amount, in the desired direction.

It must be remembered that the principle relies on applying the heat quickly, and does not require a high temperature.

In some instances, it may be found to be advantageous or necessary to assist the process with mechanical aids such as jacks, clamps, wedges. For example, in the case of heavy members the unsupported weight might act against the desired direction of movement during expansion and contraction.
Metals & Fabrication

Gas Welding

Fig 3.3 – Sequence of events in flame straightening heating pattern

In almost all applications involving structural sections a wedge-shaped heating pattern is required. The proportions of the wedge are shown in Fig 3.5 (a).
Chapter 3 – Flame heating

Bent member

Deformed area to be flame straightened

Intense heat applied in the correct wedge shaped pattern

Abnormal expansion occurs here

Expansion resisted in these directions by cold surrounding metal

Upon cooling contraction occurs equally in all directions

Movement occurs in these areas because of contraction here

Final result of carefully planned and executed heating pattern

Fig 3.4 – Proportion of the heating wedge
This wedge-shaped area should be marked out on the member to guide the operator. The apex of the wedge should commence at the root of the member and extend across its full width. This wedge-shaped heating pattern must be maintained regardless of the cross-sectional shape of the member being heated. Examples of the application of the wedge-shaped heating pattern to various structural sections and their resultant direction of movement is shown in Fig 3.5 (a), Fig 3.5 (b) and Fig 3.5 (c).

Fig 3.5 – Application of the heat wedge to structural sections (a), (b) and (c)
Cooling procedure

This process relies on the metal surrounding the heat wedge to be kept as cool as possible, and where more than one wedge is required, the metal must be allowed to cool between heats. It will be desirable in most cases to speed up the cooling rate by water quenching. Quenching the heated steel will not cause any undesirable change in properties provided the temperature in the first place is kept below the lower critical range (600 °C maximum for plain carbon steel). Fig 3.6 shows a suitable quenching spray using water and compressed air.

Fig 3.6 – Equipment for providing an atomised spray for quenching

The advantage of the atomised spray is that the fine spray produced is rapidly converted to steam on contact with the heated steel, and as well as absorbing the heat quickly, evaporates leaving the metal dry.
Application to plates

The principles described above can be employed successfully to straighten distorted or buckled plates. Local buckling should be tackled by spot heating on the convex side of the buckle, as in Fig 3.7.

![Fig 3.7 – Spot heating shrinks excessive metal on the convex side of the buckle](image)

Buckles which extend to the end of the plate, can be removed by employing the wedge-shaped heating pattern as in Fig 3.8.

![Fig 3.8 – Use of the heat wedge to correct buckles extending to the edges of plates](image)
Precautions to be observed

- Members under stress from external loads should be treated carefully as this stress may cause pronounced buckling or even failure at the heated zone.
- Care must be taken with welded components, as any residual stresses caused by welding will tend to be relieved when heated. This may add to, or subtract from, the normal movement gained from contraction in the heated zone.
- The process should not be carried out on material other than mild steel without knowing the resultant change in the metal’s properties.
- Due to the size of the heating equipment required, the allowable draw-off rate for single cylinders of acetylene is likely to be exceeded in prolonged work. In such cases, consideration should be given to manifolding several cylinders together.

It is worth noting again, that the maximum temperature of the steel must be restricted to 600 °C, particularly when water quenching, so as to avoid any undesirable change in the properties of the metal.
Activity

- Identify safe working practices and protective equipment in the workshop.
- Set up an acetylene and oxygen plant starting with upright and secure cylinders:
  - purge the cylinders
  - fit correct regulators, flashback arrestors, fittings, hoses, blowpipe and heating tip.
- Adjust correct working pressures.
- Test for leaks.

Ask your lecturer to assist you

Light up the heating tip, and:

- ensure the blowpipe acetylene valve is slightly cracked open to produce a small flow of acetylene gas
- adjust the flow of gas until the acetylene and air flame produces a minimum of soot.

Then:

- adjust the oxygen valve to produce a neutral flame
- adjust the flame to produce an oxidising flame and then a carburising flame
- shut down the flame by closing the blowpipe acetylene valve first and then the oxygen valve
- use a neutral flame to heat and forge materials as directed.
Chapter 4 – Oxy fuel gas welding

Introduction

Given the efficiency and advantages of other welding processes, there are few welding applications for which the oxy-acetylene flame is considered to be the most efficient production process. The gas welding process is characterised by low heat input, with slow travel speeds and high heat transfer into the parent metal.

A competent operator can use the gas welding process to fuse, weld or repair nearly any material. The gas welding process remains as an occasional back-up process for situations where other processes are not available, or portability of equipment is a problem.

In the maintenance industries, and for the occasional welding of thin materials, and the welding of small bore pipe, the oxy-acetylene fusion welding process is still a viable alternative to other welding processes.

In this chapter you will look at the following.

- Principles
  - applications
  - advantages
  - limitations
- Gas welding equipment
- Oxy-acetylene flames
- Oxy welding techniques
- Gas welding of small diameter pipes
- Braze welding
  - uses of braze welding (with bronze filler)
  - braze welding techniques
  - preparation of materials
  - method
  - silver brazing
  - special hazards associated with braze welding/brazing.
Principles

The combination of oxygen and acetylene in near equal proportions produces a flame that has the intense heat (3000 °C) required to melt most metals. The oxy-acetylene gas combination is the only oxygen-fuel gas combination that burns completely to produce a non-reactive secondary flame or envelope suitable for fusion welds. This secondary flame does not influence the weld pool and also acts as a neutral shield that protects the weld and weld area from the effects of atmospheric gases.

If the adjacent edges of two compatible materials are melted, then the edges may fuse together. A suitable filler may or may not be required.

Other fuel gases such as LPG or propane produce a reactive secondary flame that interferes with the molten metal.

Applications

- Flux free fusion welding of plain carbon steel
- Fusion welds of pure aluminium and some alloys (flux required)
- Fusion welds of some stainless steels (flux required)
- Fusion welds of copper and copper based alloys (flux required)
- Fusion welds of other metals (requires great skill)
- General repairs

Advantages

- Equipment set-up simple
- Equipment is readily available and portable
- Wide range of applications
- Cheap consumables

Limitations

- Large heat affected zone (distortion)
- Slow output
- More suitable processes are available
Gas welding equipment

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<tr>
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<th>Definition</th>
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<tbody>
<tr>
<td>fusion welding</td>
<td>any welding process in which fusion (melting of materials at their common area to join them together) is employed to complete the weld</td>
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</table>

Fusion welding operations require a cylinder of oxygen and acetylene, regulators for both gases, flashback arrestors, correct couplings and hoses, blowpipe, mixer and welding tips.

Oxygen and acetylene gases are set at equal pressures of approximately 50 to 75 kPa.

Fig 4.1 shows common welding equipment, blowpipe and swaged welding tip. The swaged tip provides smooth gas flow and a soft, quiet neutral flame for all welding purposes.

Fig 4.1 – Gas welding equipment
Oxy-acetylene flames

Characteristics of the oxy-acetylene flame

Oxy-acetylene blowpipes utilise the Bunsen burner principle of mixing gases together before they reach the point at which combustion is to take place. This prior mixing of the gases produces a much hotter and shorter flame than when fuel gases are simply allowed to flow out into the air and burn.

For example, acetylene when premixed and burnt with pure oxygen produces the highest temperature gas flame that is safe and convenient for welding.

Theoretically it requires two volumes of oxygen to burn one volume of acetylene, but the blowpipe is designed to only supply the oxygen necessary to form the luminous or incandescent cone for which the volume is 1:1. When the flame is adjusted to neutral (Fig 4.2) the extra one and a half volumes of oxygen are obtained from the atmosphere.

![Image](Acetylene and oxygen in equal proportions (neutral flame))

Chemistry of the oxy-acetylene flame

The maximum temperature obtainable from the oxy-acetylene flame is approximately 3300 °C, (oxy-coal gas flame: 2000 °C, oxy-hydrogen flame: 2300 °C, air-acetylene: 2400 °C, liquid petroleum gas: 2700 °C), and the heat concentration is 1–2 mm in front of the extreme tip of the inner cone.

Combustion is recognised as taking place in two main stages.

1. Oxygen and acetylene (O\(_2\) and C\(_2\)H\(_2\)), in a 1:1 ratio, burn in the inner white cone. In the cone two separate reactions take place, the oxygen combines with the carbon of the acetylene to form carbon monoxide (CO) while hydrogen (H\(_2\)) is liberated.

2. Two more separate reactions take place in the outer envelope to complete combustion. The carbon monoxide takes up oxygen from the atmosphere to form carbon dioxide (CO\(_2\)) and the hydrogen burns with oxygen, also from the atmosphere, to form water vapour (H\(_2\)O).
**Flame adjustment**

Three types of flame adjustment can be obtained when using the gas welding plant:

- neutral
- carburising
- oxidising.

It is essential that the operator learns to recognise the three types of flame because incorrect flame setting could lead to weld problems or failure of the weld.

**Neutral flame**

A neutral flame is produced when acetylene and oxygen burn in the proper proportions, ie equal volumes. It is made up of a distinct and clearly defined incandescent cone or jet surrounded by a faint secondary flame or envelope. The length of the inner cone should be between three to five times its own width. The flame desired is what may be termed as a ‘gentle’ or ‘soft flame’, not a ‘harsh flame’. A harsh flame increases the agitation of the molten metal and causes metal to be forced over unfused areas.

Temperature 3000 °C – uses the following.

1. Fusion welding of:
   - mild steel and alloys
   - cast iron
   - aluminium and alloys
   - stainless steel
   - chrome-nickel alloys
   - copper and alloys
   - lead.

2. All heating applications and cutting pre-heating flames.

**Carburising flame**

This flame is produced when there is an excess of acetylene and can be readily recognised by a luminous intermediate cone or ‘feather’ around the inner cone caused by unburnt particles of carbon which are burnt and disappear as they reach the outer edge of the feather.

The carburising flame has an excess of carbon and will add carbon to the surface of the material. It is also sometimes referred to as a ‘reducing flame’. A reducing flame is one that, because of its need for oxygen, will reduce oxides such as iron oxide.

The temperature of the carburising flame is lower than that of the neutral flame. It causes mild steel to seemingly sweat or look greasy. (This is brought about by the unburnt particles of carbon in the flame reacting on the steel’s surface and lowering the melting point of the steel before it melts to any depth).

Temperature 2800 °C – uses the following.

1. Fusion welding high carbon steels.
2. Hard surfacing operations.
Oxidising flame

This flame is produced when there is an excess of oxygen in the flame, so named because of its oxidising effect on the molten metal. The effect of too much oxygen is to decrease the length and width of the outer envelope and to shorten the inner cone. It is very harmful in certain welding applications, such as the welding of mild steel, aluminium and stainless steels.

When welding mild steel excess oxygen can be detected by the intense sparking of the melted metal and the appearance of a whitish scum.

Temperature 3300 °C – uses the following.

1. Fusion welding of:
   - brass
   - bronze
   - zinc die castings.

2. Bronze welding of:
   - cast iron
   - galvanised iron
   - mild steel.
Oxy welding techniques

Forehand welding technique
The definition of forehand welding is welding with the blowpipe flame pointing in the direction in which the weld progresses, ie towards the unfilled seam, where the blowpipe follows the filler rod (Fig 4.5).

![Fig 4.5 – Forehand welding](image)

This technique is the most commonly used for mild steel on flanged edges, unbevelled plates up to 3 mm, and bevelled plates up to 5 mm. It is also the technique adopted for cast iron and non-ferrous metals.

Backhand welding mild steel
The definition for backhand welding is welding with the blowpipe flame pointing in the reverse direction in which the weld progresses, ie towards the filled seam, where the blowpipe is ahead of the weld and filler rod (Fig 4.6).

This technique requires great skill and is the most common method used for full fusion root welds on pipe.
Tip sizes
Tip sizes are designated in tenths of a mm, ie $8 = \frac{8}{10} = 0.8$ mm.
Size $20 = 2$ mm.

<table>
<thead>
<tr>
<th>Tip sizes</th>
<th>Filler rod diameter (mm)</th>
<th>Thickness of mild steel</th>
<th>Pressure* kPa</th>
<th>oxygen</th>
<th>acetylene</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1.6</td>
<td>0.8 mm</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>8–10</td>
<td>1.6</td>
<td>1.6 mm</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>10–12</td>
<td>1.6</td>
<td>2.4 mm</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>12–15</td>
<td>2.4</td>
<td>3 mm</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 4.1 – Typical tip sizes and settings

These pressures apply only to equal pressure blowpipes, where you can adjust both regulators.
Filler rods

<table>
<thead>
<tr>
<th>Type</th>
<th>Marking</th>
<th>Remarks</th>
<th>Sizes mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>mild steel</td>
<td>none</td>
<td>free running, high ductility mild steel and wrought iron</td>
<td>1.6, 2.4, 3.2, 5 and 6.3</td>
</tr>
<tr>
<td>high test</td>
<td>copper coating</td>
<td>high quality rod for welding steel where high mechanical properties of joint are required</td>
<td>as above</td>
</tr>
<tr>
<td>super steel</td>
<td>copper coat blue tip</td>
<td>low alloy steel containing balanced quantities of Si and Mn produces welds of high strength and suitable for many low alloy steels</td>
<td>1.6, 3.2, 5 and 6</td>
</tr>
</tbody>
</table>

Table 4.2 – Filler rod selection chart

Requirements for fusion welding of steel

1. **Flame**: a neutral flame is required for the welding of mild steel.
2. **Flux**: not required as the oxides of steel melt at a lower temperature than the melting point of steel.
3. **Filler rods**: a filler rod of the same composition as the base metal is mostly used. The diameter of the rod should be the same or close to the thickness of the base material to enable easy control of the weld pool and filler rod melt-off.

Preparation – tacking and gap

**Tack welding** is the term given to small welds which are used to maintain the correct joint gap, the alignment of parts and to control distortion during the welding process. The tack weld is made by producing a small molten puddle across the seam to produce local fusion of the joint faces. A small circular motion of the tip may be used and a filler rod introduced to assist in making a strong tack weld.

The distance between tack welds should ensure that the joint is stable during welding operations. On thin plate, eg 1.6 mm thick material, the recommended distance between tacks should be no greater than 40 mm. This is to stop the plate edges from distorting between the tacks as the welding heat is applied. Usually one edge rises and the other drops down, resulting in uneven joint faces. As the plate thickness increases, so then does the distance between the tack welds. In many instances it is wise to make some allowance for expansion and contraction when tacking up the joint.
Methods in common use are (Fig 4.7):
- allowing a slightly larger joint gap than normal
- setting the gap wider at one end of the joint where welding is to commence
- combined with the above, plates are usually overset to allow for and use contraction forces to align the welded plates and reduce distortion.

![Diagram of tacking methods](image)

**Fig 4.7 – Common methods of tacking**

**Joint gap**
Table 4.3 sets out the correct edge preparation and accompanying joint gap for forehand welding in the flat position.
Table 4.3 – Joint gap examples

Table 4.3 should be used as a starting point. Minor adjustments can be made to allow for expansion and contraction forces produced during welding. However, depending on the type and grade of material, thickness and length of weld, the allowance may vary, and only through experience can the operator decide the most suitable joint set-up.

A sound weld is produced by the correct employment of such factors as flame setting, flame control, tip angle, filler rod angle and feed. The operator should choose a comfortable position and through experience be able to coordinate and control all factors to produce consistently good welds. Welding should take place with the operator welding across the body – in the case of a right-handed person, from right to left.

1. The flame – the inner cone is brought to within 2 mm of the metal surface, and directed at a point to melt the metal and form a molten pool. The flame is kept in a direct line of the weld joint, maintaining recommended angles (Fig 4.8).

2. The molten pool – should extend from the top surface of the plate through to the underside edges of the seam. Welding takes place when the two molten faces fuse, the forward movement of the blowpipe makes this a continuous process.

3. The filler rod – is held in the outer envelope to raise and keep it at a welding temperature, for correct angle see Fig 4.
Welding technique
The flame is directed at a point to form a molten weld pool. The filler rod is held within the outer envelope to raise it to a welding temperature. On formation of the weld pool, the filler rod is lowered into the centre of the molten pool in a constant dipping action regulated by the amount of filler metal required.

Do not allow the molten metal from the rod to drop into the weld pool. Keep the flame on the line of the weld moving forward **without excessive** weaving motion. Increased angle of the blowpipe slows progress and increases the size of the molten pool. It is important that the filler rod be withdrawn from the molten pool so that the heat build up can occur to re-establish the correct pool depth for full penetration.

Operator control
Accurate control of the welding rod requires great operator skill. The filler metal should be deposited at an even rate to form a sound joint with adequate weld reinforcement. Operator control is also needed to prevent the rod from sticking. If the rod should stick to the parent metal, simply melt it loose using the welding flame.

When the weld is completed, or in the case of an intermediate stop, the molten pool should be allowed to slowly solidify inside the flame envelope so that oxides are not formed and gases are not trapped within the weld.
Gas welding of small diameter pipes

Oxy-acetylene welding of pipe is accomplished by one of three techniques:

- a single-pass or multi-pass forehand technique
- a single-pass or multi-pass backhand technique
- a two-pass technique using a backhand first run and forehand capping run.

Forehand technique

Pipe welds using the forehand technique are started at the bottom or '6 o'clock' position and welded upwards to the top or '12 o'clock' position. The welding flame points towards the direction of welding with the filler rod leading the blowpipe, as illustrated in Fig 4.9.

Pipe should be preheated before welding commences, particularly on pipe over 6 mm thick.

The forehand method is a slow process that involves movement of the flame from one side of the joint to the other. The filler rod is also moved from side to side, alternating with the flame. If build-up is required, the rod is stopped momentarily in the middle of the molten pool to melt off more filler metal.
**Backhand technique**

The backhand technique is illustrated in Fig 4.10. It involves the welding of pipe from top to bottom, when the pipe is in the fixed horizontal position. The flame is directed back into the molten pool and the rod is held behind the welding flame.

![Diagram showing backhand pipe welding](image)

The backhand technique is faster than forehand. The flame is directed into the root opening until both pipe edges are melted to form a molten eye, or ‘key hole’. As the molten eye forms, the rod is moved towards the forward edge of the pool.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>slag</td>
<td>impurities in the molten mix</td>
</tr>
</tbody>
</table>

**General notes**

As gas welding is slower than other processes it allows more time for change of operator position when welding small bore pipes. Welds are normally sound and no grinding or slag removal is required on completion.

Normalising of mild steel is often required. The slow process tends to promote heat transfer into the parent metal, which causes slow cooling and a relatively coarse grain structure. Any post-weld heat treatment should be carried out strictly in accordance with the specifications for the material.
Braze welding

There are four terms used in the welding trade which are frequently confused. The terms must be understood and correctly used at all times. These are:

- braze welding
- brazing
- bronze welding
- bronze surfacing.

Braze welding

The joining of metals using a technique similar to fusion welding (fillet weld external to parts to be joined or butt weld that extends to cover the surface). The parent metal is not melted and the bronze filler material bonds to the grain structure from the surface only, but without melting the parent metal (Fig 4.11).

Brazing

A process of joining metals in which, during or after heating the parent material, molten filler metal is drawn by capillary attraction into the space between closely adjacent surfaces of the parts to be joined. In general, the melting point of the filler metal is above 500 °C, but always below the melting temperature of the parent metal (Fig 4.12).
Bronze welding
A form of braze welding in which copper-rich filler metal is used.

Bronze surfacing
The deposition of bronze filler metal over an area of a metal surface, to impart certain wear resistant properties or build-up of worn parts.

Summary

<table>
<thead>
<tr>
<th>Bronze welding – Braze welding</th>
<th>Brazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature above 500 °C</td>
<td>below parent metal melt point</td>
</tr>
<tr>
<td>filler material type</td>
<td>copper/zinc alloy</td>
</tr>
<tr>
<td>joint design required</td>
<td>weld build up</td>
</tr>
<tr>
<td>bonding method (filler to metal)</td>
<td>intergranular</td>
</tr>
<tr>
<td>flux type (borax base)</td>
<td>bronze GP</td>
</tr>
<tr>
<td>flame type required</td>
<td>neutral – slightly oxidising</td>
</tr>
</tbody>
</table>

Table 4.4 – Similarities/differences between braze welding and brazing

Intergranular penetration
The molten filler metal permeates into the parent metal, around the grains, and ‘hooks’ itself in the parent metal. For this reason the parent metal must be hot (but not molten) to expand the gaps in the grain. A flux is used to clean out the gaps and help the filler metal to flow between the grains.
Capillary attraction
This is the final term requiring definition and describes where molten filler metal flows between closely fitted surfaces of a joint. This will even occur against the pull of gravity.

Braze Welding

Uses of braze welding (with bronze filler)
Bronze welding may be employed on cast irons, mild and alloy steels, and galvanised iron. It has a number of advantages over fusion welding for these materials. It also has limitations.

Advantages
- it is much faster than fusion welding
- lower heat input will not destroy the properties of the parent metal
- resultant weld is ductile.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>galvanised</td>
<td>steel coated with zinc for corrosion resistance</td>
</tr>
<tr>
<td>ductile</td>
<td>metal which is not brittle and can be easily formed or bent</td>
</tr>
</tbody>
</table>
Limitations

Bronze welding is not to be used in the following instances:

- on joints under stress; tensile strength of the joint is lower than that of the parent metal
- in conditions where the operating temperature is above 260 °C – bronze loses strength rapidly at elevated temperatures
- when the joint comes in contact with ammonia gas
- when a colour match with the parent metal is required.

Braze welding techniques

Mild steel and galvanised iron

Galvanised iron consists of mild steel, coated with zinc. Braze welding is especially recommended for joining galvanised plate or pipe, as the low heat input (compared with fusion welding) does not appreciably affect the zinc coating. The braze welded joint is also resistant to corrosion, and it alloys with the zinc coating to form a continuous protective layer. (Bronze consists of copper and zinc).

Some temperatures for comparison are:

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>zinc</td>
<td>melts at 420 °C (approximately)</td>
</tr>
<tr>
<td></td>
<td>vaporises at 926 °C</td>
</tr>
<tr>
<td>bronze</td>
<td>melts at 960 °C (approximately)</td>
</tr>
<tr>
<td>mild steel</td>
<td>melts at 1460 °C (approximately)</td>
</tr>
</tbody>
</table>

Precautions

As can be seen from the previous table, extra care must be taken to prevent the zinc from vaporising (becoming a gas). Zinc forms an oxide, from atmospheric oxygen, which is poisonous. On mild steel, only the zinc in the bronze filler can vaporise; with galvanised iron, the zinc coating can also vaporise. By using the correct flame (slightly oxidising), this problem can be minimised, but for all braze welding, the operator must avoid breathing the fumes given off.

This can be achieved by:

- using a fume extractor (exhaust fan)
- wearing a personal respirator
- working in the open air or near a draught (open the doors and windows in the workshop).

Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>vaporise</td>
<td>to change into the gas form from a liquid or a solid</td>
</tr>
<tr>
<td>viscous</td>
<td>a material that is thick – resistant to flow</td>
</tr>
</tbody>
</table>
**Preparation of materials**

The surface of parts to be joined must be absolutely clean, mechanical cleaning and a corrosive flux being required for most applications.

The base metal must be ‘tinned’ before depositing the bulk of the filler material.

**Mild steel**

**Fillet welds**: joint edges should be straight and close fitting (because of the viscous and fast freezing nature of molten bronze, a certain degree of poor fit-up may be tolerated).

**Butt welds**: preparation of butt joints for braze welding is similar to that of fusion welding of the same thickness except that a 90° vee is generally employed.

Parts should be held firmly in alignment, for example with tack welds or clamps and jigs.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>tack welds</td>
<td>short welds placed at intervals along a break or the joining edges of two pieces of metal, keeping the metal in alignment while the bead is run</td>
</tr>
</tbody>
</table>

**Galvanised iron**

It is not necessary to grind off the zinc coating, but a light rub over the joint surfaces with emery cloth will remove any grease or oxides prior to joining.

**Filler material**

A range of filler material is available for various applications. Examples are given from the BOC Gases range.

<table>
<thead>
<tr>
<th>tobin bronze</th>
<th>a low-cost copper zinc alloy for fusion weld of brass and bronze</th>
</tr>
</thead>
<tbody>
<tr>
<td>manganese bronze 411 blue tip</td>
<td>a free-flowing manganese bronze for producing high bond strength on steel and cast iron</td>
</tr>
<tr>
<td>nickel bronze 904 imperial brown</td>
<td>produces maximum bond strength in braze welds on steel and cast iron has excellent hardness and wear-resistant properties.</td>
</tr>
</tbody>
</table>

Some of those examples are also available as flux coated rods.

Filler material is manufactured in a range of rod diameters to suit various applications.
Fluxes
In general, a flux should be used to remove any contamination from the surface (oxides), and to help to protect the surface from the effects of the atmosphere. Most fluxes are slightly acidic and will etch the surface of the material when heated. Fluxes may be based on resins, borax, sodium, or fluorides. There is a particular flux blend to suit each application; examples are given from the BOC Gases range.

<table>
<thead>
<tr>
<th>Flux Type</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>general purpose flux</td>
<td>braze welding of mild steel and galvanised iron</td>
</tr>
<tr>
<td>bronze flux</td>
<td>braze welding of cast iron</td>
</tr>
<tr>
<td>bronze tinning flux</td>
<td>specially designed for difficult tinning situations – use bronze flux to complete.</td>
</tr>
</tbody>
</table>

Tip size
Generally a tip one size smaller than would be appropriate for a similar joint (if fusion welding were employed) is used for braze welding.

Flame setting
The flame adjustment for braze (bronze) welding is slightly oxidising. This creates an oxide film over the puddle and prevents the zinc from dissipating (fuming).

Fig 4.14 – Some typical braze welded joints
Method
With the joint edges properly prepared and the equipment set up correctly, the surface is brought to the correct temperature – this will generally be a dull red colour.

If the temperature is incorrect, this will cause:

- the filler material to ‘ball-up’ on the surface and not flow out or ‘tin’ if the temperature is too cold
- the filler material to boil – characterised by a spitting and popping sound. Zinc fumes will be given off in large amount and black, oxidised areas may appear in the weld if the temperature is too hot.

The forehand technique is generally used as the backhand method usually results in overheating. The inner cone should be maintained at approximately 6 mm from the surface of the metal, and the tip and the filler rod should be held at a 45° angle to the surface. If an uncoated rod is being used, this must be heated and dipped into the flux. Some flux will then adhere to the rod and be introduced to the joint. This procedure is repeated and the fluxed rod is consumed.

As an alternative, flux powder may be mixed with water to form a paste and painted onto the surface of the joint prior to welding.

Flux removal
On completion of the weld, the weld area will be coated with flux residue, a hard glassy substance. This must be removed by mechanical methods or acid pickling to prevent any corrosion when the part is put into service.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>acid pickling</td>
<td>a chemical process (e.g., nitric acid) to remove scale or oxide from metal to obtain a clean surface</td>
</tr>
</tbody>
</table>

**Silver brazing**

**Definition**
A process of joining metals in which, during or after heating, molten filler metal is drawn by capillary action into the space between closely adjacent surfaces of the parts to be joined. In general, the melting point of the filler metal is above 500 °C, but always below the melting point of the parent metal.

The process involves using an alloy filler rod consisting largely of silver and copper with other elements. Materials which can be silver brazed include: nickel, nickel-silver, copper, brass, bronze, stainless steel, carbon steel, alloy steel, tungsten carbide tool tips.

**The process**
Silver brazing is extremely easy if a few basic rules are strictly observed. Successful brazing depends upon:

- joint design
- choice of brazing alloy
- preparation of surfaces
- technique.

**Joint design**
Joints must allow for sufficient surface areas to be in close contact—large gaps do not allow capillary action to take place. Generally, a gap of 0.05 to 0.03 mm is required.

Some of the more common joints are shown in Fig 4.16.
Choice of brazing alloy

There is a large range of alloys to choose from, using between 2% to 72% silver. Silver is expensive, so the correct alloy must be chosen for each job, and only the amount required for a sound joint used. Don’t build up on the joint with alloy as it is not only wasteful, but it may harm the joint as well.

Silver brazing alloys (SBA) are classified into groups according to their uses, and the silver content indicated.

For example, SBA 102 indicates it is a Group 1 alloy with 2% silver. SBA 245 indicates a Group 2 alloy with 45% silver. As full description of all groups follows, using BOC Gases numbers (these being the most commonly used alloys).
Group 1
- these are used primarily for the brazing of copper to copper without flux
- they should be used with flux on copper alloys.
- they should not be used on ferrous or nickel-base alloys as this forms nickel-phosphide, causing severe embrittlement of the weld
- these alloys contain silver-copper-phosphorous.

Group 2
- this group is the most commonly used alloy in industry
- it is used for the low-temperature brazing of all ferrous and non-ferrous metals
- this group should not be used on food handling equipment, particularly where the equipment is at high temperature
- the alloys in this group contain silver-copper-cadmium-zinc.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ferrous</td>
<td>is the term given to metal that contains or partially contains iron</td>
</tr>
<tr>
<td>non-ferrous</td>
<td>is the term given to metal that does not contain iron</td>
</tr>
</tbody>
</table>

Group 3
- these are used for intermediate-temperature brazing of all metals and are particularly useful in the silversmith’s trade
- they should be used in the food handling industry
- these alloys are cadmium-free; they contain silver-copper-zinc.

Group 4
- these are used on vacuum units and where high electrical conductivity is necessary
- they are best used on copper, but may be used on stainless steel, copper alloys and nickel alloys
- these alloys contain very high proportions of silver (for electrical conductivity), the rest being copper.

Table 4.5 Silver brazing alloys comparison chart (see page 74) shows details of the different alloys, and may be referred to in the future. Welders need to select these brazing alloys carefully.
Special hazards associated with braze welding/brazing

It can be seen that metal fumes may be produced by the vaporisation of metals at high temperatures. Braze welding or brazing on most base metals will not cause parent metal vaporisation and fuming at the low temperatures involved. Coatings used on materials such as zinc and aluminium (used on galvanised iron or coated sheetmetal) may fume if overheated. The copper, zinc, or cadmium used in the filler material will certainly smoke and cause dangerous fumes if overheated. Solvents and degreasers should also not be used on materials to be heated.

The fluxes used can also generate dangerous or toxic fumes when heated.

Avoid breathing any fumes at all, use correct fume extraction methods or proper ventilation procedures.

Most of the fluxes that are used in oxy-acetylene welding operations are based on borax, fluorides, or other caustic materials. Avoid contamination of the hands by using gloves or applying flux with disposable items. Wash hands thoroughly before eating after using any flux.

Activity

- Identify safe working practices and protective equipment in the workshop.
- Set up an acetylene and oxygen plant starting with upright and secure cylinders:
  - purge the cylinders
  - fit correct regulators, flashback arrestors, fittings, hoses, blowpipe and welding tip.
- Adjust correct working pressures.
- Test for leaks.

Ask your lecturer to assist you

Light up the welding tip:

- ensure the blowpipe acetylene valve is slightly cracked open to produce a small flow of acetylene gas
- adjust the flow of gas until the acetylene and air flame produces a minimum of soot
- then adjust the oxygen valve to produce a neutral flame at the welding tip
- adjust the flame to produce an oxidising flame and then a carburising flame
- shut down the flame by closing the blowpipe acetylene valve first and then the oxygen valve
- with your lecturer’s assistance, produce a test weld on a practice piece of material. Use a neutral flame to weld the material as directed.
<table>
<thead>
<tr>
<th>Grade</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AS/NZS 1167.1</td>
<td>AS/NZS 1167.1</td>
<td>AS/NZS 1167.1</td>
<td>AS/NZS 1167.1</td>
</tr>
<tr>
<td></td>
<td>Alloy designation ‘B’</td>
<td>Alloy designation ‘A’</td>
<td>Alloy designation ‘A’</td>
<td>Alloy designation ‘A’</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alloys used</th>
<th>copper/silver/phosphorus</th>
<th>copper/silver/cadmium</th>
<th>copper/silver</th>
<th>copper/high silver</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Temperature</th>
<th>700 °C</th>
<th>Av 650 °C</th>
<th>Av 750 °C</th>
<th>780 °C</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Applications</th>
<th>for flux free joints on copper and for joining copper alloys such as brass and bronze</th>
<th>for low-cost general purpose jointing of steel, stainless steel, copper, copper alloys and dissimilar metals by low temperature</th>
<th>for general purpose and in joints where cadmium would be hazardous (weld temperature is slightly higher than Group 2)</th>
<th>for joints requiring better colour match such as silver or stainless and/or high conductivity on copper</th>
</tr>
</thead>
</table>

| Not recommended       | must not be used on ferrous materials such as steel or stainless steel because a brittle joint may be formed | not to be used for food or water utensils because of cadmium | not suitable for some nickel alloys | more costly |

| Flux required         | none required on clean copper (phosphorus acts as de-oxidiser and flux agent), flux may be beneficial on alloys | requires a general purpose flux on most materials | requires a general purpose flux on most materials | requires an aggressive flux on most materials |

Table 4.5 – Silver brazing alloys comparison chart
Chapter 5 – Oxy-flame cutting

Introduction

Oxy-flame cutting is an efficient method of cutting steel products. It can only be successfully employed on materials that have a lower ignition temperature than their melting point, eg carbon steels or low alloy steels.

Materials such as aluminium and stainless steel cannot be successfully cut because their oxide layer melts at a higher temperature than their melting point.

In this chapter you will look at the following.

- Principles of the process
- Equipment required
  - adjusting pressure
  - pressure
- Cutting blowpipes
  - flame adjustment
  - method of oxy-flame cutting
  - quality of the cut
  - common faults in oxy-flame cutting
- Oxy-flame cutting techniques
  - straight line cutting – by hand
  - straight line cutting – using aides
  - angle iron or heavy steel section
  - bevel cutting
  - piercing holes
  - circle cutting
  - cutting large square sections
  - rolled sections
  - pipe cutting
- Mechanical thermal – cutting equipment
  - straight line cutting machine
  - profile cutting machines
  - cross carriage profile cutting machine
- Distortion resulting from oxy-flame cutting
  - balanced cutting
  - skip cutting
  - sequence cutting
  - methods of locking scrap to prevent movement during cutting.

At the end of the chapter you will complete an activity.
Principles of the process

The process of oxy-flame cutting makes use of the burning reaction between heated iron and oxygen.

When iron is heated to above 815 °C (called the ignition temperature) it readily combines with oxygen. The resulting reaction produces iron oxide. This reaction (combustion) also gives off extra heat which keeps the process of oxidation going.

The important point to note is that the reaction occurs at a lower temperature that the melting point of steel (approximately 1500 °C).

The molten iron oxide together with some free iron, which runs off as molten slag, is removed by the kinetic energy of an introduced jet of oxygen, thus exposing more preheated iron and iron oxide.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>oxidation</td>
<td>a chemical reaction producing oxides (oxygen mixed with other chemical elements) on the metals surface</td>
</tr>
<tr>
<td>molten slag</td>
<td>impurities reduced to liquid form (melted) by heating</td>
</tr>
<tr>
<td>kerf</td>
<td>the gap left in a material as a result of the oxy cutting stream</td>
</tr>
</tbody>
</table>

The oxide remains molten as its burning point is lower than that of the steel – this is important for if the oxide has a higher melting point than the metal then normal oxy-flame cutting would not be possible.
Oxidation

Oxy-flame cutting relies on the process of oxidation.

Most elements have the property of combining or uniting with one another to form new substances which have chemical and physical properties entirely different from those of the two substances which entered into the combination. This new substance is called a compound and the process is known as a chemical combination or chemical reaction, eg iron will combine with sulphur to form iron sulphide.

Oxidation is a chemical reaction in which oxygen combines with another element to form an oxide, eg iron + oxygen = iron oxide. When steel (an alloy of iron) is exposed to the air (nitrogen and oxygen) at room temperature and moisture is present a film of oxides (rust) will form on the surface. Heat accelerates this process and when steel is heated to about 815 °C (or above) and is not protected from the atmosphere, rapid oxidation of the surface of the metal occurs, ie oxygen combines with the iron, an element in the steel, to form oxides.

In welding this oxidation results in the weld becoming porous, hard and brittle. Therefore during welding, care has to be taken to prevent oxygen coming into contact with the metal.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>porous</td>
<td>full of pores or holes able to absorb fluids</td>
</tr>
</tbody>
</table>
Equipment required

Oxy-flame cutting equipment in its simplest form requires a gas supply consisting of cylinders of oxygen and acetylene, regulators for both gases, flashback arrestors, correct couplings and hoses, a blowpipe, a cutting blowpipe attachment and cutting nozzles.

Adjusting pressures

When a cutting attachment is fitted to a multi-purpose blowpipe, the blowpipe oxygen valve should be kept fully open at all times. Oxygen flow is then controlled via the preheat oxygen valve, and the cutting lever of the cutting attachment.

Acetylene should be set to a 100 kPa maximum with the acetylene blowpipe valve open approximately one quarter of a turn.

Oxygen should be set to the appropriate pressure (Table 5.1) with the cutting lever fully depressed.

Use your pressure chart as a guide. Incorrect pressures are wasteful, they prevent you doing your best work, they cause flashbacks, and can be very dangerous.

Pressure

The following table shows pressures for hand cutting of various thicknesses.

<table>
<thead>
<tr>
<th>Thickness of plate</th>
<th>Size of nozzle</th>
<th>Oxygen pressure</th>
<th>Acetylene pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>6</td>
<td>100 kPa</td>
<td>100 kPa</td>
</tr>
<tr>
<td>6 mm</td>
<td>8</td>
<td>180 kPa</td>
<td>100 kPa</td>
</tr>
<tr>
<td>12 mm</td>
<td>12</td>
<td>200 kPa</td>
<td>100 kPa</td>
</tr>
<tr>
<td>20 mm</td>
<td>12</td>
<td>235 kPa</td>
<td>100 kPa</td>
</tr>
<tr>
<td>25 mm</td>
<td>15</td>
<td>180 kPa</td>
<td>100 kPa</td>
</tr>
<tr>
<td>40 mm</td>
<td>15</td>
<td>300 kPa</td>
<td>100 kPa</td>
</tr>
<tr>
<td>50 mm</td>
<td>15</td>
<td>350 kPa</td>
<td>100 kPa</td>
</tr>
</tbody>
</table>

Table 5.1 – Pressures for cutting
Most small workshops use a combination welding and cutting blowpipe (Fig 5.2). To change from one operation to the other it is only necessary to unscrew the welding attachment from the barrel of the blowpipe and replace it with the cutting attachment.

Where thicknesses greater than 50 mm are to be cut it is advisable to use a heavy-duty cutting blowpipe which is a complete unit (Fig 5.3).
Chapter 5 – Oxy-flame cutting

Cutting blowpipes

Oxy-flame adjustment

With all oxy-flame cutting, a preheating flame is necessary. This usually surrounds the orifice through which the oxygen jet passes and its purpose is to bring the surface of the metal to ignition temperature and to maintain it at that temperature. The flame is adjusted to neutral with the oxygen cutting stream ON.

Correct adjustment (neutral flame).

This should be checked with the cutting oxygen flowing at recommended pressure.

The cutting oxygen stream should be clearly defined as shown.

Method of oxy-flame cutting

The oxy-flame cutting method may be summarised as follows.

1. The heating of the metal to its ignition temperature above 815 °C (dull red).
2. The introduction of a pure oxygen stream causing combustion (oxidation of the iron) in the path of the oxygen jet.
3. The removal of the molten slag consisting of a mixture of oxides and molten steel by the force of the oxygen stream (kinetic energy).
4. The continued and even movement of the blowpipe along the line of the cut. With the movement of the cutting blowpipe and with it the cutting stream, a narrow cut or kerf is produced (Fig 5.1).
The burning or oxidation process produces heat. This is what preheats the next layer of iron prior to oxidation.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>kinetic energy</td>
<td>energy of an object due to its motion</td>
</tr>
<tr>
<td>kerf</td>
<td>is a slot or trough formed in material by a cut</td>
</tr>
</tbody>
</table>

**Quality of the cut**

A satisfactory cut may be defined as one fulfilling the following requirements:

- accurate shape and size of finished object
- reasonably smooth surface of cut face (drag lines not too pronounced)
- sharp upper and lower edges of cut
- slag adhesion light or non-existent.

To produce high quality cuts the following factors should be observed.

1. Make sure that the cutting equipment is in good condition.
2. Select a nozzle size appropriate to the thickness of metal to be cut.
3. Ensure that the nozzle face and the cutting and heating orifices are clean.

A nozzle which has been correctly cleaned and in good condition will exhibit a clean, long jet of cutting oxygen. This appears as a long parallel sided pipe or zone through the centre of the heating flame.

A short, indefinite or bushy jet indicates a dirty or damaged nozzle. When inspecting the cutting jet it should be viewed from two positions at right angles to each other.

4. Adjust gas pressures to suit nozzle size and plate thickness.
5. Correct heating flame adjustment (ie neutral flame of suitable size).
6. Clean surface of work along the line of the cut (ie free of rust, scale).
7. The nozzle must be a correct distance from plate, ie tip of preheating cone about 2 mm above the work.
8. Cutting blowpipe held at correct angle.
9. Suitable and uniform speed of cutting.
10. Suitably trained operator.
Other factors which may affect the quality of the cut are:
- quality of the material, eg presence of laminations, slag pockets and heavy surface scaling
- purity of the oxygen
- angle of nozzle to plate surface, eg bevel cutting more difficult than a 90° cut
- training and experience of operator.

By observing all the above factors oxy-flame cutting will be of very high standard. The positive results of good quality oxy-flame cutting are:
- less time and effort spent in cleaning up the job by grinding and filing
- greater accuracy means final finishing or machining is kept to a minimum
- less material wastage
- overall quality and finish is attained which promotes a general feeling of pride in those associated with the work or product.

Common faults in oxy-flame cutting
When all the conditions are correct, a good quality cut should have the following features:
- a sharp top edge
- a smooth surface, with draglines barely visible
- very light scale or oxide film on the cut face which is easily removed
- a square face
- a sharp bottom edge.
A good operator will endeavour to maintain a high standard of workmanship when it comes to oxy-flame cutting.

Before starting, the operator should check the equipment and settings and prove the procedure by a trial cut, preferably on scrap steel. The operator should make periodic checks to see that the quality is maintained and if not, determine reasons for the low quality.

The necessary adjustments should then be made immediately before carrying on with the work. Table 5.2 outlines the common faults and possible causes when oxy-flame cutting.

Example: Rounded top edge – condition 3 in Table 5.2.

Possible causes:
- too much preheat
- cutting oxygen pressure too low
- cutting speed too slow
- preheat flame too high above work
- preheat flame too close to work
- dirty nozzle
- dirty or rusty plate.
## Table 5.2 – Common faults in cutting and possible causes

<table>
<thead>
<tr>
<th>Common faults in cutting</th>
<th>Condition of cut</th>
<th>Diagram 1 to 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>line of cut wavy or irregular</td>
<td>1.</td>
</tr>
<tr>
<td></td>
<td>gouging on the cut face</td>
<td>2.</td>
</tr>
<tr>
<td></td>
<td>top edge melted or rounded</td>
<td>3.</td>
</tr>
<tr>
<td></td>
<td>undercut just below</td>
<td>4.</td>
</tr>
<tr>
<td></td>
<td>bottom edge rounded, rough or irregular</td>
<td>5.</td>
</tr>
<tr>
<td></td>
<td>cut tapered</td>
<td>6.</td>
</tr>
<tr>
<td></td>
<td>pronounced lag or drag excessive or tenacious slag</td>
<td>7.</td>
</tr>
</tbody>
</table>

- **Possible cause**
- **not enough preheat**: Master 1, 2, 3
- **too much preheat**: Master 2
- **cutting oxygen pressure too low**: Master 3
- **cutting oxygen pressure too high**: Master 4
- **cutting speed too slow**: Master 5
- **cutting speed too fast**: Master 6
- **bent magnet spindle or unsteady blowpipe**: Master 7
- **preheat flame too high above work**: Master 8
- **preheat flame too close to work**: Master 9
- **dirty nozzle**: Master 10
- **dirty or rusty plate**: Master 11
- **nozzle too large**: Master 12
- **nozzle too small**: Master 13
Oxy-flame-cutting techniques

The following segments outline the recommended techniques (methods to be used when oxy-fuel cutting).

Straight line cutting – by hand

1. It is usual to start the cut from the edge of the plate (other starting positions will be covered later).

2. Heat the metal until it reaches red heat ignition temperature. The tip of the preheating cone should be held 2–3 mm from the surface of the plate for this operation.

3. Depress the cutting oxygen lever slowly and let the oxygen to come into contact with the heated steel. This allows the resultant reaction oxide stream to track down the face of the plate edge.

4. The cutting action is continued by a smooth movement of the cutting blowpipe. The cutting oxygen stream produces a fine spray of sparks under the cut, together with droplets of molten metal. The correct cutting speed is accompanied by a spluttering sound.

Straight line oxy-flame cutting by hand demands a high degree of skill to maintain a smooth travel and to keep the cut to a given line.

To assist the operator when cutting straight lines, a set of roller guides can be attached to the cutting blowpipe.

Roller guides can also be adopted for cutting bevels and for assisting with the cutting of circular shapes.

Straight line cutting – using aides

Roller guides

1. Fit the roller guides to the cutting blowpipe making sure the cutting nozzle fits snugly into the recess provided in the roller guide body.

2. Partially tighten clamp nut. Ensure that the roller guides are at 90° to the cutting blowpipe (Fig 5.6). Fully tighten clamp nut.

3. Check the nozzle distance off the plate. Adjust by raising or lowering wheels (Fig 5.7).

4. Finally, by having both wheels placed on the metal surface, make sure the cutting nozzle is at 90° to the horizontal. This ensures that a square cut will be made.
Chapter 5 – Oxy-flame cutting

Fig 5.6 – Roller guides – top view

Fig 5.7 – Roller guides – elevation
Angle irons or heavy steel sections

1. Fig 5.8 shows how an angle iron (ASA) can be used in conjunction with the cutting blowpipe.

2. Any steel section that will not distort easily due to local heat can be used. The section is set away and parallel to the line of cut.

Bevel cutting

- Machine bevelling produces a consistently high quality finish. Bevels produced by hand cutting can also be of a similar standard where machines cannot be used conveniently or economically.
- Aids such as roller guides (Figs 5.6, 5.7) or a piece of angle iron (Fig 5.8) can be used to help maintain a straight and even bevel.
- The length of the bevel face (T), not the plate thickness determines the nozzle size, gas pressures and cutting speed (Fig 5.9).
- Where angular bevelling operations occur, an increase in the preheating flame and a decrease in cutting speed, using the same nozzle as fitted for square cutting, can be employed.
- Preheating the plate edges is recommended before cutting is started.
- The cutting angle can be proved by inspecting a short trial cut so that minor adjustments can be made if necessary.
Chapter 5 – Oxy-flame cutting

Select angle iron to suit required bevel angle

Nozzle angle adjusted to bevel angle using roller guides

Cutting nozzle size selected for bevel length ‘T’

Angle iron guide

Fig 5.9 – Bevel cutting

Piercing holes

There are many occasions where a cut is started away from an edge. Piercing holes are made to start a cut. This special technique requires practice to prevent overheating and damage to the cutting nozzle and prevent molten slag from blowing back and burning the operator.

The method consists of four distinct movements, as follow.

1. The blowpipe cutting nozzle is held vertically over the desired position with the tips of the preheating cones approximately 2–3 mm away form the surface of the plate.

Fig 5.10 (a)
2. When the ignition temperature is reached, the cutting nozzle is raised so the tips of the preheating cones are approximately 8–10 mm from the surface of the plate before any oxygen is applied.

3. The blowpipe is then angled slightly and moved to give a small slicing action as the cutting oxygen is applied slowly to prevent a blowing back of the pressure which may cause a back fire or damage to the nozzle from molten slag.

4. When the hole is completely through, the cutting oxygen is applied quickly and the blowpipe is brought back to its vertical position and original distance from the surface of the plate.
5. Further circular movements will give the desired hole and the cut is continued from that point.

Fig 5.10 (e)

Circle cutting
Manual oxy-flame cutting of a round hole or disc can be made easier using a radius bar or radius rod.

1. **Radius rod** (Fig 5.11) is fitted into the roller guide stock. It can be made in a variety of sizes to suit mainly small radii.

   The wheel shown fitted is optional as it may hinder the operator in small work but can be a steadying influence with slightly larger radii.

   ![Radius rod fitted to roller guide](image.png)

   **Fig 5.11 – Radius rod fitted to roller guide**

2. **Radius plate** (Fig 5.12) has a larger range than the radius rod and can be used for both small and medium sized radii. The design of the fixing device must be made to suit the particular model of cutting blowpipe used.
3. **Radius bar** (Fig 5.13) is used in conjunction with roller guides and is suitable for medium to large circle cutting.
Cutting large square sections

A slot is cut out at the bottom edge of the solid material (Fig 5.14).

The following advantages emerge:

- the inner cross-sectional area is reduced
- the material is preheated particularly the cold underside
- this allows the cut to get well underway before the maximum thickness is reached
- with the shorter starting face the oxide stream is less likely to wander when starting the cut.

![Fig 5.14 – Cut at bottom edge of solid material](image)

Rolled sections

The general policy for the cutting of rolled steel sections such as UB, UC, angle iron and channel, is to commence the cut at the toe of the section and travel towards the thicker section with the most difficult cut being made first and the top section being cut last.

Positioning of heavy, rolled steel sections for oxy-flame cutting is important. They should be placed in such a manner that cutting can be accomplished easily and safely so that the off-cut can fall clear without the need for subsequent handling. The methods shown in Fig 5.15 depend on the rolled steel sections being in a fixed position where they cannot be manipulated during cutting.
Pipe cutting

1. The tubular section should be supported on rollers or in such a way that it can be easily turned (see Fig 5.16).

2. Half-way round one side, pierce a hole and carry the cut along the required line to the top of the pipe. The operator should maintain the nozzle at 90° to the pipe face by using a rolling action of the wrists.

3. Give the pipe a quarter turn and repeat the operation. Continue this procedure until the pipe is severed.

Fig 5.15 – Cutting rolled steel sections

Fig 5.16 – Tubular section supported on rollers
Chapter 5 – Oxy-flame cutting

Mechanical thermal – cutting equipment

Mechanical oxy-flame cutting methods utilising various types of machines are widely used in the metal fabrication industry. These machines usually produce better cut quality and productivity over manual cutting methods.

Some of the machines used are:

- straight line cutting machine
- profile cutting machines.

Straight line cutting machine

This machine is usually driven by a variable speed electric motor and follows a portable straight track. By using a straight line cutting machine running at a set speed, and at a set flame height, the operator will eliminate some of the factors that influence cut quality.

This machine is most suitable for single straight cutting but cutting arms can be fitted with multiple cutting heads and this makes the machine capable of strip cutting. The cutting head can also be tilted for bevel cuts for plate edge preparation.

Modern machines can also be fitted with special attachments for cutting of circles.
Fig 5.17 – Straight line cutting machine
Profile cutting machines

Profile cutting machines have some of the advantages of straight line cutters in the fact that direction, speed, and height are all controlled. The main advantage of a profile cutting machine is its ability to reproduce items or cutting complex shapes repeatedly and with great accuracy.

Profile cutting machines can be divided into two groups:

- the radial arm type machine
- the cross carriage type machine.

The radial arm profile cutting machine

The radial arm type machine will not be discussed fully here as it is considered to be obsolete. The radial arm profile cutting machine has limited application and is only able to work over a small area and can only produce one item at a time. There may however be some workshops that still use this type of profile cutting machine because of its ability to produce multiple copies of an item from a template.

Cross carriage profile cutting machine

The cross carriage machines are also known as cross traverse machines and are widely used in the metal fabrication industry. The machine operates in a longitudinal plane along a set of machined beams and transversely across a large table area. Straight cuts can easily be accommodated on the cross carriage type by locking one action and allowing the machine to run in only one axis or direction. Long straight line or plate stripping cutting operations involving large pieces of material are also easily performed. Most cutting arms can also be equipped to carry multiple heads.

The cutting arms can also be fitted with any thermal cutting head ranging from oxy-propane, oxy-acetylene, plasma, and new technology laser and abrasive cutting heads.

Modern cross carriage type machines are designed to trace shapes from drawings, which simplifies the production of templates. Photo-electric cells in the tracing head will precisely follow ink or pencil lines drawn on paper. The pattern is drawn full size and the cut corners produced can be relatively sharp. A small radius of 3 mm is often employed to minimise the risk of run-off on corners. Some machines can follow a white pattern on a black background, which means all the operator needs to do is trace around a shape on white paper and then use scissors to produce a template.

Most modern cross carriage type profile cutting machines incorporate adjustment of the scanner to suit lines of varying line thickness and intensity, and they also allow adjustment of the kerf allowance.

On a more modern cross carriage profile cutting machine the table area is sometimes assigned to compass points or coordinate numbers and this makes guiding the machine cutting heads easier. For example, an instruction to go north from a set point to a stop point will result in a straight line along the table. An instruction to go east from that stop point will result in a line at right angle travelling across the table area.

Cross carriage machines can be computer controlled and linked to computer aided design (CAD) systems for very complex cutting operations. Information is processed in a drawing office and recorded in the computer, then downloaded to the profile cutter to produce exact duplicates of component pieces or complex cutting operations.
Reproduced with permission of Lincoln Electric Company

Fig 5.18 (a)

Reproduced with permission of Lincoln Electric Company

Fig 5.18.1(b)
Fig 5.18 – Cross carriage profile cutting machines (a), (b), and (c)
Distortion resulting from oxy-flame cutting

During oxy-flame cutting operations the steel being cut is heated locally to a high temperature, and subsequently cooled rapidly, thus the residual stresses resulting from expansion and contraction forces may cause distortion.

Fig 5.19(a) illustrates an example in which a bar of mild steel is oxy-flame cut along one edge. The narrow section that is raised to a high temperature is prevented from expanding freely by the rigidity of the cool section of metal. This results in the upsetting of the heated section, and when cooling occurs the strip develops a curved shape as in Fig 5.19(b).

![Diagram](a)

Steel bar

Heated edge

![Diagram](b)

Steel bar

Cold edge

Fig 5.19 – Distortion resulting from oxy-flame cutting (a) and (b)

Similar contraction stresses are encountered in all oxy-flame cutting operations, but are more serious on long narrow sections. Solid compact sections are generally not affected to the same degree, although in some instances they may be more slightly out of position by the force of contractional stresses during the progress of the cut, so affecting accuracy.

Several methods are used to minimise distortion:

- balanced cutting
- skip cutting
- sequence cutting
- methods of locking scrap to prevent movement during cutting.
Balanced cutting

Balanced cutting is applied to long, narrow sections cut in straight lines. For example, if the strip plate in Fig 5.20 is cut along both edges at the same time, distortion will be reduced.

The forces set up by contraction along one edge are balanced by an equal and opposing set of forces along the other edge. This principle is often applied in straight line cutting practice using a machine. A common example being the cutting of two strips of plate by executing three cuts at the same time (Fig 5.21).

Skip cutting

When cutting narrow pieces of steel plate or bar, or splitting channel sections, skip cutting may be used to prevent distortion. With this method the cut is not continuous, but small uncut sections each about 10 mm to 20 mm long are left at intervals. These uncut sections hold material in alignment until it cools, then they are cut through to separate the parts (Fig 5.21).
**Sequence cutting**

The term sequence cutting applies to any method of dividing the complete cut into several operations. Cutting is therefore divided into different operations as indicated in Fig 5.22 which relates to the oxy-flame cutting of a frame plate. The main outline is cut in four operations.

![Diagram of sequence cutting]

**Methods of locking scrap to prevent movement during cutting**

**Locking of scrap**

Scrap may be locked as shown in Fig 5.23 to prevent movement of scrap and subsequent lack of accuracy if the scrap forces movement in the work piece. The work piece or scrap may move and occupy the kerf space and then possibly cause movement of the work piece as cutting proceeds.

![Diagram of methods of locking scrap]

Fig 5.23 – Methods of locking scrap (a) and (b)
The use of wedges

Small tapered wedges may be used to prevent movement of the part being cut. Contraction stresses tend to draw the cut edges together causing production of a part that is not true to the required shape. This action is counteracted by insertion of wedges in the kerf as the cutting progresses.

Use of wedges to prevent movement of the shape

Creating a lock in the lead-in cut to prevent movement of the discard

Fig 5.24 – The use of wedges
Activity

- Identify safe working practices and protective equipment in the workshop.
- Set up an acetylene and oxygen plant starting with upright and secure cylinders:
  - purge the cylinders
  - fit correct regulators, flashback arrestors, fittings, hoses, blowpipe and cutting nozzle.
- Adjust correct working pressures with cutting lever depressed.
- Test for leaks.

Ask your lecturer to assist you

Light up the cutting nozzle, then:

- ensure the blowpipe acetylene valve is slightly cracked open to produce a small flow of acetylene gas
- adjust the flow of gas until the acetylene and air flame produces a minimum of soot.

Then:

- adjust the oxygen valve to produce a neutral flame at the cutting nozzle with the cutting lever pressed
- with your lecturer’s assistance, produce a test cut on a practice piece of material.

Use a flame to heat the material then depress the cutting lever to cut the material as directed.
Chapter 6 – Oxy-flame gouging

Introduction

Oxy-flame gouging has similarities to the oxy-flame cutting process: the equipment required is the same, except for the nozzle.

Oxy-flame gouging relies on the chemical process of oxidation for its operation and it is suitable only for use on carbon and low alloy steels.

In this chapter you will look at the following.

- Oxy-flame gouging principles
- Equipment required
  - adjusting pressure
- Oxy-flame gouging techniques
  - progressive gouging
  - spot gouging
  - backstep gouging
- Oxy-flame gouging applications
  - preparation of plate edges for welding
  - removal of weld defects
  - back gouging welds
  - oxy-flame gouging of cracks and defects in steel castings.

At the end of the chapter you will complete an activity.
Oxy-flame gouging principles

The process of oxy-flame gouging makes use of the burning reaction between heated iron and oxygen. Heating iron to above 815 °C (called the ignition temperature) can cause it to readily combine with oxygen.

The oxy-flame gouging process uses a low velocity oxygen stream, as opposed to the high velocity oxygen stream used for oxy-flame cutting. This is achieved by increasing the diameter of the oxygen orifice at the outlet end of the gouging nozzle, as opposed to the cutting nozzle which reduces in size.

![Gouging nozzle design](image)

Fig 6.1 – Gouging nozzle design
(a) normal cutting nozzle - low pressure high velocity and
(b) gouging nozzle - high pressure low velocity
Equipment required

The equipment required for oxy-flame gouging is similar to oxy-flame cutting and consists of cylinders of oxygen and acetylene, regulators, flashback arrestors, correct couplings and hoses, a blowpipe, a cutting blowpipe attachment and gouging nozzles.

Adjusting pressures

When a cutting attachment is fitted to a multi-purpose blowpipe, the blowpipe oxygen valve should be kept fully open at all times. Oxygen flow is then controlled via the preheat oxygen valve, and the cutting lever of the cutting attachment.

To allow for the use of the higher gas flow rates a heavy-duty blowpipe may be required.

Acetylene should be set to 100 kPa maximum with the acetylene blowpipe valve open approximately one quarter of a turn.

Oxygen should be set to the appropriate pressure (Table 6.1) with the cutting lever fully depressed.

To obtain the volume of oxygen required for gouging, relatively high oxygen pressures (higher than those used for oxy-flame cutting) must be set at the regulator.

<table>
<thead>
<tr>
<th>Nozzle size</th>
<th>Regulator pressure</th>
<th>Speed</th>
<th>Groove dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>oxygen kPa</td>
<td>acetylene</td>
<td>mm/min</td>
</tr>
<tr>
<td>32</td>
<td>350–450</td>
<td>100</td>
<td>300/500</td>
</tr>
<tr>
<td>40</td>
<td>400–450</td>
<td>100</td>
<td>500/650</td>
</tr>
<tr>
<td>48</td>
<td>450–500</td>
<td>100</td>
<td>500/560</td>
</tr>
</tbody>
</table>

Table 6.1 – Approximate data for oxy-flame gouging
Oxy-flame gouging techniques

There are three basic techniques in gouging:

- progressive gouging
- spot gouging
- backstep gouging.

Progressive gouging

The flame for gouging is adjusted in the same way as for oxy-flame cutting. The preheat flame should be neutral with the oxygen lever fully depressed. When starting to gouge, the nozzle is held at an angle of 20° to 40° from the metal surface and above the line of gouge. As the metal reaches a bright red heat, the oxygen lever is slowly depressed and gouging begins. The nozzle angle is gradually lowered to about 7° and a smooth and constant travel speed is maintained. Cone points of the preheat flame should be 6 mm to 13 mm behind the reaction zone and the nozzle just clear of the groove bottom.
Spot gouging

Spot gouging uses a step back sequence with which it is easier to control the depth of the cut. This method uses the same technique for starting as progressive gouging. Once the gouge has been started and the depth of groove obtained, the operation is stopped, moved back along the line of cut and the starting procedure repeated. This action reduces the possibility of damage to the cutting nozzle.
Backstep gouging

For certain types of work, it is necessary to make a long deep gouge. This procedure combines both progressive and spot gouging techniques. The surface of the metal is preheated as for normal gouging, the cutting oxygen is turned on and the nozzle angle reduced. The angle is then gradually increased until the desired depth is obtained and the nozzle moved backward approx 25–30 mm while reducing the angle to the normal 7°.

At the end of this sequence the nozzle angle is again increased and the sequence repeated until the gouge has progressed along the required line. In effect a spooning action is employed (see diagram below).

![Diagram of Backstep gouging](image)
Oxy-flame gouging applications

Preparation of plate edges for welding

Oxy-flame gouging is one method of preparing U and J type weld joints. Individual plate edges can be gouged before assembly, or plates can be abutted when U joints are required and both edges gouged together, (Fig 6.6). Welds may be placed on the underside of a joint before gouging takes place to form a sound backing bead, provided the gouge is deep enough to remove any trace of slag or defect.

When gouging is carried out from both sides, a double U or double J can be produced, as is often required for thicker materials. Plate edges may be prepared by gouging in the vertical position, with the gouging blowpipe travelling downwards and nozzle angles corresponding to those used in the flat position.

Fig 6.6 – Preparation of plate edges
Removal of weld defects

Oxy-flame gouging is very effective for removing isolated defects in welds, and spot gouging can be applied to minimise repair welding, providing the position of defects is known. It is particularly effective for removing weld metal which has cracked, as the heat tends to open the crack and complete removal can be assured by visual inspection. Removal of the defect is easily witnessed while gouging is in progress. When faulty welds are removed by oxy-flame gouging no further preparation is usually necessary, apart from clearing away the oxides and slag.

![Diagram of removal of weld defects and faulty welds](image)

Fig 6.7 – Removal of weld defects and faulty welds (a) and (b)

Back gouging welds

It is common practice to back gouge the root of butt welds using the oxy-flame gouging process, prior to deposition of the backing run. Back gouging of welds should be carried out in a convenient position, preferably flat. The procedure is the same as for preparing plate edges or removing weld beads. This process is illustrated in Figs 6.7 and 6.8.

![Back gouging welds diagrams](image)

Fig 6.8 – Back gouging used in conventional butt welds (a), (b) and (c)
Oxy-flame gouging of cracks and defects in steel castings

General rules for this operation are that gouging may be carried out when the material is capable of being oxy-cut and when hardening or other problems will not arise as a consequence.

Hardening problems in certain alloy steel and cast steels may be overcome by preheating, post heating and cooling precautions. Tests should be carried out in doubtful situations.

Oxy-flame gouging is not generally recommended for quench and tempered steels due to the risk of a reduction of mechanical properties from the relatively high heat input associated with this gouging.

Fig 6.9 – Crack in cast steel frame prepared by gouging
Activity

- Identify safe working practices and protective equipment in the workshop.
- Set up an acetylene and oxygen plant starting with upright and secure cylinders:
  - purge the cylinders
  - fit correct regulators, flashback arrestors, fittings, hoses, blowpipe and gouging nozzle.
- Adjust correct working pressures with cutting lever depressed.
- Test for leaks.

Ask your lecturer to assist you

Light up the gouging nozzle, then:

- ensure the blowpipe acetylene valve is slightly cracked open to produce a small flow of acetylene gas
- adjust the flow of gas until the acetylene and air flame produces a minimum of soot.

Then:

- adjust the oxygen valve to produce a neutral flame at the gouging nozzle with the cutting lever pressed
- with your lecturer’s assistance, produce a test gouge on a practice piece of material. Use a neutral flame to heat the material then depress the cutting lever to gouge the material as directed.
Chapter 7 – Plasma cutting

Introduction

Plasma is the name given to a superheated ionised gas. Ionised means capable of conducting electricity. Some plasma is found in all arc welding processes. In the plasma arc process a higher proportion of gases in the arc zone are ionised by constricting the gas flow and arc. High plasma cutting temperatures enable metals to be easily cut by rapidly melting material in the path of a fast moving plasma arc.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>plasma</td>
<td>any ionised gas (gas containing ions and electrons)</td>
</tr>
<tr>
<td>ionised</td>
<td>being capable of conducting electricity</td>
</tr>
<tr>
<td></td>
<td>the state of losing one or more electrons from an atom</td>
</tr>
<tr>
<td></td>
<td>atoms of a gas that lose one or more electrons, is referred to as being ionised</td>
</tr>
</tbody>
</table>

In this chapter you will look at the following.

- The process
- Equipment
  - the power source
  - the gas supply
  - the cutting torch
- Cutting techniques
  - variables
  - pilot arc
  - control
  - common faults in plasma cutting
  - edge quality
  - applications
- Special hazards associated with plasma cutting
  - flumes
  - electric shock
  - noise
  - radiation.

At the end of this chapter, you will complete an activity.
Chapter 7 – Plasma cutting

The process

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>electrode</td>
<td>an electrically conductive structure which transfers electrons to or from reactant atoms or molecules</td>
</tr>
</tbody>
</table>

In the plasma arc cutting process, a reactive gas is forced through a constricting nozzle. This gas is then superheated by an electric arc which is established between the tungsten electrode and the torch (non-transferred arc), or more commonly between the electrode and the work piece (transferred arc). The superheated plasma gas results in a highly conductive, high velocity and extremely hot plasma stream at between 10 000 °C and 27 000 °C.

The temperature achieved is easily able to melt most materials and molten metal is blown clear of the cut by the high velocity plasma stream. Similarly, the refractory oxides common to stainless steels and aluminium alloys are broken down by the intense heat.
**Equipment**

The three major components of a plasma cutting system are:

- power source
- gas supply
- cutting torch.

*Fig 7.1 – Transferred arc*
The power source

The power source used for plasma arc cutting (PAC) is usually a drooping characteristic transformer/rectifier, or increasingly, an inverter.

For most applications, output in the range of 50 to 100 amps will suffice, as these will cut up to approximately 30 mm. Larger power sources are available, however rarely will a power source for plasma cutting exceed 300 amps.

Direct current is required to the electrode being connected to the negative pole.
Plasma arc power sources feature high open circuit voltages up to around 200 volts. This presents an obvious safety hazard to the operator. Power sources will usually incorporate a micro-switch, which cuts off all current once the machine terminals are exposed.

Although separate control panels are available, the PAC power source usually incorporates:

- amperage control
- gas pressure regulators
- gas purge facility
- high frequency pilot arc.

The gas supply

Important considerations regarding the gas supply for plasma cutting are:

- the cost, composition and reactivity of the plasma gas
- whether or not a separate primary and secondary (or shielding) gas is required
- gas pressures and flow rates.

Heavy-duty plasma cutting systems use two gases: one for plasma and another for shielding and cooling purposes. Most of these systems use nitrogen as the main plasma gas for general cutting. Mixtures of argon and hydrogen may also be used as a main plasma gas for greater productivity or high quality cuts on stainless steel or aluminium.

In a two gas system, carbon dioxide is used as a secondary shielding and cooling gas.

Secondary shielding gas:

- helps reduce oxidation of the material surface
- helps to keep the plasma stream concentric
- helps to cool the torch.

General purpose and light-duty plasma cutting systems using one gas and compressed air (78% nitrogen) are by far the most commonly used.

Air offers the following advantages:

- it is readily available
- it does away with the costs associated with cylinders
- it produces the hottest plasma stream.

If a secondary gas is to be used in a single gas, it is normally compressed air as well.
The compressed air supply should be around 560–700 kPa pressure. This will ensure that a sufficient volume of gas is supplied. As the diameter of the orifice in the cutting tip is increased to cut increasing plate thicknesses, the volume of gas consumed will increase accordingly. The air must be dry as any water or moisture can quickly destroy the cutting nozzle.

Fig 7.3 shows a plasma torch which uses a secondary gas.
The cutting torch

Many different torch designs are available both for manual and mechanical operations. The central feature is the tungsten electrode itself – the end of which may be ground to a point or have a flat face. Both electrode types have to be centred and positioned precisely, which is ensured by good torch design. Flat-faced electrodes are changed when pitting reaches a certain level, with both ends being used, and pointed electrodes are re-sharpened as necessary.

Another critical feature is the tip through which the plasma stream flows. The tip is exposed to wear and spatter which adversely affects cutting efficiency.

Replacement of the tip should be made when edge quality shows signs of deterioration. Tip sizes correspond to the orifice diameter and are usually within the range 1.5 mm, 1.8 mm and 2.0 mm.

Fig 7.4 – Plasma arc cutting torches
As discussed under gases, the torch must be equipped to suit the gas system used. It may be a single gas system with or without water cooling (Fig 7.5) or it may incorporate a secondary gas with or without water cooling. Other torches provide for secondary constriction by water instead of gas, or use water as a curtain to surround the plasma arc and reduce noise, radiation and fume levels (Fig 7.6).
Cutting techniques

Variables
Gas type, gas flow, current and travel speed should be set up to manufacturers’ recommendations. Gas lines must be purged for three minutes, when equipment has been standing overnight, to clear lines of moisture. Clean, dry air is essential to maximise electrode life.

Pilot arc
The pilot arc is a high-voltage current used to initiate the arc by producing a high-voltage plasma gas stream which allows the current to start flowing and produce the required heat.

The pilot arc is visible in some systems but not in others (Fig 7.7). Visible arcs are useful in hand-cutting operations for positioning the torch on the line of cut, and to set the distance from tip to material. Visible pilot arcs have the appearance of an oxy-acetylene inner cone and the tip of this cone should be touching the material surface. Visible arcs are not as necessary in machine operations. When the pilot arc is not visible a distance of approximately 6 mm should be maintained from tip to material.

When the switch is closed, (ie switch is turned on), the pilot arc is initiated. After a short delay of two to three seconds, the arc will start. In some systems it will automatically cut out after a predetermined time, perhaps 10 to 30 seconds, and in all systems when the main transferred arc is established.
Control

Machine control begins by setting-up, and arranging templates and materials into appropriate locations. Cuts are best started at an edge. There they will begin instantaneously, even with the machine travelling at the correct speed. Internal cuts by a machine in heavy plate should be started from a drilled or hand pierced hole. Maximum speeds can be used when machine cutting, provided the machine is designed for high plasma cutting speeds. The operator is able to look at the underside of the cut as it progresses to check speed settings. A good cut will show a slightly trailing stream of molten metal at approximately 50° to the vertical, with no dross adhering.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>dross</td>
<td>dross is a mass of solid impurities floating on a molten metal bath</td>
</tr>
</tbody>
</table>

Hand operation depends on operator skill, just as in oxy-fuel cutting. Experience is necessary to maintain correct travel speeds, steady and smooth forward travel, and correct stand-off distance. Travel speeds on thin materials are likely to be too high for efficient hand operation.

The transferred arc is automatically broken when the end of a cut is reached, or the torch is withdrawn from the material.

An important factor in plasma cutting is ‘direction’ of travel. Some torches are designed to produce a circular gas flow leaving the tip, resulting in one square, smooth edge, and the other edge tapered and less smooth. The operator should travel in a direction producing the best edge on the work required. The flat-faced electrode can identify torches of this type.

Common faults in plasma cutting

1. Cut does not penetrate full thickness.
   Insufficient heat can be remedied by reducing travel speed or increasing current.

2. Edge is rough, dross is excessive.
   Travel speed should be increased, if this fails to rectify the problem then the electrode and tip should be checked, together with the gas type and setting.

3. Main transferred arc breaks.
   Check the stand-off distance is not too high, and that cutting travel speed is not too slow.

4. Tips burning out too quickly.
   Ensure proper fitting of tip, check that current is not excessive, check that gas pressure is not too low, maintain correct stand-off distance with no possibility of tip contact on material, clean along line of cut if necessary. Ensure that clean, dry air is used.
Edge quality
The plasma arc can produce smooth, square edges on all materials. Truly square edges are difficult to obtain, however, and many jobs do not warrant the necessary expenditure of time and effort. Results vary considerably with different grades of stainless steel, for example, and operators should be quick to respond with adjustment to travel speed and gas pressures as the need arises. Cut edges can also be quite free of adhering dross, but small amounts are easily and quickly removed.

Applications
Plasma cutting is normally associated with the cutting of stainless steel and aluminium alloys, for which it was developed. Oxy-fuel gas cutting processes fail to cope effectively with these materials.

Plasma cutting applied to modern high-speed profile cutting machines is particularly effective, with speeds of 8 to 10 m/min being reached on 8 mm to 10 mm thick material. An additional benefit arising from high speed and effective cooling is the production of complex shapes which are virtually free from distortion. (Fig 7.8)

Fig 7.8 – Complex shape free from distortion
Special hazards associated with plasma cutting

Fumes
Metal fumes are produced by the vaporisation of metals at high temperatures. Most metals can be plasma cut and large volumes of toxic fumes may be produced from materials containing lead, cadmium, zinc, manganese, beryllium and mercury.

Vapours of chlorinated solvents can form the toxic gas phosgene when exposed to ultraviolet radiation from the arc. Solvents and degreasers should not be used on materials to be cut.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ultraviolet radiation</td>
<td>sources are invisible rays of energy from the sun (natural), also cutting and welding operations</td>
</tr>
<tr>
<td></td>
<td>ultraviolet radiation can damage the skin causing varying types of skin cancer</td>
</tr>
</tbody>
</table>

Materials for plasma cutting can be positioned over a bath of water to assist in fume control. To be effective the water level should be close to the underside of the material, and it has been established that distances as close as 20 mm are not harmful to the cut itself.

Plasma torches have been developed to allow for cutting on, or below the actual water surface. Fume extraction equipment is also desirable to remove fumes from above the material (Fig 7.9) or to draw them from underneath the cut instead of using water.
Electric shock

High open-circuit voltage increases the risk of electric shock in plasma cutting; it is sufficient to cause fatal injury. Plasma equipment should be maintained in perfect condition and repairs carried out immediately faults are observed. Before any changes in connections, assembly or disassembly of parts are made, the external primary power switch must be opened (ie switch is turned off).

The risk of electric shock is further increased by the common use of water, both within the plasma process and for fume control. Extra care should be taken when operating in damp areas. It is essential that the cutting table is properly grounded.
Noise
The noise level from plasma cutting can be high enough to cause damage. All people working in the vicinity of plasma equipment should use approved ear protection.

Radiation
The plasma arc cutting process produces high levels of ultraviolet radiation. Consequently, complete covering of the skin is required and eye protection consisting of safety glasses and shield fitted with the appropriate shade filter lens should be worn at all times as per AS/NZS 1338.1:1992 (Table 7.1).

<table>
<thead>
<tr>
<th>Recommended filters for PAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>50–100 A</td>
</tr>
<tr>
<td>shade 8</td>
</tr>
<tr>
<td>100–200 A</td>
</tr>
<tr>
<td>shade 10</td>
</tr>
<tr>
<td>200–300 A</td>
</tr>
<tr>
<td>shade 11</td>
</tr>
<tr>
<td>300–400 A</td>
</tr>
<tr>
<td>shade 12</td>
</tr>
<tr>
<td>above 400 A</td>
</tr>
<tr>
<td>shade 13</td>
</tr>
</tbody>
</table>

Based on AS/AZS 1338.1: 1992 – Table A2 (www.saiglobal.com)

Table 7.1 – Recommended filters

Fortunately, recent developments in plasma cutting, such as water shielded plasma, cutting in/on a water bath, and torches designed to contact the surface of the plate being cut, have reduced the hazards of noise, fume and radiation. However, the potentially hazardous nature of the process should be kept in mind, and the appropriate safety precautions taken at all times.
Activity

- Identify safe working practices and protective equipment in the workshop.
- Set up a plasma arc cutting plant.
- Adjust correct gas working pressures and amperages.
- Ask your lecturer to assist in producing a test cut on a practice piece of material.
- Use the plasma cutter to cut a range of materials as directed.
- Refer to Fig 7.2 and identify any breaches in safety standards.
# Appendix

## Metals and fabrication competency mapping

### Gas welding

<table>
<thead>
<tr>
<th>Book title</th>
<th>Chapter title</th>
<th>Comp Code</th>
<th>Competency title</th>
<th>Full = ✓</th>
<th>Partial = ✓</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas welding</td>
<td>1. Oxy safety</td>
<td>MEM 5.4C</td>
<td>Perform routine oxy-acetylene welding</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.6B</td>
<td>Perform brazing and or silver soldering</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.7C</td>
<td>Perform manual heating and thermal cutting</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.8C</td>
<td>Perform advanced manual thermal cutting, gouging and shaping</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.22C</td>
<td>Perform advanced welding using oxy-acetylene welding process</td>
<td></td>
<td>✓</td>
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<tr>
<td></td>
<td></td>
<td>MEM 5.52</td>
<td>Apply safe welding practices</td>
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<tr>
<td>2. Oxy-acetylene and propane equipment</td>
<td></td>
<td>MEM 5.4C</td>
<td>Perform routine oxy-acetylene welding</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.6B</td>
<td>Perform brazing and or silver soldering</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.8C</td>
<td>Perform advanced manual thermal cutting, gouging and shaping</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.22</td>
<td>Perform advanced welding using oxy-acetylene welding process</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.7C</td>
<td>Perform manual heating and thermal cutting</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Book title</td>
<td>Chapter title</td>
<td>Comp Code</td>
<td>Competency title</td>
<td>Full</td>
<td>Partial</td>
</tr>
<tr>
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<td>---------------------</td>
<td>-------------</td>
<td>----------------------------------------------------------------------------------</td>
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<tr>
<td>3. Flame heat</td>
<td>MEM 5.7C</td>
<td>Perform manual heating and thermal cutting</td>
<td>*</td>
<td></td>
<td></td>
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<tr>
<td>4. Gas weld</td>
<td>MEM 5.4C</td>
<td>Perform routine oxy-acetylene welding</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEM 5.6B</td>
<td>Perform brazing and or silver soldering</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEM 5.22C</td>
<td>Perform advanced welding using oxy-acetylene welding process</td>
<td>*</td>
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<td></td>
</tr>
<tr>
<td>5. Oxy-flame cutting</td>
<td>MEM 5.7C</td>
<td>Perform manual heating and thermal cutting</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEM 5.8C</td>
<td>Perform advanced manual thermal cutting, gouging and shaping</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Flame gouging</td>
<td>MEM 5.8C</td>
<td>Perform advanced manual thermal cutting, gouging and shaping</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEM 5.9C</td>
<td>Perform automated thermal cutting</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Plasma cutting</td>
<td>MEM 5.8C</td>
<td>Perform advanced manual thermal cutting, gouging and shaping</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Gas welding

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 TAFE WA (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 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.
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.

Topics covered include the following.
- Oxygen-fuel gas plant safety
- Oxygen-acetylene and propane equipment
- Flame heating
- Oxy fuel gas welding
- Oxy-flame cutting
- Oxy-flame gouging
- Plasma cutting

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