National Occupational Health and Safety Commission

WELDING:

FUMES AND GASES

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Foreword

The National Occupational Health and Safety Commission, Worksafe Australia, is a tripartite body established by the Commonwealth Government to develop, facilitate and implement a national approach to occupational health and safety.

The National Commission comprises representatives of the peak employee and employer bodies - the Australian Council of Trade Unions (ACTU) and Confederation of Australian Industry (CAI) - as well as the Commonwealth, State and Territory governments.

Since its establishment, the National Commission has produced occupational health guides. Before the National Commission was established, a series of similar guides was published by the National Health and Medical Research Council.

This Guide has been reviewed and endorsed by a working group of the National Commission as part of the co-ordinated effort by the Commonwealth, State and Territory governments and employee and employer organisations to make Australian workplaces safe and healthy.

Although this Guide has been endorsed by the National Commission, it is an advisory document only. It is produced and distributed in the interests of providing useful information on occupational health and safety for employers, employees and others. This document does not replace statutory requirements under relevant State and Territory legislation.

This Guide is aimed primarily at workers and managers but should also be useful to occupational health and safety personnel and others. It may be used in conjunction with appropriate training and consultation, in line with good management practice.

Contents

Introduction

Welding is the principal industrial process used for joining metals. The industrial use of welding is highly labour intensive, labour accounting for 80 to 90 per cent of production costs for all but the most automated processes. In typical industrialised countries 0.2 to 2 per cent of the total workforce is engaged in welding, the majority of welders being employed in the ship building, transport equipment manufacturing, building construction, petrochemical, mining and metallurgical industries. These workers are exposed to fumes and gases which may be hazardous to their health.

Many cases of acute poisoning due to excess exposure or severe short term exposure to one or more welding fume or gas have been documented. However, other than lung involvement, that is, mainly respiratory irritation and related effects, few chronic, long term effects have been directly attributed to welding fumes and gases. Due to the presence of chromium, nickel and aluminium, there is concern about the effects of chronic exposure on special groups such as welders of stainless steel and aluminium. At this stage, there is insufficient information to be conclusive about the effects of welding these metals.

This Guide describes some of the potential health hazards associated with welding fumes and gases. It also discusses the control and management of these hazards. A brief description of the various types of welding and allied processes is included as background information.

This Guide should be read in conjunction with the Worksafe Australia Guide, *Atmospheric Contaminants*, and the National Commission publication, *Exposure Standards for Atmospheric Contaminants in the Occupational Environment* (latest edition).

Australian Standards which are relevant to this Guide include:

- AS 1715 *Selection, Use and Maintenance of Respiratory Protective Devices*;
- AS 1716 *Respiratory Protective Devices*;
- AS 1668 Part 2 *Rules for the Use of Mechanical Ventilation and Air Conditioning in Buildings - Ventilation Requirements*; and
- AS 2865 *Safe Working in a Confined Space*.

Health and Safety in Welding, published by the Welding Technology Institute of Australia, should also be read in conjunction with this Guide.

The two most common types of welding used are:

- the electric arc welding of metal using a flux-coated electrode (manual metal arc welding, MMAW); and
- the electric arc welding of metal using a gas-shielded wire electrode (gas metal arc welding, GMAW).

The following five combinations account for 60 to 70 per cent of all welding activity:

- MMAW/mild steel;
- MMAW/stainless steel;
- GMAW/mild steel;
- GMAW/stainless steel; and
- GMAW/aluminium.

Welding Processes and Materials

The generic term ‘welding’ refers to the union between pieces of metal at joint faces rendered plastic or liquid by heat or pressure, or both. The two most common sources of heat are air/oxygen fuel gas flames, and the electric arc.

Common types of welding processes

There are about 20 major types of welding processes used on 10 major classes of materials, and hence an extremely wide range of work environments is possible. MMAW and GMAW are the two most common types of welding used. In general, the five combinations MMAW/mild steel, MMAW/stainless steel, GMAW/mild steel, GMAW/stainless steel and GMAW/aluminium account for 60 to 70 per cent of all welding activity.

Figure 1 shows the various welding and allied processes used. The more common types of welding and related processes are briefly described in Appendix 1. Further information on the different types of welding processes can be obtained from *Health and Safety in Welding*, published by the Welding Technology Institute of Australia, and the International Labour Office publication, *Encyclopaedia of Occupational Health and Safety.*

Materials used in welding

Core and filler metals

Core and filler metals are usually made of alloy similar in chemical composition to the materials being welded. The most commonly used material is mild steel. Special steels may contain chromium, nickel, molybdenum, aluminium, cobalt, vanadium or tungsten. Stainless steel electrodes may contain up to 26 per cent chromium and 21 per cent nickel. Manganese as high as 14 per cent may also be present in certain types of steel electrodes, for example, high-manganese hardfacing electrodes. High-chromium hardfacing electrodes may contain up to 30 per cent chromium, present as chromium metal and chromium carbides.

Electrode coatings (fluxes)

MMAW electrodes are coated with a complex mixture of materials which, by melting and chemical decomposition, provide the following functions:

- a non-oxidising atmosphere (cellulose, carbonates);

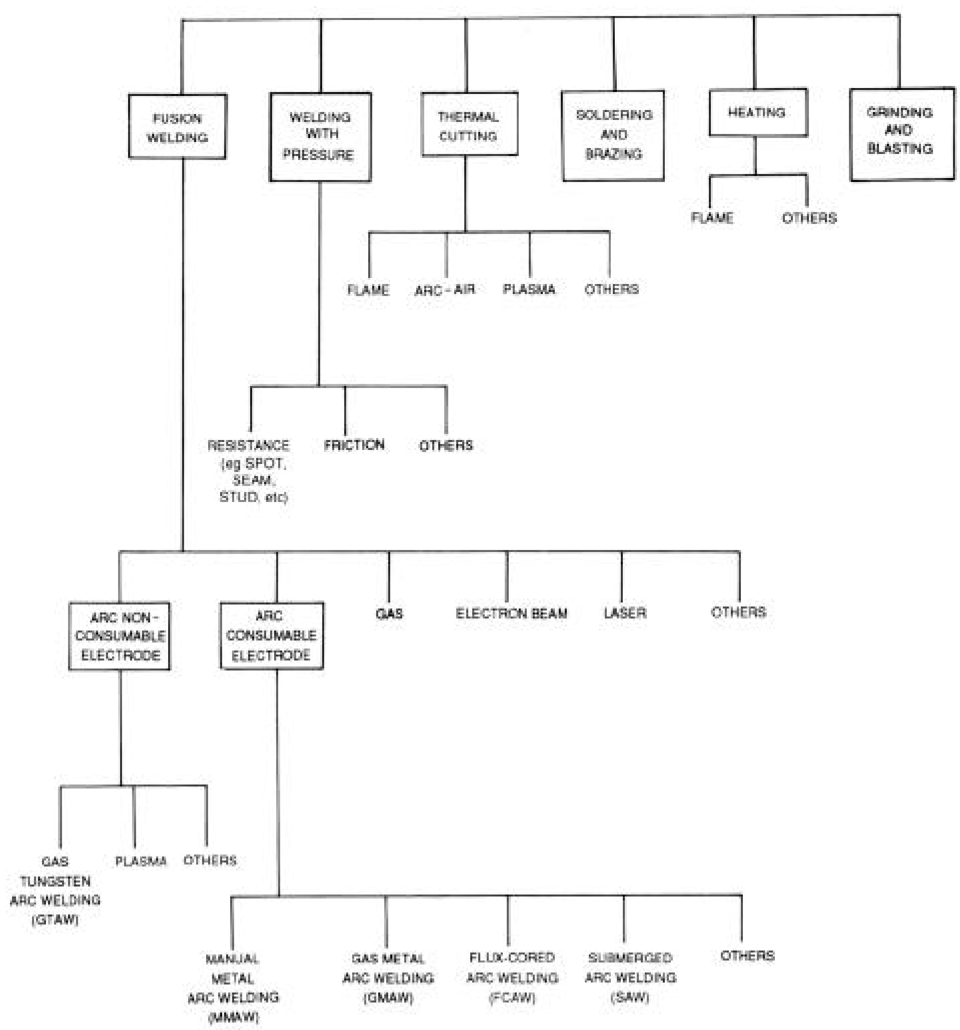

Figure 1. Welding and allied processes

- optimum weld and weld pool metallurgy (various metals or their oxides, calcium fluoride);
- slag formers (clays and oxides of titanium, silicon, manganese and magnesium); and
- additional charge carriers to the plasma (readily ionisable elements such as sodium, potassium and calcium from their compounds).

Electrode coatings may also include ferro-manganese, ferro-vanadium and ferro-silicon. In addition, the following agents are used in manufacturing MMAW electrodes:

- moulding agents, such as aluminium and magnesium silicate;
- extruding agents, such as starch, glucose and methyl cellulose;
- binders, such as potassium and sodium silicate; and
- fibrous materials, such as mica (asbestos is not used now).

Coatings of low-hydrogen electrodes have a high fluoride content. Electrode coatings in certain instances may have substantial amounts of metallic constituents added which contribute to the weld deposit, for example, iron, manganese, chromium and nickel.

Coatings on materials to be welded

Materials being welded may be:

- metal coated with zinc, lead or tin, which may be achieved by electroplating, hot dipping or metal spraying;
- electroplated with cadmium, copper, chromium or nickel;
- primed, painted with coatings containing lead pigments, zinc chromate, zinc dust or copper (as in anti-fouling coatings); and
- coated with resins, such as epoxy, phenol formaldehyde, vinyl, polyurethane, bitumen, oil modified alkyd and sodium/potassium silicate.

Cleaning of welding materials

Cleaning of metal surfaces before welding is often necessary. Abrasive methods of cleaning include grit or shot blasting, and mechanical or hand grinding. Chemical cleaning methods involve the use of degreasing solvents, the hazards and control of which are described in the Worksafe Australia Guides, *Solvent Vapour Degreasing*, and *Industrial Organic Solvents.*

Health Hazards

When considering the hazards associated with any workplace, it is essential to understand the relationship between 'hazard', 'exposure' and 'risk'.

'Hazard' is the potential for an agent or process to do harm. 'Risk' is the likelihood that an agent will produce injury or disease under specified conditions.

Health effects can only occur if a worker is actually exposed to the hazard. The risk of injury or disease usually increases with the duration and frequency of exposure to the agent, and the intensity/concentration and toxicity of the agent.

Toxicity refers to the capacity of an agent to produce disease or injury. The evaluation of toxicity takes into account the route of exposure and the actual concentration of an agent in the body.

This Guide is limited to discussion of the potential hazards of welding fumes and gases. General health hazards associated with welding are listed in Appendix 2. The hazards of soldering and brazing are adequately covered in *Health and Safety in Welding*, published by the Welding Technology Institute of Australia.

Appendix 3 on fume formation and production in welding processes complements the section on welding processes and materials and Appendix 1.

Notes on specific atmospheric contaminants, fumes and gases produced by welding and their health effects are given in Appendix 4.

Health effects

Acute, short term effects of the inhalation of the various components of welding fumes and gases (see also Appendix 4) can generally be related to a particular process and exposure. Such effects are well documented. Chronic, long term effects have, however, received less attention because of the confounding effects due to population dynamics, for example, job mobility, and from the masking of welding-related health effects by other factors such as cigarette smoking.

Short term effects

Metal fume fever

Metal fume fever occurs in welders who inhale zinc oxide fumes, although other components, for example, copper, aluminium and magnesium, may also produce this condition. Symptoms of metal fume fever, which resemble influenza, usually occur several hours after exposure and include a metallic or sweet taste, chills, thirst, fever, muscle aches, chest soreness, fatigue, gastro-intestinal pain, headache, nausea and vomiting. The symptoms usually subside within one to three days of exposure with no residual effect.

Exposure to ozone

Exposure to ozone generated in GMAW and plasma arc welding may produce excessive mucus secretion, headache, lethargy, eye irritation and irritation and inflammation of the respiratory tract. In extreme cases, excess fluid and even haemorrhage may occur in the lungs. The irritant effects of the gas on the upper respiratory tract and the lungs may be delayed.

Exposure to nitrogen oxides

Nitrogen oxides produce somewhat similar respiratory tract effects to ozone. Inhalation of nitrogen oxides does not always produce immediate irritant effects but may result in excessive fluid in the lung tissues (pulmonary oedema) some hours after exposure ceases.

Long term effects

Details of long term health effects specific to individual welding fume and gas components are given in Appendix 4.

Respiratory system

On the basis of studies which have been undertaken, there is evidence that chronic obstructive diseases are made worse by smoking.

Nervous system

Out of the possible welding fume components, lead and manganese are toxic to the nervous system (see Appendix 4).

Cardiovascular system

Carbon monoxide, generated in carbon dioxide-shielded GMAW processes, combines readily with haemoglobin, thereby lowering the oxygen-carrying capacity of blood. For this reason, exposure to carbon monoxide may present an added health risk to welders with heart disease.

Skin

Chromium (VI) compounds, which may occur in stainless steel or related welding fumes, are a frequent cause of dermatitis (see Appendix 4).

Carcinogenic effects

There is concern regarding the presence of potential cancer causing agents, *carcinogens*, in certain types of welding fumes and gases. In this context:

- the particulate form of fume may be carcinogenic, but no definitive human or animal study results are available;
- chromium (VI) and nickel (see Appendix 4) are implicated in respiratory tract cancer in other, non-welding, industrial settings;
- ozone is a suspect lung carcinogen in laboratory animals, but no studies of the long term effects of ozone on exposed welding populations have been documented; and
- the welding arc emits ultraviolet radiation of wavelengths that have the potential to produce skin tumours in animals and in over-exposed individuals, however, no confirmatory studies of this effect in welders have been reported.

Lung cancer is the most common form of human cancer. Studies of lung cancer among welders indicate that they may experience a 30 to 40 per cent increased risk compared to the general population. Since smoking or exposure to other cancer-causing agents, such as asbestos fibres, may have influenced the results, it is not known whether welding represents a significant lung cancer risk. It is considered that welding done on mild steel represents little risk. Stainless steel welders are exposed to chromium and nickel and may be a high risk group, which might account for the overall increase in lung cancer incidence among welders.

Prevention and Control Measures

Following the identification of a hazard, evaluation of work practices and conditions must be undertaken so that effective prevention and control measures can be implemented. This should be considered an integral part of management's responsibilities.

Control measures

Where there is a likelihood of worker exposure to welding fumes and gases, steps should be taken to minimise that exposure as far as workable. A thorough examination of work practices is essential. Procedures should be adopted to ensure that workers are not unnecessarily exposed to the hazard. Control measures include, but are not limited to, the following, which are ranked in priority of their effectiveness:

- elimination/substitution and process modification;
- engineering controls;
- administrative controls; and
- use of personal protective equipment.

Substitution

Manufacturers of welding electrodes may be able to substitute less hazardous ingredients in their products without altering important metallurgical or welding characteristics. Lithium silicate or an organic binder substituted for sodium or potassium silicates reduces the hazardous chromium (VI) content of fumes during stainless steel welding.

Welding process parameters

Examples of how welding process variables can affect fume formation rates are given in Appendix 3. In addition, the type of shielding gas used can significantly affect the fume formation rate. For example, fume formation rates can be reduced by about 20 per cent when a mixture of argon and carbon dioxide is used instead of carbon dioxide alone. A possible way of reducing ozone when welding aluminium using GMAW may be to add nitric oxide to the shielding gas.

Engineering controls

Specific controls

Local exhaust ventilation is generally not effective in controlling ozone because the gas is formed at a distance away from the arc (see Appendix 4). Two novel engineering methods for reducing ozone concentrations in the use of GMAW on aluminium are described by Faggetter, et al. in the *American Industrial Hygiene Association Journal*, vol. 44, no. 5, pp. 316-20, 1983.

In the first method, a stainless steel mesh shroud is attached to the welding torch with a small viewing window left open so that the welder can still view the welding operation. The stainless steel shroud acts as a barrier to the ultraviolet radiation, which produces ozone by reacting with the oxygen in the surrounding air. Increasing the layers of stainless steel mesh further reduces ultraviolet radiation transmission and the level of ozone gas. Using this method, ozone exposures rarely exceed the exposure standard of 0.1 part per million.

The second method utilises a combination of shielding and ventilation when the stainless steel shroud cannot be used because of the size or configuration of the parts being welded. A lightweight portable fume cabinet is constructed of translucent plastic and fitted with an exhaust fan. The translucent plastic reduces the transmission of ultraviolet rays and so reduces the production of ozone gas.

Local exhaust ventilation

Hazardous atmospheric contaminants can often be controlled effectively at their source by means of a local exhaust system. This system comprises:

- a hood which captures the contaminant at its point of generation;
- a duct system with appropriate airflow;
- an air cleaning system to prevent pollution of the general atmosphere;
- an exhaust fan; and
- a stack or other means of dispersing the decontaminated air into the atmosphere.

Further details can be obtained from the following three books, *Clean Air at Work*, *Industrial Ventilation - A Manual of Recommended Practice*, and *Principles of Local Exhaust Ventilation*.

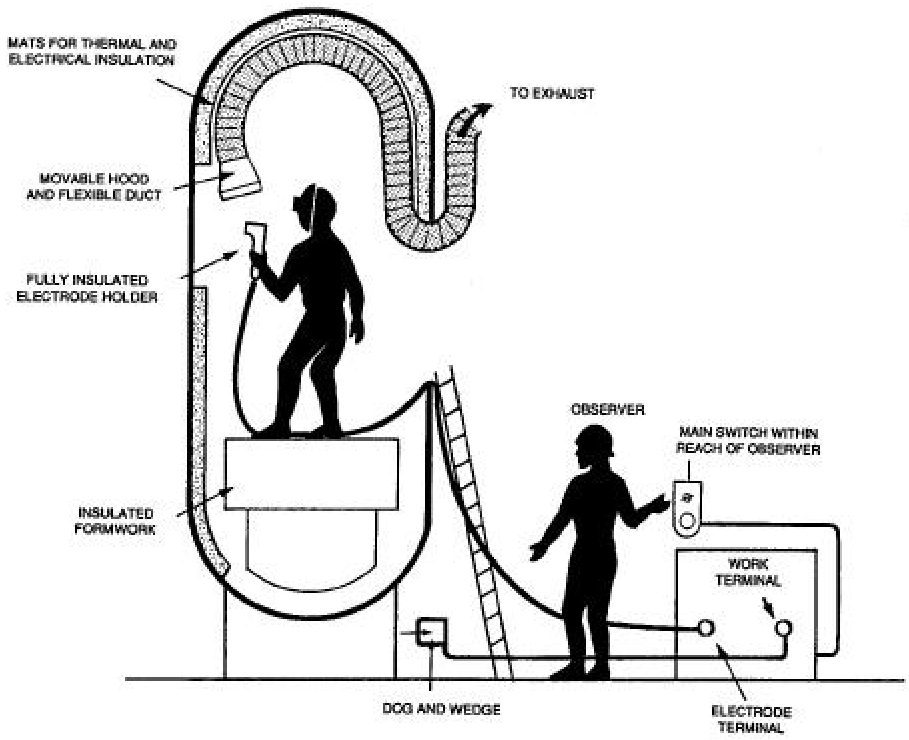

Figure 2a Ventilation in confined spaces welding

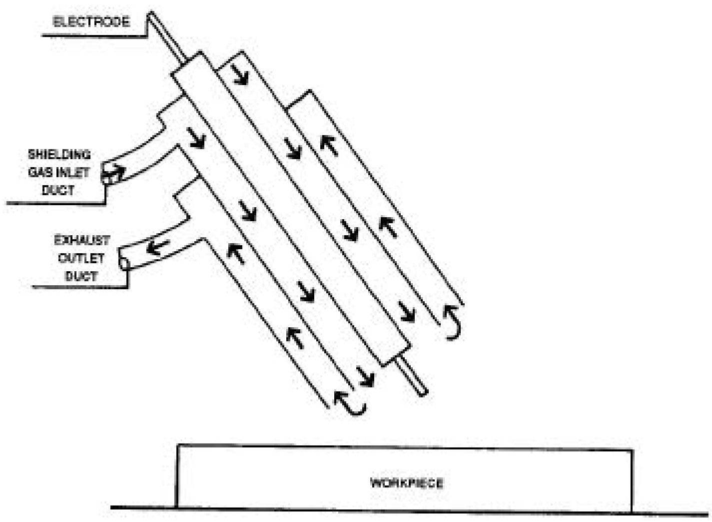

Figure 2b Principle of a fume extraction gun mounted on an exhaust hood

Care in selection, design, installation, operation and regular maintenance of a ventilation system is essential to ensure that the system adequately controls contamination at all times.

The design of an effective ventilation system is a highly skilled area of expertise and therefore should only be performed by those competent to do so. Special care in design is important where combustible, inflammable or potentially explosive materials are involved. Inlets and outlets must not be blocked and must be kept clear at all times.

Air from a local exhaust ventilation system should not be re-circulated into the workroom. It should be discharged into the outside air, distant from other work areas, air conditioning inlets or compressors supplying breathing air.

Three examples of local exhaust ventilation suitable for welding operations are:

- fixed installations, such as side-draft or down-draft tables and benches, and partially or completely enclosed booths;
- portable installations, such as movable hoods that are attached to flexible ducts (see Figure 2a); and
- fume extractors attached directly to the welding gun (see Figure 2b).

General ventilation

General ventilation systems are not usually as satisfactory in the control of health hazards as are the use of ventilated process enclosures or local exhaust ventilation, but they may be useful to control minor emissions of contaminants of low toxicity. In designing a mechanical ventilation system where such contamination occurs, particular attention should again be given to fan selection and to the placement of air extractors and fresh air supply openings. In particular, the movement of air should be arranged so that clean air streams are drawn past workers and contaminated ones lead away from them. Such systems require rigorous control over all sources of natural ventilation and air movement which may disturb planned air movement, for example, the operation of air conditioning systems or the opening and closing of doors and windows. Changes or additions to a balanced ventilation system must be implemented in such a way that they will not result in reduced efficiency of the entire ventilation system.

Dilution ventilation

It may be possible to dilute the concentration of contaminants with a sufficient volume of clean air to reduce the levels of contamination which reach personnel. This method is usually applicable to processes which can be operated in open air or with a skeleton structure and roof.

Such open construction, however, while affording good natural ventilation, requires skilled and experienced design to achieve success. In particular, the effects of thermal air movements require specialist consideration.

Note: **General ventilation and dilution ventilation are not as effective as local exhaust ventilation for the control of atmospheric contaminants. They may, however, be useful to control minor contaminant emissions of low toxicity.**

For further information on ventilation, refer to the Worksafe Australia Guide, *Atmospheric Contaminants*, and Australian Standard AS 1668 Part 2.

Monitoring

Monitoring may be used for the evaluation of a hazard and for assessing the effectiveness of control measures. The design and implementation of a monitoring program should be carried out by, or in consultation with, a properly qualified person.

Monitoring of the work environment involves the measurement of atmospheric contaminants at selected locations in the workplace (static, positional monitoring). Personal monitoring involves the measurement of atmospheric contaminants in the breathing zone of the individual worker. Biological monitoring involves measurement of the concentration of a contaminant, its metabolites or other indicators in the tissues or body fluids of the worker. In some cases, biological monitoring may be required to supplement static or personal monitoring.

In the control of health hazards due to a specific contaminant, where it has been demonstrated that the exposure of the employee to the contaminant is approaching the relevant exposure standard, or where biological monitoring indicates that an unacceptable exposure is occurring, *immediate action must be taken to reduce the health hazard* and intensive monitoring should continue.

Records of the results of any monitoring should be maintained and employees should be informed of these results.

Fume may be analysed, particularly for specific toxic constituents, for example, nickel, chromium (VI) and manganese, using standard methods.

If required, gases may also be monitored.

Exposure standards

Exposure standards for welding fumes and for the various components in welding fumes and gases are listed in the National Commission publication, *Exposure Standards for Atmospheric Contaminants in the Occupational Environment* (latest edition).

The exposure standards represent airborne concentrations of individual chemical substances which, according to current knowledge, should neither impair the health of, nor cause undue discomfort to, nearly all workers. Additionally, the exposure standards are believed to guard against narcosis or irritation which could precipitate industrial accidents.

Except where modified by consideration of excursion limits, exposure standards apply to long term exposure to a substance over an eight hour day for a normal working week, over an entire working life.

The exposure standards do not represent 'no-effect' levels which guarantee protection to every worker.

Work practices

Work practices that can reduce fume exposure levels and adverse health effects include:

- removal of rust inhibitors, paints, degreasers or other coatings on metals to be cut or welded, although this process in itself may be hazardous;
- segregation of degreasing operations from welding tasks;
- positioning of the welder as far away from the welding fumes as possible; and
- promotion of a no-smoking policy.

Personal protective equipment

In certain circumstances, personal protection of the individual may be required as a supplement to other preventive action. It should not be regarded as a substitute for other control measures and must only be used in conjunction with substitution and elimination measures.

Personal protective equipment must be appropriately selected, individually fitted and workers trained in their correct use and maintenance. Personal protective equipment must be regularly checked and maintained to ensure that the worker is being protected.

Health and Safety in Welding, published by the Welding Technology Institute of Australia, should be consulted for a description of the different types of respirators recommended for welders. Only devices, both for fumes and gases, which conform with Australian Standard AS 1716 should be used. Expert advice should be obtained when selecting respirators. To determine the best type of respirator for a particular situation, the composition of the welding fumes and gases should be considered. To be effective, a respiratory protection program depends heavily on worker education in the correct selection, fitting, use and maintenance of the respirators (see Australian Standard AS 1715). Workers who are required to be close to the welding process, such as welders' helpers, should also be provided with respiratory protection.

Health surveillance

Due to the wide variety of processes, materials and work practices employed in different welding tasks, each individual situation and its needs should be carefully assessed by qualified occupational health professionals. Under some circumstances, health surveillance may be required, with investigations directed specifically to the effects of the work performed.

Where employees are to undergo health assessment, there should be adequate consultation prior to the introduction of any such program. Where medical records are kept, they must be confidential. It is particularly valuable to be able to relate employee health and illness data to exposure levels in the workplace.

Biological monitoring, when considered appropriate, should be tailored to specific hazards and specific exposures.

Education and training

All employees working with welding processes must be informed of the hazards from exposure to the contaminants and the precautions necessary to prevent damage to their health. Employees should be trained in appropriate procedures to ensure that they carry out their work so that as little contamination as possible is produced, and in the importance of the proper use of all safeguards against exposure to themselves and their fellow workers. Adequate training, both in the proper execution of the task and in the use of all associated engineering controls, as well as of any personal protective equipment, is essential.

Employees exposed to contamination hazards should be educated in the need for, and proper use of, facilities, clothing and equipment and thereby maintain a high standard of personal cleanliness. Special attention should be given to ensuring that all personnel understand instructions, especially newly recruited employees and those with English-language difficulties, where they are known.

Before handling all substances, material safety data sheets for the electrodes, fluxes and coatings used should be obtained from the suppliers of such materials and be made available to employees.

First Aid

If a person is overcome by welding fumes and/or gases, the following precautions should be adopted:

- remove the patient to an uncontaminated atmosphere and loosen tight clothing at the neck and waist;
- keep the patient warm and at rest;
- if the patient has difficulty in breathing, oxygen may be administered provided that suitable apparatus and a trained operator are available;
- if breathing is weak or has ceased, artificial respiration should be started (the mouth-to-mouth or mouth-to-nose methods are preferred); and
- seek medical advice.

It is important for the doctor to know the contaminants which might have been present in the air of the workplace.

Appendix 1

Common types of welding processes

Gas welding and cutting

In *oxy-gas welding*, oxygen and a fuel gas, for example, acetylene, natural gas, propane or hydrogen, are fed to a blowpipe, or torch, usually hand-held, in which they are mixed prior to combustion at the nozzle. The flame produced melts the metal faces of the parts to be joined, causing them to flow together. A filler metal or alloy is usually added, and chemical fluxes may be used to prevent oxidation and to facilitate union.

In *gas metal cutting*, the metal is heated by a flame and a jet of pure oxygen is directed onto the point of cutting and moved along the line to be cut.

In *gas pressure welding*, the parts are heated by a gas flame while under pressure, and become forged together.

Electric arc welding

The electric arc is struck between the electrode and the workpiece, or between two electrodes. It is usually necessary to add some molten metal to the joint and this is done either by:

- melting the electrode itself, *consumable electrode processes*; or
- melting a separate filler rod which is not carrying current, *non-consumable electrode processes*.

Consumable electrode processes

Manual metal arc welding (MMAW)

The electrode is coated with a flux which acts as an electrical insulator outside the arc area and which, on vapourising, forms a shielding gas (carbon dioxide) to protect the arc zone and the molten weld pool, as well as a slag thermal insulator, to protect the cooling weld deposit from the air. The coating also contains fluxing agents, arc stabilisers, deoxidisers, binding agents, etc. and, where required, alloying additives (see also the section on welding processes and materials).

Low-hydrogen MMAW electrodes contain a high amount of fluoride which facilitates complete drying, but at the same time also acts as an arc suppressant, thereby necessitating higher operating arc voltages.

MMAW is the most widely used method of welding for ferrous alloys, but is used to a much lesser extent for non-ferrous alloys.

Gas metal arc welding (GMAW)

An arc is struck between a continuous spool-fed wire-consumable electrode and the workpiece. The electrode melts and provides filler metal to the weld. The arc and the weld are shielded by one of a variety of shielding gases - carbon dioxide, argon or helium with, in some cases, small additions of oxygen, hydrogen or chlorine. The electrode is fed automatically in GMAW. GMAW is used in the welding of both steel and aluminium.

Submerged arc welding (SAW)

The electrode is submerged beneath a pile of loose flux which protects the arc zone and the weld from the air and takes part in the metallurgical reactions with the molten weld metal. The electrode is fed automatically in SAW processes.

Flux-cored arc welding (FCAW)

Flux-cored welding processes, which may or may not be gas-shielded, employ a continuous wire containing a flux-core which is similar to the coatings used for MMAW electrodes.

Non-consumable electrode processes

Gas tungsten arc welding (GTAW)

A shield of inert gas is used to protect the arc zone and the weld metal from the air, thus preventing oxidation and contamination of the metal. The electrode is of tungsten and the inert shielding gas is argon, helium or a gas mixture. The electrode contributes no metal to the weld, but weld metal may be added by means of a suitable uncoated filler rod.

Resistance welding

This process includes spot, seam, projection, butt, flash and stud welding. A high current at low voltage flows through the workpiece from electrodes usually made of copper. Both heat and pressure are involved in producing a forge weld.

Metal cutting

In arc-air cutting or gouging processes, an arc is struck between a copper-coated carbon electrode and the workpiece. The pool of molten metal produced is blown away by jets of compressed air. Metal cutting with the electric arc may also be done by the oxygen arc cutting or tungsten arc cutting methods.

Other types of welding processes

Other types of welding processes include metal spraying, microwelding and special processes such as electron beam welding, friction welding, laser welding and drilling, plasma arc welding, spark erosion machining and thermit welding.

Plasma arc welding, and cutting, are now gaining wide industrial applications. Plasma arc welding may be carried out with or without the use of a filler metal. Gases used in plasma arc welding or cutting include argon, hydrogen and nitrogen. A mixture of argon and nitrogen is the most suitable plasma gas, but is used only under special circumstances, for example, mechanised plasma arc cutting of stainless steel. Nitrogen is usually avoided as a plasma gas because of the health hazards of nitrogen oxides.

Appendix 2

General health hazards associated with welding

Health hazards associated with welding, other than those related to fumes and gases, include:

- electric shock;
- fire and explosion;
- burns due to hot metal splashes;
- eye and skin effects of ultraviolet and infra-red radiation;
- effects of radiant heat; and
- effects of noise, for example, plasma arc welding and arc-air gouging process.

The above hazards and appropriate protective measures are described in *Health and Safety in Welding*, published by the Welding Technology Institute of Australia. The following are also of relevance in welding processes:

- *Prevention of Eye Damage*, Worksafe Australia Guide; and
- *Effects of Heat on Health, Comfort and Performance*, National Health and Medical Research Council.

Protective and safety measures for some of the welding health hazards are also described in Australian Standards AS 1336, AS 1337, AS 1338 Part 1, AS 1338 Part 2, AS 1338 Part 3, AS 1715, AS 1716 and AS 2745.

Appendix 3

Fume in welding processes

Fume formation

Welding fume is an extremely complex by-product of certain kinds of welding processes. In MMAW, fume arises by vaporisation of the core metal and flux components of the electrode. The various constituents of the core metal and flux react at the high temperatures of the welding arc to produce fume particles consisting of a mixture of complex oxides, etc. The extent to which the products of reaction of core and flux components will appear in the welding fume depend on factors such as:

- welding conditions, which influence arc and gas temperatures;
- heats of formation, a thermochemical factor; and
- relative volatilities, that is, vaporisation behaviour, of the metal oxides, etc.

In certain cases, materials other than the welding consumables may represent a significant source of atmospheric contamination. Some examples are:

- where the workpiece itself contains volatile constituents, such as beryllium in copper;
- where ferrous alloys have a surface coating (see the section on welding processes and materials), or where non-ferrous metals, such as copper and nickel or their alloys, are cut, heated or welded; and
- where painted metal surfaces are used, metal fumes may result from the paint pigment and organic pollutants from the paint binder.

Fume production in different welding processes

As a rough guide, it may be noted that among the arc processes, SAW has the lowest fume formation rate. Then, in ascending order, come GTAW, GMAW, MMAW and FCAW. In GMAW, carbon dioxide-shielding results in much higher fume formation rates than argon or helium gas-shielding. Oxygen or carbon dioxide additions to the inert shield gas stabilise the arc, but usually result in increased fume formation rates. However, small additions of carbon dioxide to argon or helium have been found to result in spray transfer at low arc voltages, accompanied by very low spatter rates and low fume formation rates.

Grinding and abrasive blasting are known to produce large amounts of fume and dust. In SAW there may be a dust problem due to flux handling but, since there is no open arc, fume and gas problems are minimal. The arc-air gouging process represents environmental hazards of both noise and atmospheric contaminants showing not only high total fume levels but also high copper in the fume from the copper coating on the graphite electrode, and significant concentrations of nitrogen oxides, ozone and carbon monoxide.

The amount of fume given off during plasma welding or cutting is, in general, greater than that encountered in GMAW. Microwelding and specialist processes such as friction welding, electron beam, and laser welding generally produce very little fume.

Fume formation rates and fume composition

Both the fume formation rate and the chemical composition of the fume are affected by the welding parameters and the type of application. Listed below are the most important factors which have been shown to affect the rate of fume formation and the fume composition:

- voltage drop across the welding arc which is related to the arc length being maintained;
- welding mode, that is, AC, DC electrode positive (DCEP) or DC electrode negative (DCEN);
- arc current;
- angle between electrode and workpiece;
- position and type of weld, that is, fillet, bead-on-plate, etc.; and
- heat input, which is related directly to arc power (arc voltage **x** arc current) and inversely to welding speed.

Fume formation rates may vary critically with arc length, which in turn may be affected by the degree of skill of the welder. In general, fumes increase with increasing current, with increasing voltage and with longer arc lengths.

Fume formation rates may be expressed as:

- g/min;
- g/kg electrode; or
- g/kg weld deposit.

Note: **Fume (g/min) =** $\dfrac{\textbf{fume (g/kg electrode) x electrode melting rate (kg/hr)}}{\textbf{60}}$

Fume particle size

Welding fume particles are less than 1 µm, that is, 0.001 mm in diameter, when produced, but they appear to grow in size with time due to agglomeration, that is, particles sticking together. Particles in the size range 1-7 µm thus develop with time. The 1-7 µm diameter particles constitute the greatest health hazard because of their ability to penetrate deep into the lungs and because they are not readily cleared by the cilia lining the respiratory tract. The particles visible in the fume plume are usually the heavier, that is, larger, particles which will rapidly precipitate onto adjacent surfaces as ‘dustfall’. Particles in the welder's breathing zone are usually 2 µm or less - these lighter, smaller, particles may remain in the air for some hours if they are not removed by ventilation.

Appendix 4

Notes on atmospheric contaminants and their health effects

Metal fumes

Lead

Potential lead exposure occurs during welding and cutting of any metal coated with lead or lead-based paint. Lead poisoning is rare in welders, but may occur in persons employed in operations such as cutting lead-painted steel in ship breaking and bridge demolition. Occupational lead poisoning, which in welders results from exposure to lead oxide fume, may affect the blood, gastro-intestinal tract and nervous system.

Cadmium

Cadmium may be present as a coating in certain materials being welded. Cadmium oxide fume on inhalation may cause acute irritation of the respiratory passages, bronchitis, chemical pneumonia or excessive fluid in the lung tissues (pulmonary oedema). There may be a latent period of several hours between exposure and onset of symptoms. The effects of overexposure to cadmium fumes may resemble metal fume fever initially. A single exposure to a very high concentration of cadmium oxide fume may be fatal. Chronic cadmium poisoning results in injury to lungs and kidneys.

Manganese

Potential exposure to manganese occurs whenever this metal is used in electrode cores and coatings or in electrode wire. Acute poisoning from oxides of manganese is very rare in welders, although respiratory tract irritation from the fume may occur. Exposure to fume from welding on manganese steel may give rise to acute inflammation of the lungs. Metal fume fever is also a possibility after exposure to manganese fume. Chronic manganese poisoning, characterised by a severe disorder of the nervous system, has been reported in welders working in confined spaces on high-manganese steels.

Zinc

Zinc may be present as a surface coating on steel products, that is, galvanised steel. Exposure to freshly formed zinc oxide fume may produce a brief acute self-limiting illness known as metal fume fever, zinc chills or brass founders' ague. The symptoms, which resemble those of an acute attack of influenza, usually occur several hours after exposure to fume and usually with complete recovery within about 24 to 48 hours. Freshly formed oxide fume from several other metals has also been reported to cause metal fume fever. Leucocytosis, a transient increase in white blood cell counts, is reported to be a common finding in metal fume fever, but is not known to be common among welders.

Iron

Most welding involves ferrous materials. The most abundant constituent of ferrous alloy welding fume is iron oxide. Long, continued exposure to such welding fume may lead to the deposition of iron oxide particles in the lungs. When present in sufficient quantities, the deposition is demonstrable on chest X-ray films as numerous fine discrete opacities (nodulation and stripping) resembling silicosis. The technical name for this is siderosis and it is a benign form of pneumoconiosis. Siderosis tends to clear up when the exposure to metallic particles stops.

Molybdenum

Molybdenum is found in some steel alloys. Molybdenum fumes may produce bronchial irritation and moderate fatty changes in the liver and kidneys.

Cobalt

Cobalt is a component in some high-strength, high-temperature alloys. Inhalation of cobalt fumes can cause shortness of breath, coughing and pneumonitis. Hypersensitivity appears to be involved because lung changes occur at low incidence and are varied in intensity and time of onset. In most cases, the symptoms disappear after exposure ends.

Vanadium

Vanadium may be present in some filler wires and special alloy steels. Exposure to oxide fume, especially pentoxide (V2O5), gives rise to severe irritation of the eyes, severe throat and respiratory tract irritation, and may also cause chemical pneumonia.

Nickel

Nickel is a potentially carcinogenic metal found in fumes from the welding of nickel-plated mild steel, and stainless steel and high-strength low-alloy steel electrodes. Nickel oxide has been found to be carcinogenic in laboratory animals. There is, however, very little direct information on the health effects of nickel-bearing welding fume on welders. Irritation of the respiratory tract has occurred in stainless steel welders.

Chromium

Chromium may be present as a coating on the workpiece, and mainly in stainless steel, hardfacing and chrome-alloy electrodes. Chromium is normally not present in any significant amount in aluminium alloys. Chromate, which may be generated in stainless steel welding fumes or in fumes from hardfacing and chrome-alloy electrodes, is an irritant to the mucosal tissue in the respiratory tract. Exposure to fume containing high concentrations of water-soluble chromium (VI) during the welding of stainless steel in confined spaces has been reported to result in both acute and chronic chrome intoxication, dermatitis and asthma.

Epidemiological studies and animal tests have confirmed certain chromium (VI) compounds as occupational carcinogens. These health risks were determined from non-welding occupations. GMAW stainless steel welders are usually likely to be exposed to much smaller concentrations of chromium (VI) than MMAW stainless steel welders. A considerable amount of stainless steel welding is carried out nowadays using GMAW and GTAW methods.

Chromium (III) compounds are generally believed to be biologically inert. Welding fumes may contain Cr_2O_3 (a chromium (III) compound), or double oxides, such as FeO Cr_2O_3, or both.

Silica and silicates

The silica and silicates formed in welding fumes are amorphous, that is, not crystalline, and are generally believed not to be harmful.

Fluorides

Welders may be exposed to fluoride dust, fume and vapours from certain MMAW, FCAW and GMAW operations and SAW fluxes. Fluoride fumes may produce irritation of the eyes, throat, respiratory tract and skin. Chronic fluorosis is a syndrome characterised by an increased density of bones and ligaments due to fluoride deposition. However, no corroborating data are available which identify a relationship between exposure to fluoride-containing welding fumes and disorders of bones or ligaments.

Other metals

Welding may produce fume from other metals, including aluminium, copper, magnesium, tin, titanium and tungsten. Within the confines of the current information available, no serious health disorders in welders are known to occur from exposure to fume from these metals but, under certain conditions, copper, aluminium and magnesium may give rise to metal fume fever and others to irritation of the respiratory tract.

Beryllium is a volatile and toxic component that may be present in many copper alloys being welded, that is, in the workpiece itself. Beryllium oxide fume is very toxic to the respiratory tract, lungs and skin, and is quick-acting. Beryllium is a suspect human carcinogen. Note that beryllium may also be present in some aluminium or magnesium brazing alloys.

Gases

Oxides of nitrogen

The oxides of nitrogen, nitric oxide and nitrogen dioxide, are frequently formed by the direct combination of oxygen and nitrogen in the air surrounding the arc or flame, as a result of heat from the electric arc or gas torch (oxidising flames). In outdoor or open shop welding, hazardous abnormal concentrations are unlikely, except perhaps for short periods. In confined spaces, hazardous concentrations of nitrogen oxides may rapidly build up in welding operations. High concentrations of nitrogen oxides have also been found during gas tungsten-arc cutting of stainless steel.

Exposure to oxides of nitrogen may not always produce immediate effects but may result in fatal excessive fluid in the lung tissues (pulmonary oedema) some hours after the exposure stops.

Ozone

Ozone is formed only in small amounts in MMAW and in gas welding. It is, however, produced in significant amounts in GMAW when welding with argon, especially when high amperages are used. High ozone concentrations are especially a problem when welding on reflective surfaces, such as aluminium and its alloys and stainless steel, and with high-energy processes such as plasma arc welding.

Ozone is actually formed a short distance away from the arc. The persistence of ozone under certain conditions may be explained as an inverse function of the amount of fume produced. The greater the mass of fume (particulate), the less the penetration by ultraviolet radiation and thus the less ozone produced by the ultraviolet radiation acting on oxygen. Ozone also reabsorbs ultraviolet radiation of wavelengths of 200 to 290 nm and can spontaneously decompose back to oxygen.

Harmful levels of ozone may be found in welding in confined spaces. The gas is very irritant to the upper respiratory tract and lungs and its effects may be delayed.

Ozone is capable of reacting explosively with combustible materials.

Carbon monoxide

Carbon monoxide is derived from carbon dioxide-shielding atmospheres by reduction of shielding gas, and to a much lesser extent in all welding of steel by partial oxidation of carbon in the consumables.

Carbon monoxide will also be produced in gas welding when combustion of acetylene is incomplete, as with a reducing flame. Carbon monoxide levels may build up in confined spaces and poorly ventilated spaces. Overexposure may cause drowsiness, headache and nausea. If carbon monoxide exposure is sufficiently severe, unconsciousness may occur.

Carbon dioxide

Carbon dioxide at high concentrations can act as an asphyxiant. It is therefore necessary in GMAW in confined spaces to maintain adequate air and oxygen to avoid asphyxiation of the welder. Note that high oxygen concentrations should also be avoided since they constitute a fire hazard.

Phosgene

The toxic gas phosgene, also known as carbonyl chloride, is not a normal component of welding gases, but is formed by the oxidation of chlorinated hydrocarbons (for example, trichloroethylene, trichloroethane and perchloroethylene), such as when welding is carried out in the presence of solvent vapours escaping from a nearby degreasing tank or when solvent is left behind after degreasing. Exposure to phosgene produces, after a latent period of several hours, irritation of the respiratory tract or perhaps serious lung damage.

Phosgene formation is promoted by ultraviolet radiation, hot metal surfaces, flame and cigarette smoking. The gas-shielded arc welding processes (GMAW and GTAW) and plasma processes provide greater ultraviolet light intensity than the flux-shielded arc welding processes (MMAW, SAW, FCAW). Note also that heat and ultraviolet radiation from the welding arc may react with solvent vapour to produce irritant gases such as acetylchloride and acetylchloride derivatives such as dichloroacetylchloride.

Phosphine

Phosphine is generated when steel coated with a rust proofing compound is welded. High concentrations of phosphine gas are irritating to the eyes, nose and skin. There may also be serious effects on the lungs and other organs.

Insufficient oxygen

In GMAW, the presence of inert gases (argon, helium) in confined work environments may reduce the oxygen content of the atmosphere to dangerous levels, with the threat of asphyxiation. See also the section on carbon dioxide in this appendix.

Pyrolytic products of resins used in primers/paints

The main products of thermal decomposition of resins used in primers and paints are carbon monoxide and carbon dioxide. Specific toxic or irritant chemicals given off from the resins used in priming materials include such hazardous substances as phenol, formaldehyde, acrolein, isocyanates and hydrogen cyanide. Usually, a very complex mixture of organic gases is formed.

Further Reading

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