PULMONARY HEALTH HAZARDS IN MANUAL WELDING OPERATION IN CONSTRUCTION: A STUDY ON ENGINEERING CONTROL MEASURES

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1. INTRODUCTION:
Welding is a metallurgical process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the work pieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld.

In construction work involving structural steel and pipelines, welding is an important process such as pipe welding, structural steel fabrication, structural steel welding etc.

The electric arc is struck between the electrode and the work piece, 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

Welding operation adopted is hazardous in nature and classified as hot work. Hot work activities, such as welding and gas cutting, involve the use of heat.

Besides health hazards due to exposure to welding products including fumes, sparks etc. The flames, sparks and heat produced during the hot work are ignition sources which can cause fires and explosions in many different situations.

Examples of potential exposure associated with the various welding process are:

<table>
<thead>
<tr>
<th>Process</th>
<th>Potential Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMAW</td>
<td>Excessive fume concentration and fluoride (MS)chromium and nickel (SS)</td>
</tr>
<tr>
<td>FCAW</td>
<td>Excessive fume levels</td>
</tr>
<tr>
<td>Air carbon arc/ Plasma arc cutting</td>
<td>Excessive fume; noise</td>
</tr>
<tr>
<td>Oxy-gas cutting</td>
<td>Production of carbon monoxide or oxides of nitrogen</td>
</tr>
<tr>
<td>Thermal spraying</td>
<td>Excessive fume levels of sprayed metal, e.g. zinc</td>
</tr>
<tr>
<td>Confined spaces</td>
<td>Oxides of nitrogen</td>
</tr>
</tbody>
</table>

Contents of the welding fumes depend on the components of the base metal, coatings and/or filler materials and the temperatures used in the welding process. Types of metals commonly found in welding fumes include aluminum, beryllium, cadmium oxides, chromium, copper, fluorides, iron oxide, lead, manganese, molybdenum, nickel, vanadium and zinc oxides. Types of gases, includes carbon monoxide, fluorine, hydrogen fluoride, nitrogen oxide, ozone etc.

Since such fumes and gases could be hazardous to worker health. It is necessary to study the chemical characteristics of these chemicals suitably to find out suitable mitigation measures.

Exposure to welding fumes can cause numerous health problems. When inhaled, welding fumes can enter the lungs, bloodstream, brain nerve cells, spinal cord and other organs and can cause both short- and long-term health effects.

1.1 Materials used in welding

1.1.1 Core and filler metals

Generally, core and filler material are of identical alloy in chemical composition to the material being welded. Most commonly used material is mild steel. Special steels may contain chromium, nickel, aluminum, or tungsten etc. Stainless steel electrodes may contain up to 26 per cent chromium and 21 per cent nickel.

1.1.2 Electrode coatings (fluxes)

We understand from research papers that complex mixtures are coated with MMAW electrodes generates the following during welding:

- cellulose, carbonates various metals or their oxides, calcium fluoride etc.
- oxides of titanium, silicon, manganese and magnesium
- Readily ionisable elements such as sodium, potassium, calcium etc.

Electrode coatings may also include ferro-manganese, ferro-vanadium and ferro-silicon.

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.

1.2 Welding Process:

Before studying the health hazards of welding fumes, we need to understand various Welding Processes which are as given below:

1.2.1 Health hazards related to various manual welding processes:

1.2.1.1 Manual metal arc welding (MMAW)

The flux material of MMAW while vaporizing it forms a shielding gas (carbon dioxide) to protect the cooling weld deposit from the air.

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.

1.2.2 Non-consumable electrode processes

1.2.2.1 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.

Examples of welding gases:

Gases used in welding and cutting processes include:

- Shielding gases such as carbon dioxide, argon, helium, etc.
Oxygen, used with fuel gases and also in small amounts in some shielding gas mixtures

Gases produced from welding and cutting processes include:

- Carbon dioxide from the decomposition of fluxes
- Carbon monoxide from the breakdown of carbon dioxide shielding gas in arc welding
- Ozone from the interaction of electric arc with atmospheric oxygen
- Nitrogen oxides from the heating of atmospheric oxygen and nitrogen
- Hydrogen chloride and phosgene produced by the reaction between ultraviolet light and the vapours from chlorinated hydrocarbon degreasing solvents (e.g., trichloroethylene, TCE)

Gases are also produced from the thermal breakdown of coatings:

- Polyurethane coatings can produce hydrogen cyanide, formaldehyde, carbon dioxide, carbon monoxide, oxides of nitrogen, and isocyanate vapours.
- Epoxy coatings can produce carbon dioxide and carbon monoxide.
- Vinyl paints can produce hydrogen chloride.
- Phosphate rust-inhibiting paints can release phosphine during welding processes.
- Minimizing exposure to degreasing solvent vapours.

### Table 1: Health Hazards of Metal Fumes

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<tr>
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<td>Alloys, e.g., Inconels, copper, zinc, steel, magnesium, and brass and filler materials</td>
<td>Respiratory irritants</td>
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<td>Lead</td>
<td>welding / cutting of metal that which may contain lead in different forms</td>
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<td>Coating of certain element that is being welded</td>
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### 1.2.3.3 Gases

#### 1.2.3.3.1 Fume formation

Welding process generates considerable amount of welding fumes. Due to the high temperature of welding arc constituents of core metal and flux reacts which eliminates fume particles consisting a mixture of complex oxides etc. Formation of welding fumes due to product of reaction of core and flux components will depend on the following:

- welding conditions, which influence arc and gas temperatures;
- heats of formation, a thermochemical factor; and
- relative volatilities, that is, vapourisation 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 work-piece 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.

#### 1.2.3.3.2 Metal fumes

In welding processes, metals may be alloyed with other elements to form metallic mixtures of complex oxides, etc. Formation of welding fumes which eliminates fume particles consisting a mixture of oxygen, used with fuel gases and also in small amounts in some shielding gas mixtures

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A study on 870 illness cases reported at medical facilities have reported that Illness pattern of welders may be classified in various ways including its nature of exposure to welding fumes. Equipment generated during welding operations particularly, for stainless steel or plasma arc cutting of stainless steel. Overexposure may cause drowsiness, headache and nausea. If carbon monoxide exposure is sufficiently severe, unconsciousness may occur.

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<th>Effect of Welding</th>
<th>Ventilation Arrangement</th>
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<tr>
<td>Carbon monoxide</td>
<td>Through 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</td>
<td>Overexposure may cause drowsiness, headache and nausea. If carbon monoxide exposure is sufficiently severe, unconsciousness may occur.</td>
</tr>
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<td>Carbon dioxide</td>
<td>Common in GMAW</td>
<td>Can cause asphyxiation</td>
</tr>
<tr>
<td>Phosphine</td>
<td>steel coated with a rust proofing compound is welded</td>
<td>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.</td>
</tr>
<tr>
<td>Insufficient oxygen</td>
<td>In GMAW, the presence of inert gases (argon, helium) in confined work environments may reduce the oxygen content of the atmosphere to dangerous levels, Can cause asphyxiation</td>
<td></td>
</tr>
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1.3 Welding in construction industry: Challenges

As already discussed, welding in construction industry is different in various ways including its nature of work such as work at height for e.g., on structures, pipe racks, equipment, etc. Welding sometimes take place at below ground level in excavated pits or tunnels for example during welding of underground pipes, utilities etc. In some instances such welding operations are also carried on inside confined space. In all the above mentioned cases each activity differs in terms of control measures. Such welding operations at construction sites are ideally to be carried out by providing an enclosed booth-like set-up to prevent the ingress of oxidation material (air) during welding. Since the job is dynamic, 100% effective engineering controls to handle the welding fumes is really very difficult. Personal Protective Equipment have limited effectiveness in reducing the likelihood and the consequence of risks and harm associated with exposure to welding fumes.

2. Methods:

Illness patterns of large number of welders deployed at various project sites were studied. Based on the findings suitable engineering intervention possibilities were explored. Details are given below:

2.1 Study on Illness pattern of welders

A study on 870 illness cases reported at medical centre at five major construction projects were analyzed and it was found that 73% of the welders have reported eye irritation followed by eye irritation as well body pain by 16% of the welders. Details highlighted in Chart 1

Ventilation arrangements were studied for various welding applications. In outdoor or semi-outdoor situations, natural air circulation can be sufficient to provide enough ventilation. Its effectiveness, however, depends on whether the day is windy or calm and in wind direction upwind or downwind. Using welding curtains, spark enclosures or hoardings when working outside prevents exposure to natural air movement and therefore prevents effective ventilation.

2.2 Interventions:

2.2.1 General ventilation

In indoor locations and confined spaces, draft fans or air-movers provide general or dilution ventilation. A well-designed and well-maintained ventilation system is usually effective for most situations involving clean, uncoated, mild steels. However, the only means of judging if the system is doing its job is to take regular airflow measurements and to sample for exposure. For example, in the U.S.A. Occupational Safety and Health Administration (OSHA) require that a minimum of 65 cubic metres (2000 cubic feet) of air be moved per minute for each welder in a room. These figures might vary if, for example, a plasma-arc machine is being used inside a room.

2.2.2 Local exhaust systems

Vent hoods or gun-mounted exhausts can provide local exhaust ventilation. Local exhausts are the most effective ventilation systems for all situations that generate fumes containing heavy metals and, particularly, for stainless steel or plasma-arc welding. In field locations portable hoods may be explored. The effectiveness of local exhaust ventilation depends on the distance the hood is from the source of gases and fumes, on the air velocity and on the hood placement.

2.2.3 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

3. RESULTS:
Reduction of harm potential is achieved through reduction of concentration of hazardous fumes/gases in the breathing zone of the operator. Accordingly, concentrations of relevant common hazardous fumes/gases are measured in before and after the intervention.

As per hierarchy of controls, engineering control is one of the effective options after elimination and substitution. However, additional controls such as regular medical examination of welders, regular supervision/surveillance of welding operation is also very important aspect of consideration for an effective and safe welding operation.

A simple, easy-to-fix, forced ventilation equipment to handle welding fumes was fabricated. This equipment can easily be fixed at various typical work-spots based on the specific requirements. The new ventilation system has the following components:

- **Divergent Portion**: The place through which the welding fumes are taken inward through the battery operated fan fixed inside the body of the equipment.
- **Body**: It is the central portion through which fumes are transferred to the filtration process; the filter is generally a honey comb metallic filter.
- **Filter**: This is simple metallic honey comb structured metallic filter. This will facilitate the filtration process of welding fumes.
- **Convergent**: The convergent portion enables venting of welding fumes that are generated from the filtration process.
- **Leveler & fixing arm**: The ventilation system has a leveler and a fixed arm. The leveler arm helps in projecting the divergent portion towards the welding fumes and fixing arm helps in fixing the same to the any structure. Hence this arm enables the quick fix arrangements.

The new ventilation system helps in handling welding fumes that get generated and removed from workplace. Since filtration is a part of the ventilation process, generated welding fumes get filtered before emanating to atmosphere.

The applications of the ventilations systems are being utilized for various types of applications as given below:
- Ventilation system for welding pipes
- Ventilation system for welding structural steel
- Ventilation system inside confined space (Inside Pipes, Equipment etc.)

3.1 Findings:
Reduction of harm potential is achieved through reduction of concentration of hazardous fumes/gases in the breathing zone of the operator. Accordingly, concentrations of relevant common hazardous fumes/gases are measured in before and after the intervention.

<table>
<thead>
<tr>
<th>Description</th>
<th>Before</th>
<th>After</th>
<th>Safe Concentration Limits as per Schedule XII of BOCW Central Rules</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide</td>
<td>32.5 PPM</td>
<td>9 PPM</td>
<td>50 PPM</td>
<td>Instrumental Analyzer Procedure</td>
</tr>
<tr>
<td>Lead &amp; certain inorganic compounds</td>
<td>0.15 mg / m³</td>
<td>0.10 mg / m³</td>
<td>-</td>
<td>0.15</td>
</tr>
<tr>
<td>Oxides of Nitrogen</td>
<td>20 PPM</td>
<td>12 PPM</td>
<td>25 PPM</td>
<td>-</td>
</tr>
<tr>
<td>Cadmium or its compounds</td>
<td>0.05 mg / m³</td>
<td>0.03 mg / m³</td>
<td>-</td>
<td>0.05</td>
</tr>
</tbody>
</table>
3.2 Conclusion:
Implementation of the above-mentioned engineering control measures are effective for reducing the concentration of harmful substance at the breathing zone of workers exposed during manual metal arc welding process at construction sites.

REFERENCES:
   http://www.asse.org/practicespecialities/articles/weldingfumes.php
5. Canadian Centre for Occupational Health & Safety (2010). (Internet) Available from:
   http://www.ccohs.ca/oshanswers/safety_haz/welding/fumes.html