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Welding and Industrial Hygiene: The Welding Process and Lessons Learned

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Welding presents a variety of potential occupational health hazards, including possible exposures to welding fumes, particulates and gases. This paper will provide an overview of industrial hygiene issues related to potential exposures to welding emissions, including the types of welding processes and equipment, the industrial hygiene "science" of welding fumes, air monitoring variables, and information on the OSHA standard for hexavalent chromium (CrVI) as it applies to welding activities.

Specifically, this paper will provide a brief summary of the common types of welding processes and equipment and how they contribute significantly to the potential for exposure to welding fumes. Readers will understand why the proper use of the equipment is a major factor in preventing health issues related to welding.

Readers will then be provided with details of the "science" behind welding fumes through a discussion of industrial hygiene (IH) best practices related to the identification and investigation of welding health issues, including preferred respiratory protection. Air monitoring for welding fumes requires particular attention to the variables involved in the welding process. Variables to be discussed include the types of welding, the content of the base metal and welding rods, as well as general and point-of-operation ventilation.

Finally, as an example of the regulatory aspects of welding and industrial hygiene, a summary of the Occupational Safety and Health Administration (OSHA) standard for CrVI will be presented including the significance of the permissible exposure limit (PEL) and the action level (AL), required work practices, and exposure assessments, including the use of objective and historical data, as well as methods of compliance.

What Happens During Welding

Arc welding is probably the most common type of welding done today. In arc welding, an electrode is connected to one end of an electrical power supply, and the metal to be welded is connected to the other end. The welder touches the tip of the electrode to this metal, then draws it away to produce a short gap, a fraction of an inch in length, between the electrode and the metal. The voltage in the power supply causes an electrical current to bridge this gap. The current heats the air to create a plasma, which emits a very intense light, which is the welding arc. In the high-power welding arc plasma, all the particles—the negatively charged electrons, the positively charged heavier particles ("ions"), and the remaining neutral atoms—are at nearly the same temperature, which exceeds 11,000˚F. This temperature is well above the melting temperature of all known materials, and above the boiling point for most elements found in metals commonly used in industrial applications. Everything in contact with this intense plasma melts or vaporizes, and the edges of the metal pieces to be joined melt and form a liquid pool.

In most arc welding processes, the tip of the electrode also melts, and the resulting liquid metal transfers across the arc to the weld pool as drops of liquid to combine with and enlarge that pool. As the arc is removed, the weld pool cools and solidifies to form a weld. The electrode material melted into the weld is called "filler" metal, as it fills the gap between the metals being welded.

Generally, electrodes have the same composition as the base metals that are being welded. Electrodes are manufactured as bare wire, or they are manufactured as lightly or heavily coated with flux material. While they are the least expensive, bare wire electrodes are difficult to maintain and they produce inferior welds. The electrode may be coated with a copper layer to control oxidation (rusting) before the electrode is used. Flux material is used to protect the electrode before it is used, and generates a shielding gas that prevents or removes oxides and other undesirable materials during the process. Flux generally consists of fluorine compounds, minerals, metal oxides and carbonates.

In most modern-day welding processes, gas shielding is used to protect the weld pool from contamination and rapid oxidation. Gases such as helium, argon, and carbon dioxide are used.

Welding Processes

Welding is a fabrication or sculptural 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. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the pieces to form a bond between them, without melting the work pieces.

Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding can be done in many different environments, including open air, under water, and in outer space.

Regardless of location, welding remains hazardous, and precautions are taken to avoid burns, electric shock, eye damage, and exposure to chemical fumes and ultraviolet light.

Welding is performed in numerous industries, including shipbuilding, construction, fabrication shops, railroads, aerospace, manufacturing and many other trades and industries. The type of welding used is based on a number of considerations, including the type of base metal used, the quality of the weld required, and other variables. Many distinct factors influence the strength of welds and the material around them, including the welding method, the amount and concentration of energy input, the weldability of the base material, filler material, and flux material, the design of the joint, and the interactions among all these factors

Gas tungsten arc welding (GTAW), also known as *tungsten inert gas* (TIG) welding, is an arc welding process that uses a nonconsumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas (usually an inert gas such as argon), and a filler metal is normally used, though some welds, known as *autogenous welds*, do not require it.

A constant-current, welding power supply produces energy, which is conducted across the arc through a column of highly ionized gas and metal vapors known as a *plasma*. GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals, such as aluminum, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing procedures, such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques. A related process, plasma arc welding, uses a slightly different welding torch to create a more focused welding arc and, as a result, is often automated.

Plasma arc welding (PAW) is an arc welding process similar to gas tungsten arc welding (GTAW). The electric arc is formed between an electrode (which is usually, but not always, made of sintered tungsten) and the work piece. The key difference than GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope. The plasma is then forced through a fine-bore copper nozzle, which constricts the arc, and the plasma exits the orifice at high velocities (approaching the speed of sound), and a temperature approaching 20,000 °C. Plasma arc welding is an advancement over the GTAW process. This process uses a non-consumable tungsten electrode and an arc constricted through a fine-bore copper nozzle. PAW can be used to join all metals that are weldable with GTAW (i.e., most commercial metals and alloys).

Gas metal arc welding (GMAW), sometimes referred to by its subtypes *metal inert gas* (MIG) *welding* or *metal active gas* (MAG) *welding*, is a semi-automatic or automatic arc welding process in which a continuous and consumable wire electrode and a shielding gas are fed through a welding gun. A constant-voltage, direct-current power source is most commonly used with GMAW, but constant-current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called *globular, short-circuiting, spray,* and *pulsed-spray*, each of which has distinct properties and corresponding advantages and limitations.

Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it allowed for lower welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases, such as carbon dioxide, became common. Further developments during the 1950s and 1960s gave the process more versatility and, as a result, it became a highly used industrial process. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed, and the relative ease of adapting the process to robotic automation. The automobile industry in particular uses GMAW welding almost exclusively. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility.

Flux-cored arc welding (FCAW or FCA) is a semi-automatic or automatic arc welding process. FCAW requires a continuously fed, consumable tubular electrode containing a flux and a constant-voltage or, less commonly, a constant-current welding power supply. An externally supplied shielding gas is sometimes used, but often the flux itself is relied upon to generate the necessary protection from the atmosphere. The process is widely used in construction because of its high welding speed and portability.

Shielded metal arc welding (SMAW), also known as *manual metal arc* (MMA) *welding* or informally as *stick welding*, is a manual arc welding process that uses a consumable electrode coated in flux to lay the weld. An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination.

Because of the versatility of the process and the simplicity of its equipment and operation, shielded metal arc welding is one of the world's most popular welding processes. It dominates other welding processes in the maintenance and repair industry, and though FCAW is growing in popularity, SMAW continues to be used extensively in the construction of steel structures and in industrial fabrication. The process is used primarily to weld iron and steels (including stainless steel) but aluminum, nickel and copper alloys can also be welded with this method.

Oxy-fuel welding (commonly called *oxyacetylene welding, oxy welding*, or *gas welding* in the U.S.) and *oxy-fuel cutting* are processes that use fuel gases and oxygen to weld and cut metals, respectively. Pure oxygen, instead of air (20% oxygen/80% nitrogen), is used to increase the flame temperature to allow localized melting of the work piece material (e.g., steel) in a room environment. A common propane/air flame burns at about 3630 °F (2000 °C), a propane/oxygen flame burns at about 4530 °F (2500 °C), and an acetylene/oxygen flame burns at about 6330 °F (3500 °C).

Oxy-fuel is one of the oldest welding processes, though in recent years it has become less popular in industrial applications. However, it is still widely used for welding pipes and tubes, as well as for repair work. It is also frequently well suited, and favored, for fabricating some types of metal-based artwork.

In oxy-fuel welding, a welding torch is used to weld metals. Welded metal results when two pieces are heated to a temperature that produces a shared pool of molten metal. The molten pool is generally supplied with additional metal called *filler*. Filler material depends upon the metals to be welded.

Submerged arc welding (SAW) is a high-productivity welding method in which the arc is struck beneath a covering layer of flux. This increases arc quality, since contaminants in the atmosphere are blocked by the flux. The slag that forms on the weld generally comes off by itself, and combined with the use of a continuous wire feed, the weld deposition rate is high. Working conditions are much improved over other arc welding processes, since the flux hides the arc, and almost no smoke is produced. The process is commonly used in industry, especially for large products and in the manufacture of welded pressure vessels. Other arc welding processes include atomic hydrogen welding, electroslag welding, electrogas welding, and stud arc welding.

Characteristics of Welding Emissions

The composition of the plume of smoke generated during welding processes is highly variable, and depends on several factors including: the type of welding being performed; the base metal (or work piece) being welded, including any coatings present and residue from any surface preparation processes (like degreasing); the electrode or filler metal; the flux used; the voltage and amperage used; the skill of the welder; and, other environmental conditions. While the composition varies, substances present in the plume can be categorized into three classes: (1) metal fumes, (2) particulates, and (3) gases.

Fumes are small metal aerosols generated when metals are heated above their boiling point, causing the metal to volatilize. The plasma temperature in the welding arc is well above the boiling point of many of the elements commonly found in metals and alloys. As the vaporized metal aerosol cools, it condenses into very small particulates. The size of the fume particulate generated is also highly variable, with diameters ranging from nanometers (nm) to about 5 micrometers (μm).

In addition to "boiling" the metals being welded, the energy in the plasma field is sufficient to alter the valence states of the metals. The most notable is the oxidation of chromium (Cr) to a hexavalent state, or CrVI. While the chromium content present in welding electrodes or base metals is not CrVI, the oxidation of Cr during the welding process produces CrVI fume. CrVI fume is more likely to be present in welding activities conducted on corrosion-resistant steel (CRES), such as stainless steel and steel alloys. CRES differs from carbon steel in the amount of chromium present in the metal or alloy, where CRES has a higher chromium content. The chromium forms a protective chromium oxide layer on the surface of metal, protecting the metal from corrosion. The more chromium is present in the base metal, the more CrVI is formed during arc welding processes.

The largest source of metal fumes generated during the welding process is the electrode or filler metal. Therefore, the composition of the fumes generated during welding is likely to be very similar to the composition of the electrode or filler metal. Electrodes used when welding CRES typically have higher chromium content, and therefore yield more CrVI as they are consumed in the arc welding process.

Some fumes are generated from the base metal of the work piece, and some may be generated from coatings applied to the work piece (such as corrosion conversion coatings containing chromium or cadmium, or paints containing lead, copper, chromium, and other metals). Flux material applied to the electrode may also be a source of metal fumes.

Fumes are not the only particulates generated during the welding process. In some types of welding processes, powdered flux may be used. This powered flux can become airborne during the welding process, resulting in fugitive emissions of dusts. The components of flux that is manufactured into the electrodes are also emitted during welding as the electrode is consumed, and can include fluorides, nitrogen oxides (NO_x), carbon monoxide (CO), and hydrofluoric acid (HF). In addition, metal particulates are typically generated by surface preparation and finishing processes, such as grinding and brushing, which can be considered part of the welding process. Finally, the shielding gases used in the welding process and byproducts of the combustion of these gases can be present in welding emissions.

Table 1 summarizes the sources of the gases and particulates found in welding emissions.

Table 1. Sources of Fumes, Particulates and Gases in Welding Emissions

Component	*Source*
Iron Oxide (Fe_2O_3)	• Principal alloying element in steel manufacture
Zinc (Zn)	• Used in large quantities in the manufacture of brass, galvanized metals, and other alloys
Cadmium (Cd)	• Used as a rust-preventive coating on steel and as alloying agent
Manganese (Mn)	• Largest user is steel industry (adds strength and hardness and removes sulphur contamination); • Component of flux in many SMAW and FCAW electrodes and GMAW consumables (content is usually <6%)
Chromium (Cr)	• Cr is an alloy constituent used in stainless steel base and filler material, chrome plating and anodized aluminum • CrVI is generated by the oxidation of Cr under intense temperature/energy
Beryllium (Be)	• Alloying agent used in production of beryllium-copper alloys
Copper (Cu)	• Used in wire and electrical components due to high electrical conductivity and relative abundance in nature • Most commonly seen in welding world as chief ingredient in brass and bronze
Lead (Pb)	• Lead oxide fumes generated by cutting and welding of lead-bearing alloys or metals coated with lead-based paint
Nickel (Ni)	• Used to make austenitic stainless steel, steel alloys and superalloys
Mercury (Hg)	• Metal coating for rust inhibitor
Fluorides (F) Hydrogen Fluoride (HF)	• Component in many welding fluxes • Produced by the combustion of flux containing F
Chlorinated Hydrocarbons	• Used in degreasing operations • Coating systems on base metals (PCB-containing paints)
Phosgene ($COCl_2$)	• Formed by decomposition of chlorinated hydrocarbons by UV

Table 1. Sources of Fumes, Particulates and Gases in Welding Emissions	
Component	*Source*
	radiation and heat
Carbon monoxide (CO)	• Welding and cutting may produce significant amounts
Ozone (O_3)	• Produced by UV light from welding arc (GMAW, GTAW, and plasma cutting produce higher quantities)
Nitrogen Oxides (NO_2)	• Produced by GMAW, GTAW, and plasma cutting

Industrial Hygiene Considerations in Welding

Welding emissions can contain a variety of airborne metal fumes, dusts, and gases. While some components that may be present in the welding emission plume can be hazards to the skin, the primary concern is exposures through inhalation. Inhaling the fumes, dusts, and gases is the primary route of entry into the body.

Acute and Chronic Exposures

The potential for disease from welding-related exposures depends on the type of welding being performed, the characteristics of the metal being welded and of any coatings present on the metal, the makeup of any consumable electrode in use, and the intensity and duration of the exposures. Certain welding situations are well recognized for their potential to cause acute respiratory problems, such as welding on zinc-containing galvanized metals that can cause metal fume fever, a flu-like illness.

Chronic respiratory problems have also been associated with welding in poorly ventilated spaces, including higher rates of chronic bronchitis symptoms and decreased lung function. Decreased lung functions tend to be related more to welding on stainless steel as compared to mild or carbon steel, and to manual metal arc welding as compared to MIG welding. Some studies have suggested that welding-related exposures may cause asthma. Most studies are limited by a lack of information on the types, durations, and intensities of workers' exposures.

All CrVI compounds, including CrVI fumes, are considered potential occupational carcinogens; the National Institute for Occupational Safety and Health (NIOSH) has reported an increased risk of lung cancer in workers exposed to CrVI compounds. Breathing small amounts of CrVI, even for long periods, may not cause respiratory tract irritation in most people. However, breathing in high levels of CrVI can cause irritation to the nose and throat. Symptoms may include runny nose, sneezing, coughing, itching and a burning sensation. Repeated or prolonged exposure can cause sores to develop in the nose, and result in nosebleeds. If the damage is severe, the nasal septum can develop a perforation.

CrVI can also cause allergic skin reactions, called *allergic contact dermatitis*. Once an employee becomes allergic, brief skin contact with CrVI compounds can cause swelling and a red, itchy rash that becomes crusty and thickened with prolonged exposure. Allergic contact dermatitis is long-lasting and more severe with repeated skin contact. Direct contact with CrVI can also cause a non-allergic skin irritation. Contact with non-intact skin can also lead to chrome ulcers.

Exposure limits for welding-related particulates have historically been based on the amount (or mass) of particulate in the air, and have not considered particle size. The toxicity of particulates has a lot to do with where they are deposited in the respiratory system. Some particulates can be hazardous regardless of where they are deposited in the respiratory system, while others are only considered hazardous if they enter into the lowest regions of the lung where oxygen exchange with blood occurs. Metal fumes can vary widely in size, and can be small enough to enter the lowest regions of the lung. In recent years, the American Conference of Governmental Hygienists (ACGIH) has recognized particle size in recommending threshold limit values (TLVs) for various particulates, including welding fumes. Many of the current and proposed TLVs for certain dusts and fumes are based on particulate sizes considered "inhalable," meaning they are capable of doing harm if they can enter the upper respiratory system, and "respirable," meaning they are capable of doing harm if they enter the lowest regions of the lung.

Medical Surveillance

Because of the nature of welding, and the variety of hazards to which welders may be exposed, any medical surveillance program developed should include an examination that addresses the respiratory system, eyes, and skin. An effective medical surveillance program must consider:

- the hazards present and the extent of the exposure to those hazards (the frequency, duration and environmental conditions of activities must be considered);
- known or estimated exposure levels, including an evaluation of any exposure monitoring results;
- medical surveillance requirements specified in OSHA standards for certain constituents present in welding emissions, such as lead, cadmium, and CrVI;
- personal protective equipment (PPE) used; and
- the frequency and nature of reported illnesses or injuries related to welding.

Medical surveillance programs should consider pre-placement or pre-employment exams to assess functional capacity relative to work demands, and to establish baseline medical data that can be used for comparison in subsequent medical exams. The pre-placement exam should include a medical history review and a clinical examination. Specialized tests, such as a pulmonary function test or chest X-ray, may also be recommended by the examining physician; biological monitoring for metals and fluorine in blood or urine may also be recommended.

Annual exams should be conducted to assess changes in the health of the employee. In addition, exams, including specialized testing and biological monitoring, should be conducted following an event where an employee is exposed as the result of an accident.

OSHA has prescribed medical surveillance for lead, cadmium, and CrVI, which must be implemented if exposures exceed the established action level (AL) for any of these metals. The following standards specify the content and frequency of medical surveillance:

- *Lead:* 29 CFR 1910.1025(j) and 1926.62(j)
- *CrVI:* 29 CFR 1910.1026(k), 1926.1125(i), and 1915.1026(i)
- *Cadmium:* 29 CFR1910.1027(l) and 1926.1127(l)

Medical surveillance requirements for lead and cadmium in the shipyard industry are found in the General Industry standards for these substances.

In addition, any employer that provides a welder a respirator to control an exposure to a potentially hazardous substance that exceeds the PEL must comply with the medical surveillance requirements specified in the OSHA standard 29 CFR 1910.134, *Respiratory protection*. This standard requires that, at a minimum, a medical history questionnaire be evaluated by a physician or other licensed healthcare provider (PLHCP). The PLHCP may require additional exams or medical tests based on the employee's reported medical history.

Workplace Exposure Monitoring

Exposure monitoring in the workplace should be based on the type of welding being conducted and the recognized occupational exposure limit (OEL) that has been selected as the criteria for assessing exposures. The three principal organizations that have established OELs that are recognized in the U.S. are OSHA, the American Conference of Government Industrial Hygienists (ACGIH), and NIOSH:

- *OSHA* regulates workplace exposures of airborne contaminants through established permissible exposure limits, or PELs, specified in Subpart Z of the General Industry, Construction, and Shipyard Industry standards.
- *ACGIH* publishes recommended threshold limit values (TLVs) for airborne contaminants.
- *NIOSH* publishes recommended exposure limits (RELs) for airborne contaminants.

Generally, exposure monitoring for welding should be designed to measure exposures to:

- Metals that may be present in the base metal, the electrode, or filler metal
- Components of any coating or residue that may be present on the base metal
- Gases generated during the combustion of organic material or flux, and ozone

When conducting workplace exposure monitoring, it is important to understand that the only recognized technique for assessing representative worker exposures to welding emissions is *personal breathing zone air monitoring*. This technique involves collecting a sample of the air from the welder's breathing zone during the actual work shift. Other methods are not acceptable for an evaluation of occupational exposure. For example, many published studies present air testing to characterize the composition of welding fume that has been collected in a small, unmanned, sealed chamber by placing a cone close to the point where welding is conducted and drawing air through a large filter. This type of data, collected accordance with methods such as the American Welding Society's AWS F1.2:1999, *Laboratory Method for Measuring Generation Rates and Total Fume Emission of Welding and Allied Processes*. (AWS 1999), may be useful for metallurgists in measuring deposition and losses from the composition of the emissions generated at the weld pool from a specific welding process. The results from this type of testing are not intended to characterize the welder's breathing zone exposures, and they should not be applied to that purpose.

OSHA and NIOSH have developed and published validated sampling and analytical methods for assessing workplace exposures to the components of welding emissions. These methods are used to identify specific components of the welding emissions. Recognized sampling methods for welding fumes involve collecting an air sample from the welder's breathing zone, using a filter cassette attached to a calibrated, battery-powered air-sampling pump by flexible tubing. Most commercial, accredited laboratories provide welding fume profile analyses, which include the analysis of multiple metals typically found in welding emissions from a single air sample.

Sampling and analytical methods for measuring CrVI exposures are different than methods for measuring other welding fumes. Because CrVI is reactive and can be readily reduced to chromium in the presence of organic material, air samples are collected on inert filter media (typically polyvinyl chloride), and must be transported to the laboratory quickly. Studies have shown that organic dusts captured in the air sample can reduce CrVI over time, which may result in an artificially lower-measured CrVI concentration.

Recently, the ACGIH published TLVs based on particle sizes. For some welding fumes, like manganese (Mn), the TLVs are based on the inhalable or respirable sizes of the dust or fume. For direct comparison to these TLVs, air sampling techniques that differentiate particle sizes must be conducted. For TLVs that are based on the inhalable fraction of airborne dusts or fumes, exposure monitoring must be conducted, using an air sampler that has a collection efficiency of 50% (50% cut-point) at 100µm. For TLVs that are based on the respirable fraction, exposure monitoring must be conducted using an air sampler that has a 50% cut-point at 4µm.

When conducting exposure monitoring during welding processes, PPE used during the process must be considered. Welding face shields provide some protection of the welder's breathing zone; the concentration of welding emissions inside the mask can be dramatically different than concentrations outside of the mask. To characterize breathing zone exposures, placing the filter cassette or monitoring device inside the welding shield provides results that best represent the welder's exposure.

Workplace and Monitoring Variables

The variables involved in evaluating and monitoring for welding fumes, including CrVI, need to be addressed in order to achieve consistent results and information for workplace revisions and proper protection of workers. Variables can be divided into four main categories: (1) location of the work, (2) personal factors, (3) air movement and air movers, and (4) the welding process.

The location includes variables such as the estimated size of the immediate work area. The work area could be a welding booth, a small room, a large room, or an outdoor worksite. It would be beneficial to record both the square feet and cubic feet of the work area. It is helpful to provide a verbal description and diagram of the welding area/room on separate sheet or in an activity diary.

The first critical determination is to evaluate and decide if the area or work space meets the definition of a confined space. *Confined spaces* offer significant contributions to air monitoring considerations, including deceased levels of oxygen and increased levels of fumes and other contaminants. Proper, additional precautions would be required if indeed the work area is a confined space.

The number of welders in the work area, in addition to any other adjacent welding operation, is important, as the combined welding tasks contribute to the potential fume production. When looking at potential exposures, it is important to also evaluate, and include in a hazard assessment, operations involving "cutting" and "burning" as they also contribute to "fume generation."

Personal factors that could contribute to overexposure to welding fumes include the body position of the welder relative to the welding point (proximity and orientation). For example, is the welders head positioned within the rising plume? Is the work being conducted overhead, where falling debris can enter the breathing zone?

It is important to log the type of PPE worn by the welder, as varying PPE can contribute to varying monitoring results. The make and model of respirator and cartridges, the make and model of the welding helmet, and other PPE, such as gloves, aprons, and hearing protection, should be noted.

The overall air movement and air movers in the work area have a direct effect on the potential for welding fume exposure. The proper use of mechanical ventilation, such as point-of-operation ventilation, is critical to its effectiveness. All too often, the “hood” of portable and fixed point of operation equipment is not adjusted properly (within adequate distance to the weld point), resulting in poor fume removal from the breathing zone of the worker.

Mechanical general ventilation and natural ventilation in the area should be considered. As in the case of confined spaces, the lack of ventilation can cause significant fume buildup. Consider the ceiling level of manufacturing facilities where “clouds” of smoke and fume accumulate and contribute to poor air quality and possible over exposure to related chemicals. If possible, calculate the exhaust rate and number of air changes per hour as a way to determine effectiveness of overall ventilation in the area.

A hazard assessment should include any barriers to obstructing ventilation and air flow, including items such as welding screens and curtains, and balconies, partitions, walls, and other structural members. A related consideration is the use of cooling fans or makeup air units including the forced air direction relative to welder’s breathing zone.

As described earlier in this paper, the welding process (i.e., GTAW, FCAW, etc.), including the use of electrodes, wires and other “consumables,” contributes to the potential for overexposure. This also includes the amount of “power” needed to complete the weld (i.e., related considerations include the “ingredients” and thickness of the base metal).

The welded joint design being conducted and the position of the weld should also be examined, especially during welding operations in the field (versus a shop). The design and position of the weld often affects the accessibility of the welding point. Welding joint designs include fillet weld, square groove, bevel, flange, back-up, melt thru, plug, and spot. The position of welds includes flat, horizontal, vertical, and overhead.

Controlling and Preventing Exposures

The protection of workers involved in welding tasks can be categorized into four main sections: (1) consumables and processes; (2) source and local extraction; (3) general extraction and dilution; and (4) personal protective equipment (PPE).

As discussed in other parts of this paper, the welding process and related consumables contribute to the potential for overexposure to welding chemicals for numerous reasons. Therefore, the evaluation of the process should include the potential for fume generation, and include the possibility of replacing the process or consumable with a "less hazardous" choice.

Source and local extraction of fumes is fairly common but often used incorrectly. The idea behind this type of "point of operation" ventilation (extraction) is to remove the contaminant before it has the opportunity to reach the welder's breathing zone. It is imperative, therefore, that the position of the duct/hood of the system be placed properly. All too often, workers fail to move the hood to the correct position, thereby decreasing the effectiveness. Welding booths provide the same type of protection but at a larger scale

General extraction and dilution includes the use of more sophisticated methods, such as a "push-pull" system, whereby clean air is produced behind the worker and "pushes" the welding fume towards an extraction point. A general dilution system forces large quantities of air into the work area under the premise that the amount of "clean" air will dilute the level of contaminants to below hazardous levels.

The "last line of defense" is the use of respirators to prevent welders from breathing contaminated air. Respirators for welding tasks have come a long way, and they provide significant levels of prevention if used properly. Respirators should be used in conjunction with the controls described above to ensure the fullest personal protection. There are two main types of respirators: air purifying and supplied air. The type of respirator is dependent on various conditions, including the expected chemicals to be generated, the expected "amount" of chemicals in relation to the PELs or ALs, and the use of other controls and PPE, such as source extraction or welding helmets. Use of respirators is clearly spelled out in OSHA standards, including requirements for a written program, medical fit tests, training, and medical surveillance.

There are three points to remember when considering and implementing control measures:

- One solution does not fit all welding operations.
- Ongoing service and maintenance is critical.
- Training and education is the key. The proper use of point-of-operation systems and PPE greatly improve employer exposures.

Hexavalent Chromium (CrVI) Exposures during Welding

In February 2006, OSHA promulgated an expanded health standard for workplace exposures to hexavalent chromium (CrVI). This new standard became effective November 27, 2006, for large employers. This new standard has significant impact on welding activities. Occupational exposure limits for CrVI are summarized in Table 2.

Table 2. U.S. Occupational Exposure Limits for Hexavalent Chromium (CrVI)

Organization	*Occupational Exposure Limit*
NIOSH REL	0.2 $\mu g/m^3$ (TWA)
NIOSH IDLH	15,000 $\mu g/m^3$
OSHA PEL	5 $\mu g/m^3$ (TWA) 2.5 $\mu g/m^3$ (TWA) - Action Level 0.5 $\mu g/m^3$ (TWA) - Exemption Criteria

ACGIH TLV	50 μg/m^3 (TWA) - Water-soluble 10 μg/m^3 (TWA) - Insoluble Other TLVs for specific chromate compounds

In order to promote a practical and well-directed effort in assessing CrVI exposures during hot work activities for compliance with the OSHA standard, the shipbuilding industry collected and reviewed existing historical objective CrVI exposure monitoring data. Some general observations can be made based on exposure monitoring conducted in the shipbuilding industry, as well as other industries, including the petrochemical, aerospace and metal fabrication industries concerning exposures to CrVI:

1. The magnitude of CrVI exposures can be somewhat predicted by the type of welding conducted; however, it is important to understand that factors, including welder experience and body position, process variables (e.g., wire speed, equipment condition, etc.), and environmental conditions (e.g., workspace configuration, ventilation, etc.) can substantially influence fume concentrations in the breathing zone. Exhibit 1 shows a comparison of CrVI exposures measured during various welding activities in shipyards. Studies conducted in other industries showed similar trends.

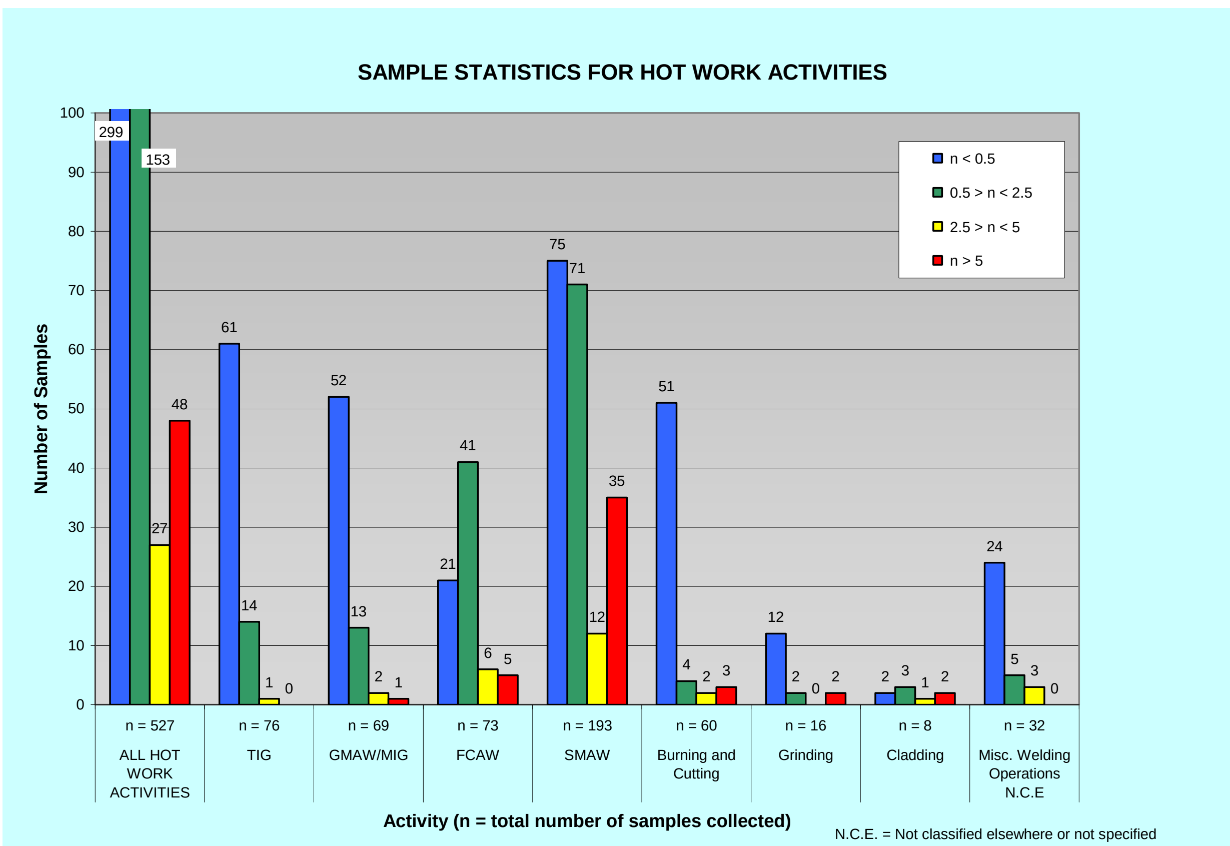

Exhibit 1. Comparison of CrVI Exposures (in μg/m^3) Measured During Shipyard Welding Activities.

2. Base metal composition influences CrVI exposures. Exposures during welding of base metals with higher chromium (Cr) content, such as stainless steel or other corrosion-resistant alloys, were higher than those during welding of mild steel. CrVI exposures during welding aluminum where notably lower than welding steel.
3. The composition of the filler/electrode has a significant influence on exposures to CrVI. Higher exposures have been measured during the use of filler metals or electrodes that contain higher concentrations of chromium (Cr). Exhibit 2 shows comparisons of exposures based on the filler/electrode used.
4. In assessing exposures during GMAW/MIG welding, exposures to CrVI were lower during pulsed-MIG welding activities when compared to standard continuous MIG welding.
5. The majority of CrVI exposures measured during TIG welding in a variety of industries were below the OSHA action level.
6. Generally, CrVI exposures were lower when localized exhaust ventilation was used, particularly in smaller, enclosed spaces.

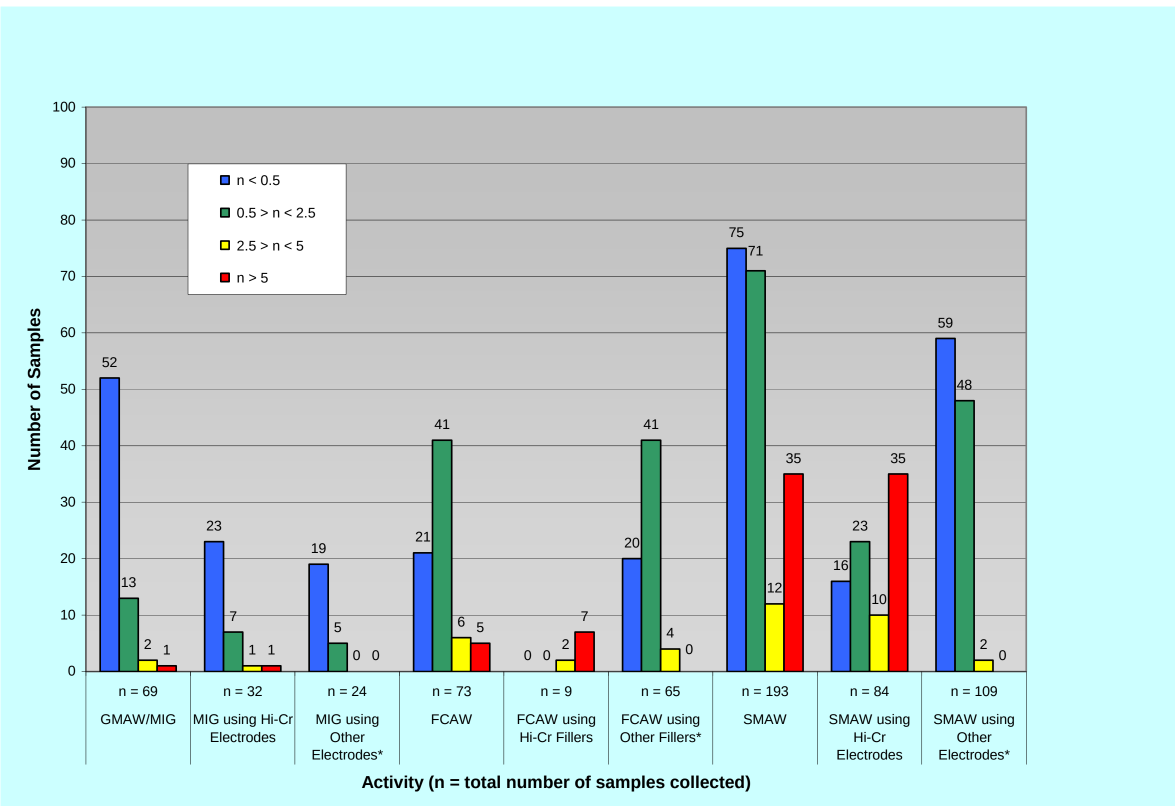

Exhibit 2. Comparison of CrVI Exposures (in $\mu g/m^3$) Based on Filler/Electrode Composition.

Manganese (Mn) Exposures during Welding

In 2009, the ACGIH proposed a ten-fold reduction in their threshold limit value (TLV) for manganese (Mn) to 0.02 mg/m^3 of air over an eight-hour period, measured as “respirable” size fractions. In addition, the ACGIH included a proposed a TLV for "inhalable" particle fractions at 0.2 mg/m3 of air, TWA, in its 2009 *Notice of Intended Changes* (NIC).

In 2012, the ACGIH revised its proposed changes to the TLV for manganese, further lowering its NIC for Inhalable Mn to 0.1 mg/m3 of air, TWA. Historically, exposure monitoring for welding fumes, including Mn, has collected "total" airborne Mn.

Upon review, the NIC for Mn proposed by ACGIH appears to suffer from two serious scientific limitations:

1. No epidemiological studies have been identified that found a statistically significant connection between exposure to Mn in welding fume and neurological disease (faint tremors), cited as the basis for this NIC. Many published studies have concluded that there is no correlation.
2. No published reports have been found in the technical literature that demonstrate that the respirable or inhalable size fractions of Mn are measureable in the breathing zone, while welding, in any credible or reproducible way.

Current and proposed U.S. occupational exposure limits for Mn are summarized in Table 3.

Table 3. Current and Proposed U.S. Occupational Exposure Limits for Manganese

Organization	*Occupational Exposure Limit*
NIOSH REL	1 mg/m^3 (TWA) 3 mg/m^3 (STEL)
NIOSH IDLH	500 mg/m^3
OSHA PEL	5 mg/m^3 (ceiling)
ACGIH TLV	0.2 mg/m^3 (TWA) Current TLV 0.1 mg/m^3 – Inhalable (TWA) – 2012 NIC 0.02 mg/m^3 – Respirable (TWA) – 2011 NIC

Unfortunately, since there is no validated method to correlate previous testing for "total" Mn to the newly proposed limits for inhalable and respirable Mn, any evaluation to determine compliance will require new air monitoring using validated methods for assessing occupational exposures to inhalable and respirable fractions of Mn. As a consequence of these changes, real-world Mn exposure data collected to date for welding and other metalworking processes cannot provide a measure of how much respirable or inhalable Mn may be released during this work.

Recent U.S. Shipyard Studies

Side-by-side testing of total, respirable and inhalable Mn exposures in operator breathing zones and general areas was conducted during various types of shipyard welding, including *hybrid laser arc welding* (HLAW) in 2011. HLAW is a highly automated process where the operator stands at a control station several feet away from the actual weld zone. The purpose of this study was to determine if air monitoring of representative tasks could be used to establish estimated or predictable ranges of exposure to Mn. The work was funded and published by the National Shipbuilding Research Program in a report, "Reduction of Weld Fume Risk in Naval and Commercial Shipyards."

Average airborne concentrations of total, inhalable and respirable Mn, measured during each welding operation testing, are shown in Exhibit 3 below.

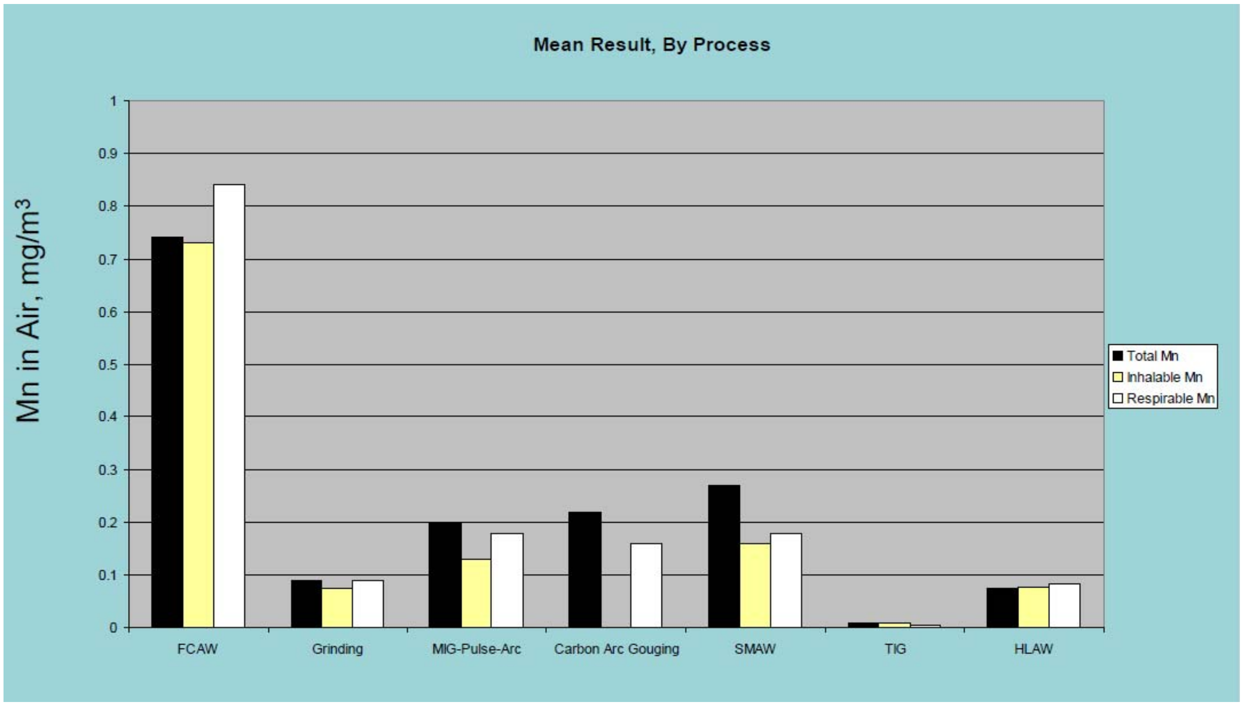

Exhibit 3. Comparison of Average Mn Fume, by Size Fraction, Measured During Shipyard Welding Activities.

The air sampling conducted during this survey showed:

1. There is a wide variation in airborne Mn concentrations found in shipyard welding and metalworking processes.
2. All results were well below the OSHA PEL for manganese of 5.0 mg/m^3 of air, expressed as a ceiling value.
3. Only TIG/GTAW (gas tungsten arc welding) was observed to be consistently below the ACGIH Notice of Intended Changes TLV for Mn of 0.02 mg/m^3 as respirable particulate. All other processes tested provided results that exceeded this limit.
4. The relationship between total, inhalable and respirable Mn does not follow any regular or predictable pattern. Side-by-side air samples will often yield results with smaller size fractions exceeding total Mn concentration or respirable Mn greater than inhalable Mn.
5. Clearly, more work will be required in the area of test equipment design and methods validation in order to provide meaningful and relevant data on which to base future standards and compliance activities.

The changes proposed in the new TLV for Mn require totally different air sampling methods from the historical OSHA compliance methods that have been used for several decades. At this time, there is no valid means to determine if any correlation may be drawn between previous air sampling data for Mn and compliance with the new and drastically lower TLVs. In addition, no body of data has been identified that has defined this relationship; consequently, employers cannot determine if previously “compliant” welding operations are operating above or below the proposed TLVs.

Summary

It is important to remember that welding is a highly engineered process that has evolved as technology has evolved. It is a process that that is conducted by highly skilled personnel. The objective is to fuse two pieces of metal, using a minimal amount of consumable electrodes, which can be costly. The more smoke and fumes generated, the more consumable electrodes are wasted and the less effective the welding process.

The variables involved in the welding processes need to be considered when evaluating welding fume exposures to welders, and knowing the “science” behind the various welding processes is important to anyone involved in protecting workers from welding fume exposures.

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