WELDING Journal

Reducing Exposure to Hexavalent Chromium in Welding Fumes

Ideally, the exhaust nozzle should be positioned close to and above the arc at an angle of approximately 45 deg.

BY SUSAN R. FIORE

Ways to comply with the new OSHA standard for lower exposure to hexavalent chromium are detailed

In October 2004, the Occupational Safety and Health Administration (OSHA) announced a proposal to amend the 8-hour time-weighted average permissible exposure limit (PEL) for hexavalent chromium (Cr(VI)), and for all Cr(VI) compounds. On February 28, 2006, OSHA issued its final rule. The new standard lowers the PEL from 52 to 5 micrograms (μg) of hexavalent chromium per cubic meter of air as an 8-hour time-weighted average (TWA). The new action level has been set at 2.5 $\mu g/m^3$ of air. Although lower limits were considered by OSHA, it was determined that a PEL of 5 $\mu g/m^3$ is the lowest level that is technologically and economically feasible for industries impacted by this standard.

Reasoning behind the Lower Exposure Limits

There are three separate standards that cover general industry (29 CFR 1910.1026), shipyards (29 CFR 1915.1026), and construction (29 CFR 1926.1126). Although the proposed standards for the three industry sectors differed in some of the detail (e.g., provisions for exposure determination) in the final standards, the requirements are very similar.

The decision to lower the exposure limit was based on a finding that employees exposed to Cr(VI) face an increased risk of significant health effects. The health effects cited by OSHA that are associated with Cr(VI) include lung cancer,

SUSAN R. FIORE is with Edison Welding Institute, Columbus, Ohio.

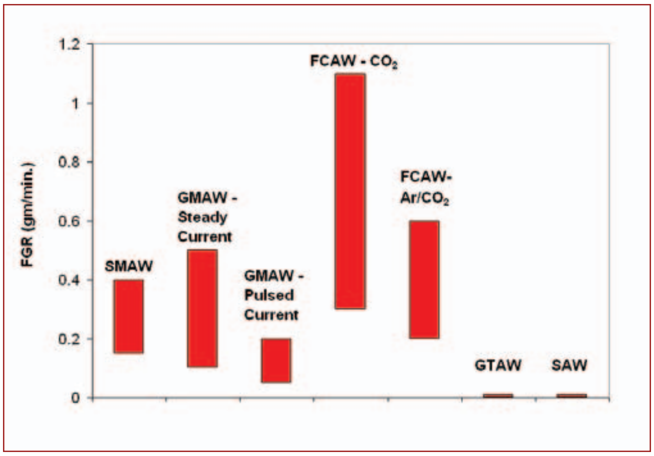


Fig. 1 — Approximate fume generation rates for various welding processes.

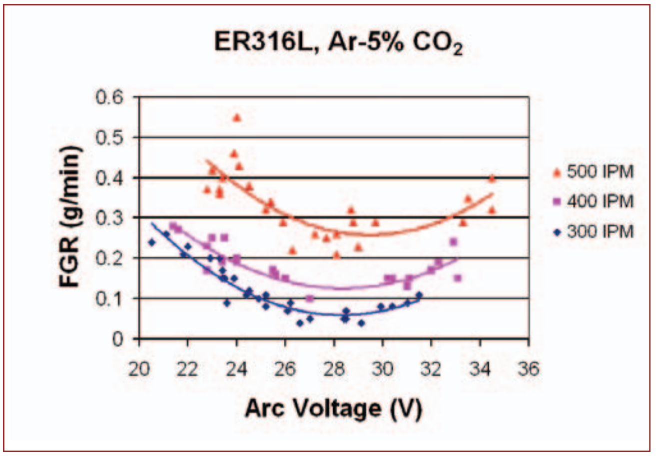


Fig. 2 — Effect of voltage on fume generation rate for ER316 L (GMAW).

asthma, nasal septum ulcerations and perforations, skin ulcerations ("chrome holes"), and allergic and irritant contact dermatitis. One group cited by OSHA as being at risk is workers who are involved with welding of stainless steels. OSHA stated, "In general, the studies found an excess number of lung cancer deaths among stainless steel welders. However, few of the studies found clear trends with Cr(VI) exposure duration or cumulative Cr(VI). In most studies, the reported excess lung cancer mortality among stainless steel welders was no greater than mild steel welders, even though Cr(VI) exposure is much greater during stainless steel welding. This weak association between lung cancer and indices of exposure limits the evidence provided by these studies. Other limitations include the coexposures to other potential lung carcinogens, such as nickel, asbestos, and cigarette smoke, as well as possible healthy worker effects and exposure misclassification in some studies, which may obscure a relationship between Cr(VI) and lung cancer risk." And "Nevertheless, these studies add some further support to the much stronger link between Cr(VI) and lung cancer found in soluble chromate production workers, chromate pigment production workers, and chrome platers."

Timeline of the Ruling

The final rule took effect on May 30, 2006, which was 90 days after the date of publication in the Federal Register, February 28, 2006. Employers have until November 27, 2006, 180 days from the effective date, to comply with the rule (1 year for employers with fewer than 20 employees). The deadline for implementing engineering controls is 4 years after the effective date, or May 31, 2010. Complete details of the standard can be found at *www.osha.gov*. The following section provides some highlights.

Requirements of the New Standard

The first step in complying with the standard is to determine the 8-h TWA exposure for each employee exposed to Cr(VI). Exposure testing should be done by taking a sufficient number of personal breathing zone samples to characterize full shift exposure on each shift for each job classification, in each work area. Representative sampling can be done instead of sampling all employees in order to meet this requirement. However, if representative sampling is performed, the employer must sample the employee(s) expected to have the highest Cr(VI) exposure.

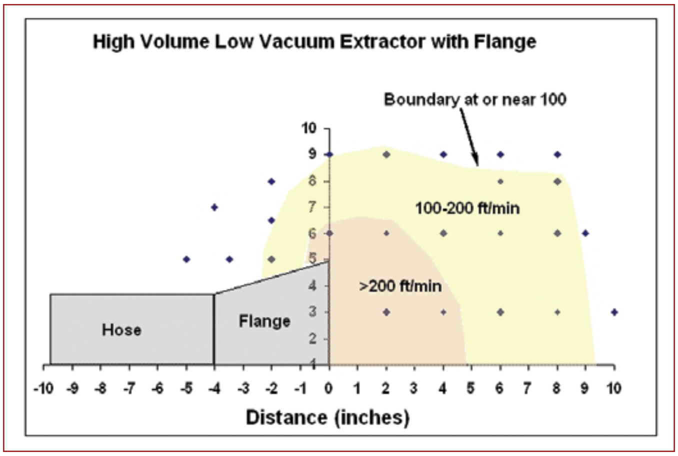
As an alternative, the employer can determine the 8-h TWA exposure for each employee based on any combination of air monitoring data, historical monitoring data, or objective data that is sufficient to accurately characterize employee exposure to Cr(VI).

If the initial monitoring shows that employee exposures are below the action level (2.5 $\mu g/m^3$), the employer may discontinue monitoring for those employees who are represented by that monitoring. If, on the other hand, exposures are found to exceed the action level, the employer must perform monitoring at a minimum of every 6 months. If the initial monitoring shows that employee exposures are above the PEL, then the employer must perform periodic monitoring at a minimum frequency of every 3 months. It is important to note that there is a specific prohibition in the standard against rotating employees to different jobs in order to comply with the standard.

In order to comply with the standard, employers must implement engineering controls to protect those workers whose exposures exceed the PEL. Respirators may be used as an interim measure while engineering controls are being implemented or in the case where the employer can demonstrate that a process or task does not result in any employee being exposed to Cr(VI) above the PEL for 30 or more days per year. Respirators can also be used in those cases where engineering controls are not feasible, or in those cases in which they have been implemented but are not sufficient to reduce exposures to below the PEL.

The Nature of Cr(VI) in Welding Fume

Chromium is found in stainless steel and many low-alloy base materials, electrodes, and filler metals. It is also found in some hardsurfacing electrodes, tool steels, and some nickel-based alloys. The chromium that is present in electrodes, welding wires, and base materials is in the form of metallic chromium and chromium alloys. It is generally not in the form of chromium oxide or other compounds of hexavalent



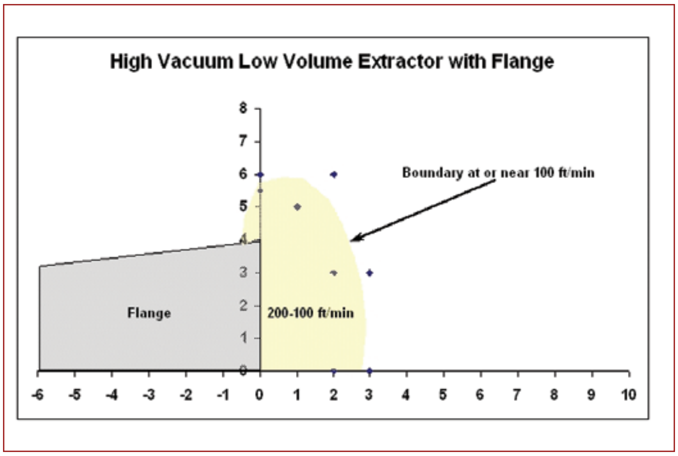


Fig. 3 — Air velocity as a function of distance from the exhaust nozzle for a typical high-volume low-vacuum fume extractor.

Fig. 4 — Air velocity as a function of distance from the exhaust nozzle for a typical high-vacuum low-volume fume extractor.

chromium. During welding, the intense heat of the electric arc vaporizes a fraction of the chromium and other metals in the electrode and weld pool. Any metal vapor that escapes the arc area condenses as it cools and oxidizes into weld fume.

Welding fume is a complex mixture of metal oxides. Fumes from some processes may also include fluorides. The predominant ingredient in mild, low alloy, and stainless steel welding fume is iron oxide. Oxides of manganese and silicon are also typically present. Fume from stainless steel and some low-alloy steel welding will also contain chromium and, in many cases, nickel. Chromium is typically not intentionally added to mild steels or mild steel welding consumables, but because of the nature of steel making and the use of scrap metal, it is not unusual to find low levels. Even though only trace amounts may be present in the steel or the welding consumable, with very low allowable limit materials such as Cr(VI), it may be possible to exceed the PEL when welding mild steels, particularly under conditions of poor local exhaust. In most mild steel welding, however, it is likely that the exposure limits for fume constituents other than Cr(VI) will be exceeded before the limit for Cr(VI) is reached.

The majority of the chromium found in welding fume is typically in the form of Cr_2O_3 and complex compounds of the trivalent form of chromium (Cr(III)). Cr(III) is an essential nutrient in the human body and has only a limited toxic effect (the PEL for Cr(III) is 500 $\mu g/m^3$). Some of the chromium in the fume is found in complex metal oxides in its hexavalent form (Cr(VI)), which is also the form found in CrO_3. Pure CrO_3 is extremely unstable and is not found in welding fume. However, in the case of welding fume, other metal oxides are present, and the presence of these metal oxides, especially alkali metals, tends to stabilize Cr(VI) (Refs. 1, 2).

Minimizing Cr(VI) Exposure from Welding

Welder exposure to Cr(VI) depends on many things. Some of the critical considerations include the quantity and distribution of ventilation (both natural and forced), the work habits and training of the welder, the size of the room in which the welding is being performed, and the material being welded.

There are a number of actions that may be taken in order to reduce exposure to Cr(VI) in the welding environment (workplace). The overall effectiveness of these measures will depend on the material being welded as well as the other factors listed above. Implementation of some of these measures may not be practical, and in some cases, may not even be possible.

Preliminary Testing

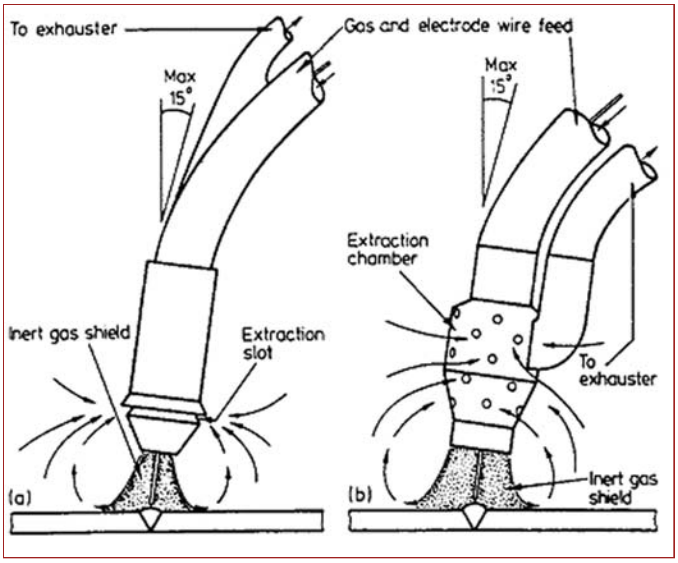
As discussed earlier, the first step that must be taken is to determine if either the PEL or the action level are being exceeded. This can only be done by performing some baseline analysis of the existing situation. A certified industrial hygienist (CIH) can perform exposure testing of workers to determine baseline conditions. The CIH must test for the fume constituents in addition to traditional total fume measurements. Testing for Cr(VI) requires extraction of the Cr(VI) from the fume sample, and must be done separately from testing for other fume constituents. The employer can either test all employees within each job classification, or he can perform representative sampling. If representative sampling is performed, the employees selected for sampling should be those expected to have the highest Cr(VI) exposures. OSHA recommends using either the National Institute of Occupational Safety and Health (NIOSH) Method 7605 (Ref. 3) or OSHA Method ID-215 (Ref. 4) for the analysis.

The ID-215 method was developed when OSHA was originally considering lowering the exposure limit, and PELs as low as 0.1 $\mu g/m^3$ were being considered. Other NIOSH methods (Method 7600 and 7604) can also be used, but their detection limits are higher than NIOSH 7605 and OSHA ID-215.

Regardless of which method is used, it should be clearly communicated to the testing laboratory that exposure levels down to 2.5 $\mu g/m^3$ (i.e., the action level) must be reported.

Ideally, exposure testing should be done over an 8-h period. If a shorter time period is chosen, it should be representative of the work pattern for the entire 8-h shift. The AWS and OSHA recommend that the fume collected for exposure testing be taken from inside the welding helmet or as close to the welder's breathing zone as possible.

If it is determined that the PEL is being exceeded, the solution may range from relatively simple process or procedure changes, to improvements in exhaust/ventilation, to changes in personnel pro-



▲ *Fig. 6 — Air-purifying respirator.*

◀ *Fig. 5 — Schematic diagram of different types of fume-extraction welding guns.*

tective equipment. The following sections outline some of the possibilities.

Welding Process and Procedure Changes

Different welding processes generate different amounts of welding fume. Processes such as gas tungsten arc welding (GTAW) and submerged arc welding (SAW) are inherently low in fume generation. Gas metal arc welding (GMAW) also tends to be a relatively low-fuming process. Shielded metal arc (SMAW) and flux cored arc welding (FCAW) tend to produce more fume, especially when the amount of fume generated per unit length of weld is considered. Alkali metals, such as sodium and potassium, stabilize Cr(VI) (Refs. 1, 2), and are often present in SMAW electrode coatings and may be present in FCAW flux. As a consequence, Cr(VI) levels tend to be higher with SMA and FCA welding. Figure 1 shows the relative amounts of total fume generated for several different welding processes (Ref. 5). Because some of the processes represent lower deposition rates, the total amount of fume generated to complete a weld should also be considered.

Unfortunately, not all processes can be used in all situations. SAW is limited to the flat and horizontal positions. GTAW tends to be very low in deposition rate and may not be the best choice for production welding. A large percentage of repair welding is done using SMAW due to its low cost, portability, and ease of use.

Other Ways to Reduce Exposure

Even if it is not possible or practical to change to a different welding process in order to reduce exposure to hexavalent chromium, it may be possible to modify the process to reduce exposure. Argon-rich shielding gases produce less fume than 100% CO_2 and shielding gases that are high in helium. For GMAW and FCAW, replacing straight CO_2 with shielding gas mixtures containing a minimum of 75% argon along with CO_2 and/or oxygen will result in a significant reduction in fume generation rate.

The oxidation potential of the arc atmosphere will affect both the amount and the composition of the welding fume. In general, as the arc atmosphere becomes more oxidizing, the total amount of fume generated will increase. Elements such as manganese and silicon, which have a high oxidation potential, will increase preferentially to those with lower oxidation potentials. It should be noted that while argon-rich shielding gases produce less fume than CO_2, the fume itself may be somewhat higher in hexavalent chromium. However, because the total amount of fume generated will be significantly less, the potential exposure to hexavalent chromium should be reduced.

It may also be possible to reduce the amount of fume generated for a given process by adjusting the welding parameters. In general, reducing the current and voltage will lead to a decrease in fume generation rate. For GMAW, as voltage increases, the fume generation rate will typically decrease to a point, and then increase with increasing voltage. This behavior, which is related to arc stability, is shown graphically in Fig. 2 (Ref. 5).

Finally, a number of studies have shown that GMAW with pulse transfer produces less fume than GMAW with spray transfer (Ref. 6). The type of pulse power (inverter vs. conventional) appears to play a role in the level of fume reduction, and the process may need to be fine-tuned to achieve the lowest possible levels. Some researchers have shown (Refs. 7, 8) that the percentage of hexavalent chromium in the fume may increase somewhat with pulsed vs. spray transfer. However, because the total amount of fume generated is reduced, the overall potential exposure to hexavalent chromium will also be reduced.

Engineering Controls

If changing the welding process is not possible, or if the changes do not reduce worker exposure levels to below the PEL, it will be necessary to introduce changes to improve the ventilation in the worker's breathing zone and the surrounding area. Local exhaust ventilation (LEV) is a system of capturing the welding fume before it reaches the operator. The effectiveness of the LEV is highly dependent upon its proximity to the source of the fumes, i.e., its position relative to the welding arc (see lead photo).

Using Ventilating Systems

The two most common types of ventilation systems are high-volume low-vacuum systems, and high-vacuum low-volume systems. High-volume

Table 1— Typical Air Flow Rates and Capture Distances for LEV Equipment

Air Flow (Q) ft^3/min	Duct or Hose Diameter (in.)	Capture Distance (in.)	Weld Length Before Repositioning (in.)
	High vacuum, Low volume		
50	1½–2	2–3	4–6 for duct 8–12 with flange
88	1½–2	2–3	4–6 for duct 8–12 with flange
110	2	3	4–6 for duct 8–12 with flange
160	3	5–6	9–12
	High volume, Low vacuum		
500–600	4–6	6–9	12–18
800–1000	6–8	9–12	18–24

low-vacuum systems use large-diameter ducts or hoses that provide for larger capture distances. Most bulk systems are high-volume low-vacuum systems. High-vacuum low-volume systems tend to be more portable and less expensive to implement than the high-volume systems. They use smaller hoses, and as a consequence, the capture distance is generally smaller. Table 1 shows typical capture distances for various systems and air flow rates (Ref. 5).

Figures 3 and 4 show the air velocity as a function of distance from the exhaust nozzle for typical high-volume low-vacuum and high-vacuum low-volume systems, respectively (Ref. 5). The rule of thumb is in order for LEV to be effective, it must achieve a minimum air velocity of about 100 ft/min at the point of fume capture. Clearly, it is critical that the nozzle be repositioned regularly during the course of welding. Adding a flange to the nozzle increases the capture distance, which increases the length of weld that can be made before it becomes necessary to reposition the exhaust nozzle.

Fume Extracting Guns

One solution to the problems associated with frequent exhaust hose repositioning is the use of fume-extraction welding guns. The typical fume-extraction welding gun has small exhaust holes or vents around the circumference of the gun. They have the advantage that the extractor is always positioned very close to the arc. Fume-extraction guns are most effective when welding in the flat or horizontal position. It should be noted that because fume-extraction guns tend to be heavier and may have stiffer hoses than traditional welding guns, an evaluation for ergonomic stresses should be performed. Welding gun weight-assists (bungee cords, counterweights, etc.) may be needed. Several types of fume-extraction welding guns are shown schematically in Fig. 5. Fume-extraction welding guns are particularly well-suited for use with self-shielded FCAW. When using fume-extraction welding guns with GMAW or gas-shielded FCAW, care must be taken to ensure that the air-velocity is not so high that it impairs the coverage of the gas-shielding.

In some situations, it may be possible to isolate the welding process to reduce worker exposures. Welding can be done in a "room-within-a-room" or similar isolated chamber. This generally requires that welding be done robotically or otherwise fully automated. Welding can also be done in a glove box, but this is only feasible for relatively small assemblies.

When LEV Is Not Enough

In some cases, process changes and engineering controls will not be sufficient to reduce the hexavalent chromium exposure to below the PEL. In those situations, it becomes necessary to introduce respirators. Respirators should not be used in place of implementing engineering controls. Rather, they should be used in those situations where engineering controls have been implemented and exposure testing has indicated that they are not adequate, or as an interim measure while engineering controls are being implemented. Respirators can also be used as an assurance/back-up to maintain exposure below the PEL. Special ventilation, air monitoring, and, in some cases, respirators should always be used for welding in confined spaces. See ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (Ref. 9) for guidelines on welding in confined spaces.

In order to determine whether respirators are needed, exposure testing should again be performed. If it is determined that respirators are indeed needed, they should be NIOSH-approved and in compliance with 42CFR part 84. The two types of respirators are air-purifying respirators and atmosphere-supplying respirators. Air-purifying respirators are either particulate respirators, gas and vapor respirators, or combination respirators. They utilize filter cartridges to remove particulate and/or gases from the air before it is inhaled by the user. Figure 6 shows an example of an air-purifying respirator.

Atmosphere-supplying respirators may be air-supplied respirators, self-contained breathing apparatus, or combination respirators. Air-supplied respirators typically have a hose that is connected to an external air supply, whereas self-contained breathing apparatus has air tanks that are integrated into the system. Combination respirators have an auxiliary self-contained air supply that can be used if the primary supply fails. Some manufacturers also make systems in which the air-supply hose is integrated into the welding helmet.

Summary

A number of steps can be taken to reduce exposure to hexavalent chromium from welding processes in the workplace. First, fume production should be considered in the choice of the welding process. Shielding gases and welding parameters should also be selected to minimize fume production. The local exhaust ventilation should be examined to determine if it is adequate and where improvements may be made.

Finally, if process modifications and engineering controls are not adequate to reduce exposures to hexavalent chromium or other contaminants to below the PEL, respirators should be employed. OSHA offers a number of publications and online tools for evaluating hazardous contaminants in the work environment. These are available at *www.osha.gov*. NIOSH also offers a number of resources, including guidelines on selection and use of respirators, available at *www.cdc.gov/niosh*.◆

References

1. Kimura, S., Kobayashi, M., Godai, T., and Minato, S. 1979. Investigations on chromium in stainless steel welding fumes. *Welding Journal* 58(7):195-s to 204-s.

2. Khoroshavin, L. B., Deryabin, V. A., Perepelitsyn, V. A., and Lapteva, T. N.

1993. Hexavalent chromium in refractories. *Refractories* 34(9/10) 457–462.

3. Details of the methods are available from the National Institute for Occupational Safety and Health, *www.cdc.gov/niosh/nmam*.

4. Details of the method are available from the U.S. Department of Labor, Occupational Safety and Health Administration, *www.osha.gov/dts/sltc/methods/inorganic/id215/id215.html*.

5. Reduction of worker exposure and environmental release of welding emissions. NSRP report, EWI, 2003.

6. Dipietro, D., and Young, J. 1996. Pulsed GMAW [GMA welding] helps John Deere meet fume requirements. *Welding Journal* 75(10): 57–58.

7. Bosworth, M., and Gordon, T. 1999. The influence of power source characteristics on Cr(VI) in fume generated during GMAW of stainless steel. *Australasian Welding Journal* 44: 48–51, 3rd Quarter.

8. Brooks, G., Mahboubi, F., French, I. E. and Tyagi, V. K. 1997. The influence of the consumable and power supply type on welding fume characteristics. *Australasian Welding Journal* 42: 38–43, 2nd Quarter.

9. ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*. Available for free download from AWS, *www.aws.org*.

Additional References from AWS

- AWS F1.1, *Method for Sampling Airborne Particulates Generated by Welding and Allied Processes.*
- AWS F1.2, *Laboratory Method for Measuring Fume Generation Rates and Total Fume Emission of Welding and Allied Processes.*
- AWS F3.2, *Ventilation Guide for Weld Fume.*
- AWS Safety and Health Fact Sheet Nos. 1 and 4.

Susan R. Fiore, Senior Engineer

EWI

1250 Arthur E. Adams Drive
Columbus, Ohio 43221-3585
(614) 688-5000