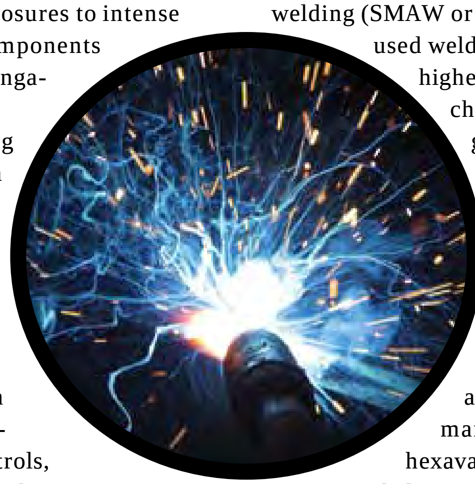
Source Reduction

Practical Issues in Minimizing Welding Fume Exposures

BY MICHAEL J. KEANE

Welding is a major occupational activity. More than 200,000 workers in the United States and 1.8 million workers worldwide do welding as all or part of their jobs. The hazards of welding are well-understood and include exposures to intense light, heat, and a number of toxic components present in welding fume, such as manganese, iron, carbon monoxide, ozone, and other toxic agents. When welding stainless steel and similar chromium alloys, the well-established carcinogen hexavalent chromium and the possible carcinogen nickel are present and are even more serious concerns.



In most cases there are well-understood approaches to control an individual welder's exposures to hazards. These include engineering controls, personal protective equipment, and other measures. Exposures can still be high, however, even after implementing protective measures. Achieving the OSHA Permissible Exposure Limit for hexavalent chromium (5 $\mu g/m^3$) is very difficult, and the NIOSH Recommended Exposure Limit (0.2 $\mu g/m^3$) is even more challenging.

The first and best strategy is to control hazards at the source; engineering controls and other measures can further augment reductions at the source. In the case of welding, source reduction is most readily achieved by substituting a lower-emission welding process for a high-emission welding process.

PROCESS SUBSTITUTION

It is not always possible to substitute one welding process for another because pressure-vessel or other critical types of welding often have only one or two approved welding procedures. However, workplace exposures are often associated with repair and maintenance operations that have less stringent requirements. In these cases, multiple types of welding can be substituted. Shielded metal arc welding (SMAW or "stick welding") is the most commonly used welding process, and generally has the highest emission rates for fume, hexavalent chromium, and manganese. Typically gas metal arc welding or flux-cored arc welding can be substituted for SMAW in most circumstances. Gas metal arc welding (GMAW; also known as MIG or MAG) has a number of process variations with a large range of fume emission profiles that have been evaluated comprehensively for both mild and stainless steel welding materials. In many cases, the emission rates of fume, hexavalent chromium, manganese, nickel, and elemental chromium have been determined and comparative cost data has been measured in actual field studies, for labor and consumables costs.

Many types of GMAW processes are available, including short-circuit, globular transfer, axial spray and pulsed spray modes, and other specialized techniques such as Surface Tension Transfer, Regulated Metal Deposition, Cold Metal Transfer, and others. Each has different capabilities and advantages. In several cases, substituting one of these GMAW processes for SMAW has resulted in dramatic reductions in emissions of fumes and toxic metals, and a significant reduction in operating costs. In the case of fume emission rates (normalized for the same electrode consumption rates), the best GMAW processes such as pulsed-spray mode have 1/40th the fume emission rates of SMAW welding. In the case of hexavalent chromium

A manikin testing for aerosol movement with a smoke source.

emission rates, some of the best GMAW choices have emissions rates that are as little as 1/250th the emission rates of SMAW welding. There are also reductions in manganese, nickel, and elemental chromium generation rates, although less dramatic in magnitude.

Flux-cored arc welding (FCAW) also generally has lower fume generation rates than SMAW, but higher rates than GMAW. FCAW can have advantages, however, especially when welding on coated or contaminated surfaces, where the use of GMAW processes would not be the best choice. Tungsten inert-gas (TIG) welding is another option that has very low emission rates, but it is generally considered too expensive for most applications due to the low deposition rates of filler metal, high skill requirements, and overall high labor costs.

In addition to emissions reductions, alternatives to SMAW often have reduced costs for labor and consumables (welding rods, electrode wire, shield gas, and more). In both laboratory and field studies (a power plant boiler repair), costs, at their lowest, were less than half the costs per finished meter of weld relative to SMAW ($7.41/m for SMAW vs. $3.15/m for pulsed spray-mode welding). Similar results were confirmed in comparative laboratory studies for similar processes. In many cases, multiple passes are required for SMAW welds, and slag removal and grinding between weld passes will further increase costs, making alternative processes even more favorable.

There are limitations on these substitute processes. Many have a limit on weld thickness, usually a quarter inch, but many welding operations can be done within that range. Also, compressed gases are required for all GMAW and some FCAW processes, but use of these gases is usually possible except in the most extreme confined spaces. Not all welders are trained in all GMAW processes, but GMAW welding is easily learned and is less difficult to use than SMAW welding. Different welding machines are also required, with increased equipment costs due to shield gas equipment and electrode feed mechanisms. The acquisition costs of GMAW and FCAW welding machines are generally somewhat higher than SMAW machines, but the lowered operating cost may make adoption highly favorable. In addition, many multi-process welding machines can be leased.

PROPER EXPOSURE ASSESSMENT

In addition to minimizing sources of hazards from welding processes, it is crucial that true exposures to welding fumes be determined. Policies by NIOSH, OSHA, the American Welding Society (AWS) and others all recommend exposure assessment sampling inside the helmet, 50 mm or less from the centerline of the breathing zone. Despite these policies, outside-of-helmet sampling, such as lapel locations, are often seen in practice; a common assumption is that lapel sampling will overestimate exposures, assuring that actual in-helmet exposures will be less. Several older studies indicate that the welding helmet does reduce fume concentrations relative to samples collected on the lapel or similar locations, but more recent work published in the *Journal of Occupational and Environmental Hygiene* shows that any "protective" effect is marginal and highly variable overall.

NIOSH and Xcel Energy are currently studying helmet effects on welding fume exposures in both shop and laboratory settings. Recent observations in an Xcel power plant welding shop, where identical welds were completed by multiple welders using three separate processes, showed that in-helmet concentrations were often larger than lapel-area concentrations. In addition, the in-helmet to lapel concentration ratios were found to be dependent on both the welding process type and the individual welder.

Another factor that appears to be important is the individual welder's orientation with respect to the weld itself, as observed from photographs taken in the shop. The first welder was oriented with the eyes directly above the weld pool, and had generally higher in-helmet to lapel ratios, with wider range of results, especially for flux-cored and shielded metal arc welding. The second welder was oriented significantly to the side of the weld and had lower or similar ratios relative to the first welder, and a narrower range of observations.

Laboratory simulation of the shop study, currently in progress, uses a manikin that was positioned similarly to the first welder in the shop study, and uses two different helmet designs, two ventilation linear velocities, and three welding processes. Again, concentrations inside the helmet have been higher for both SMAW and FCAW processes, relative to lapel concentrations for the two welders. For the GMAW welding process tested (short-circuit mode), concentrations have been lower inside the helmet for both welders. There was no significant difference in in-helmet to lapel ratios between the traditional curved-front fiberglass helmet and the more modern streamlined helmet that were tested. The ventilation velocities, simulating small shops with no local exhaust ventilation, have had only a minor effect on the concentration ratios.

RECOMMENDATIONS

There are many aspects to minimizing a welder's exposure to fumes and other toxic agents, and the most effective approaches should include minimization of the hazards at the source. When this can be accomplished with substitution of a low-emission welding technology for a high-emission process, often the operating costs of welding are also lowered. Process substitution can also sometimes reduce the requirements for engineering control solutions, personal protective equipment, and their related equipment and operating costs. Every welding process type has strengths and limitations, such as weld thickness limits and usage in certain positions, but several processes are generally capable of substituting for SMAW and other high-emission welding types.

While source emission reduction is a critical element of minimizing exposures to welding fumes, the most important issue is establishing lowest possible exposures of the individual welder, as determined by personal monitoring. This exposure assessment also serves as a validation of the effectiveness of the process substitution and any and all other control measures. The use of recommended in-helmet breathing-zone sampling is imperative for measuring true exposures. The use of lapel sampling or other substitute locations is almost certain to be in error; lapel-collected concentration can be higher, lower, or similar to true, in-helmet measures, and lapel-collected samples have no consistent, reliable relationship to true exposures.

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RESOURCES

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