Welding Galvanized Steel -- Safely

Background

Galvanizing has been used to protect iron and steel from rusting for over a hundred years in places as diverse as the wire rope used for the suspension cables on the Brooklyn Bridge to gutters on houses.

Galvanizing is simply coating of zinc over steel. Like paint, galvanizing protects steel from rusting by forming a barrier between the steel and the environment, but galvanizing goes one giant step further than paint -- it also provides electrochemical protection of the steel. Since zinc is electrochemically more reactive than steel, it oxidizes to protect the steel near it; as a result, even if a galvanized steel surface is scratched down to the bare steel, the galvanizing coating will prevent the steel from rusting. Galvanized steel is, therefore, a superior product to steel with any other type of coating on it since it protects the steel even when the coating is damaged in handling or in service.

Welding of Galvanized Products

Welding of galvanized steel is done almost exactly the same way as welding of the bare steel of the same composition; the same welding processes, volts, amps, travel speed, etc. can be used with little modification when the switch is made from uncoated steel to galvanized steel -- unless the zinc coating is unusually thick.

The difference between welding galvanized steel and welding uncoated steel is a result of the low vaporization temperature of the zinc coating. Zinc melts at about 900˚F and vaporizes at about 1650˚F. Since steel melts at approximately 2,750˚F and the welding arc temperature is 15,000 to 20,000˚F, the zinc that is near the weld does not stand a chance -- it's vaporized! By the time the weld pool freezes, the zinc is gone. This has two immediate consequences:

- The vaporized zinc increases the volume of welding smoke and fumes.
- The zinc at and near any welds is actually burned off by the heat of the arc, removing the protective zinc coating.

Zinc Fumes -- A Safety Hazard?

When zinc vapor mixes with the oxygen in the air, it reacts instantly to become zinc oxide. This is the same white powder that you see on some noses at the beach and the slopes. Zinc oxide is non-toxic and non carcinogenic. Extensive research[1] into the effects of zinc oxide fumes has been done, and although breathing those fumes will cause welders to think that they have the flu in a bad way, there are no long-term health effects. Zinc oxide that is inhaled is simply absorbed and eliminated by the body without complications or chronic effects. Current research[2] on zinc oxide fumes is concentrated in establishing the mechanism by which zinc oxide causes "metal fume fever," how its effects are self-limiting and why zinc oxide fume effects ameliorate after the first day of exposure even though the welder may continue to be exposed to zinc during subsequent days ("Monday-morning fever"). Other research[3] is being done using zinc oxide fumes together with various drugs which results in a synergetic effect for treatment of cancer and AIDS. Another area of research is use of zinc compounds as the active ingredients in throat lozengers that are recognized as significantly effective in reducing the duration and intensity of the common cold.

Typical “metal fume fever” begins about 4 hours after exposure, and full recovery occurs within 48 hours. The symptoms include fever, chills, thirst, headache and nausea. All of these symptoms, pain and suffering, as well as lost work (and play) time, can be avoided entirely by simply not inhaling the zinc oxide fumes. This can easily be done using any of the methods described later.

Unlike other heavy metals, such as copper, lead and mercury, zinc is an essential micro nutrient. Zinc is essential to the proper growth of plants and animals. Zinc forms part of the enzyme system that regulates biological processes throughout the body. As shown on any multi-vitamin/mineral bottle, the recommended minimum adult intake is 15 mg/day.

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[1] Walsh, Sandstead, Prasad, Newberne and Fraker, Environmental Health Perspectives, Volume 102, Supplement 2, June 1994, 5-46. Provides summary plus 471 references.
[2] Kuschner,D'Alessandro, et. al., Pulmonary Responses to Purified Zinc Oxide Fumes, Journal of Investigative Medicine, 1995:43:371-378.
[3] Robert Sabin, Zinc Activated Profile, COPE, March/April 1995: 16,17

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The zinc that is generally used for hot dipped galvanized coating has a naturally occurring lead content around 1/2%. Since lead is not soluble in zinc over 0.9%, it cannot exceed 0.9% concentration. This lead may be vaporized along with zinc during welding. Since lead does not vaporize until it gets over 3000˚F, and since some of it is soluble in steel, proportionately less lead is vaporized than zinc; lead oxide fumes, however, should not be inhaled, and the practices recommended below for avoiding inhaling zinc oxide fumes will also prevent inhalation of lead oxides. There is also some concern about residual lead where galvanized products will be in contact with children, such as when it is used on playground equipment without a high-qualify top coating.

Some galvanized product manufacturers use zinc that is 99.99% pure zinc, so the presence of lead is of no concern when welding these products or due to contact. Similarly, galvanized products that have very thin organic coatings or have been chemically treated to improve the adherence of top coatings are welded safely when the practices recommended below for avoiding inhaling zinc oxide fumes are observed.

Properties of Galvanized Steel Welds

The successful welding of galvanized steel is so widely accepted that there is very little recently-published mechanical property data comparing uncoated versus galvanized weld properties. The welding industry recognized fifty years ago that welds on galvanized steel and welds on uncoated steel are of comparable strength if the quality of the welds is comparable. Recent publications on welding galvanized steels deal with weld toughness, porosity control, weld appearance, restoring corrosion resistance and other issues that are much more complex than the strength of the weld.

When using SMAW ("stick") welding, galvanized steel can be welded in the same manner as uncoated steel. When using MIG or flux cored welding, one may have to adjust the voltage slightly to control spatter, and one may have to clean the welding gun of spatter and zinc oxide deposits more frequently that when welding uncoated steel. Hobart makes a flux cored wire called “Galvacore” that some users have had good success with when welding galvanized steel.

When difficulty is encountered welding galvanized steel that was not encountered during welding uncoated steel, it is usually because the Welding Engineer has not accounted for the volume of gas that is evolved by the vaporization of zinc during welding. The thicker the zinc coating, the more fumes are generated, and those fumes have to be able to escape easily into the atmosphere and not be forced through the liquid weld metal.

For example, welding galvanized plates to form a T-joint is a commonly troublesome situation. Since the galvanized edge of one plate is butted against another galvanized surface, the zinc vapors that are formed at the abutting surfaces will not be able to escape to atmosphere easily as the zinc is vaporized. Instead, they will blow into the weld pool, creating porosity or a poor weld surface. This is aggravated when welding conventionally hot-dipped products, since the edges frequently have excessively heavy zinc coatings. One solution is to separate the parts by 1/16 inch using wire spacers or fixtures which will leave a gap for the zinc vapors to escape easily. Other approaches are to use a slight (15˚) bevel on one member (Figure 1), to remove the zinc from the faying surfaces by shearing or mechanically cuting the plate where the faying surfaces will meet, and to abrasively remove most of the zinc from one or both of the faying surfaces (Figure 2). Any of these methods will significantly reduce the amount of zinc between the parts, and this will reduce the volume of gas evolved, improving weld quality.

Figure 1

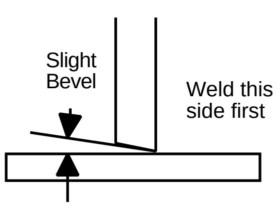
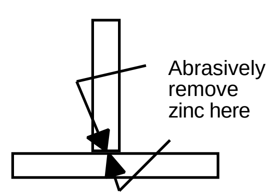


Figure 2



The welding engineer should also check the welding electrodes which are being used for high silicon levels. Excessive silicon can cause zinc to penetrate the weld metal, leading to cracking, especially when the zinc coating is thick. The silicon in welding electrodes should not exceed 0.85%; this means that commonly used ER70S-6 filler metals should not be used when welding galvanized steel.

Avoiding and Filtering Fumes

The first line of defense in dealing with zinc oxide fumes is welder training. Welders should taught -- even when welding uncoated materials -- to keep their heads out of the fume plume and to position themselves relative to the air flow around themselves so fumes and dust do not collect inside their welding shields. If a welder finds white dust inside his welding shield when welding galvanized products, he is not positioning himself properly. When welding galvanized products that have thin, uniform coatings and the process is gas-shielded MIG or flux core, the gumes generated are sparse and the shielding gas blows them away from the welder; this is frequently sufficient to avoid metal fume fever without further action.

To complement proper positioning, a fully effective method to preventing inhaling zinc fumes is to wear a suitable respirator (mask). Some of the commercial products which are suitable are:

Manufacturer	Product	Description	Cost ($ each)
3M (800-328-1667)	9920	Half-Mask, Disposable	4.50
3M	9925	Half-Mask, Disposable	5.00
3M	9970	Half-Mask, Disposable	6.50
Moldex	3400	Half-Mask, Disposable	6.00

The prices shown are list prices for purchase of 40 or more; these items are usually available with some discount.

These masks are similar to a painter's mask; although there are other larger and more complicated masks, these work, while providing minimal interference and discomfort to the welder. The higher priced masks contain activated charcoal which removes some odors as well as the zinc oxide; welders who use these masks frequently wear them even when they are not welding on galvanized steel, since they make the air smell better and they filter out other particulate matter in the welding fume plume.

Masks that are not properly fitted will not be effective in protecting the welder since the zinc oxide can be pulled through any openings between the mask and the welder's face. Welders who are given masks or any other kind of personal protection equipment have to be trained how to adjust them so that they work correctly. In addition, OSHA regulations (29CFR Part 1910.134(b) requires that fabricators have a written procedure for use of personal protective equipment such as respirators and masks; that the equipment be selected from that approved by the Mine Safety and Health Administration and the National Institute for Occupational Safety and Health; that the equipment selection be based on the hazard to which the welder is exposed; that only employees who are physically capable of doing the job and know how to use the safety equipment are assigined to perform work; that respirators are cleaned and disinfected regularly, stored in a convenient, sanitary location and kept in good repair; that the work area be monitored for changes in exposure; that the medical status of employees is reviewed regularly; and that the program be reviewed on a regular basis to appraise its effectiveness. OSHA does not currently require periodic medical evaluation of employees, but that is under consideration. Disposable masks eliminate some of the hassle associated with meeting these OSHA regulations.

More complex and expensive than masks are the "personal environment systems" in which the welder has air supplied to a loose-fitting helmet and outer shroud which drapes over the his shoulders. Portable fans or compressed air supply filtered air to each welder under positive pressure, keeping any welding fumes out of his breathing area.

Supplier	Product	System Cost (Approx)
3M	Whitecap W-8200B	$600 (CA)
Racal Airstream	AH-17	$550 (BP)
Racal Airstream	AH31, 33 or 39	$425 to 615 (CA)
Neoterik	CB14-77	$227 (CA)
Neoterik	MB14-77	$472 (BP)
Hornell Speedglas	Fresh-Air™	$880 (BP)

(CA indicates compressed air supplied, BP means battery powered)

It should be noted that any compressed air supply has to be "oil-free" air; normal shop air contains oil which, if inhaled, will coat the lungs in a short period of time, causing irreversable death.

The other approach to removing the air from the welder's breathing space is to capture it so that the fumes never rise into the welder's face. Source capture devices are usually flexible ducts attached to an exhaust or filter system. Suppliers of fixed single welding station fume extraction systems are:

Supplier	Phone	Product	System Cost ($) (est)
Nederman, Inc	313-729-3344	FilterBox	3500 to 7000
Nederman, Inc	313-729-3344	Electrostatic Filter	4,200
Torit (Donaldson Co.)	612-887-3900	Trunkline	4,000 to 7,000
Morris Mobile Clean	800-541-0817	MC-2000	3,000
Morris Mobile Clean	800-541-0817	MobileVac	2,200

One difficulty with "source capture" devices is that their range is limited to less than a foot from the end of the flexible duct; this means that the welder has to move the duct if he moves outside its capture range.

Another type of "source capture" device that can be used when "MIG" welding is a welding gun that has a vacuum nozzle attached directly to the welding gun. All "MIG" welding gun manufacturers, including Tweco, Lincoln, Hobart and Binzel make these modified guns and filter units. The primary disadvantage is that they are slightly bulkier than guns without vacuum attachments. This can make welding more difficult for the welder.

The optimum method for capturing welding fumes over a large area is a downdraft work table. This is because the fumes are drawn downward away from the welder's breathing zone. Interestingly, the effective capture distance of a downdraft table can be easily extended to over a foot simply by addition of a small overhead fan directed downward. Downdraft tables are available from:

Supplier	Phone Number
Weldsale Company	215-739-7474
Aercology	203-399-7941
Eutectic Corporation	800-323-4845

Downdraft work table will cost approximately $1,200 for a small (30" by 36") table to $5,000 for a large (4' by 8') work station plus the cost of fan, duct and, if necessary, filter system. Downdraft work stations for assembly line work, where welding is done in isolated areas, is much less costly. Downdraft ventilation is not only better than overhead ventilation, but it is usually less expensive, since many of the components are off-the-shelf items, and the ventilation system is integrated into a convenient work table.

Welding fumes and zinc oxide dust can be removed by general ventilation; however, American National Standards Institute (ANSI) Z49.1 limits zinc to 5mg/cubic meter. General ventilation or tall ceilings (over 16 feet) are needed for all welding operation to ensure adequate dilution of smoke and other pollutants associated with welding. This is true whether or not zinc is involved.

Overhead exhaust systems can be designed and engineered to remove welding-related pollutants as well as zinc oxide dust from the air. These systems can exhaust to the outside atmosphere or they can be recirculating systems. Recirculating systems can be supplied by:

Supplier	Phone
Torit (Donaldson Co.)	612-887-3900
Nederman, Inc	313-729-3344
Airomax	609-933-1780

Overhead exhaust or filtering systems will cost between $50,000 and $100,000 for four large welding stations, such as would be used for fabrication of scaffold components or playground equipment.

One of the primary considerations for engineered exhaust systems is that the flow of the air must be controlled properly. The general flow rate of the air should be 150 to 200 feet per minute, and the flow pattern should be such that the air flows from the welders left to right or right to left. Air flow should not come from behind the welder, since this creates a "smokestack" effect which brings fumes directly into the welder's breathing zone.

Restoring Corrosion Resistance

The heat from welding vaporizes the protective zinc coating near the weld. Even though the remaining zinc continues to provide some protection to the zinc-free areas, the appearance is poor, and the zinc-free areas will rust when exposed to the environment. Paints which are high in elemental zinc (i.e., "Zinc-rich"), properly applied, will effectively restore full corrosion protection to the weld areas. These paints are available in either spray cans or in containers suitable for brush or spray application. This paint can be applied to the weld after sand blasting or wire brushing to remove all welding slag followed by wiping the weld clean with a rag. Thermal- sprayed zinc is also effective in restoring corrosion resistance, but the surface has to be sufficiently roughened, usually by sand blasting or coarse abrasive conditioning to enable thermal-sprayed zinc to stick properly.

Alternative Filler Metals

Is it possible to avoid the corrosion problems resulting from vaporizing the zinc by using, for example, stainless steel welding electrodes?

Carbon steel, whether galvanized or uncoated, can be readily welded using stainless steel electrodes. Stainless steel, however, is electropositive (cathodic) to zinc and also to carbon steel. This means that, in the presence of moisture, both the zinc and the expsoed carbon steel immediately next to the weld metal will corrode to protect the stainless steel - not a happy situation!

Another possible filler metal is aluminum bronze (Copper with 7 to 15% aluminum). This alloy has a melting point lower than the steel, bonds well to the steel, flows nicely against the galvanize, and is more like brazing than welding. However, aluminum bronze is electropositive (cathodic) to zinc and also to carbon steel (more electropositive than stainless steel, in fact.). This means that both the zinc and the expsoed carbon steel immediately next to the weld metal will corrode to protect the aluminum bronze - again, not a happy situation!

Why not galvanize after welding?

Why not avoid the entire problem of dealing with welding over galvanized steel by galvanizing after fabrication? Steel products, after all, were always galvanized after fabrication because there used to be no practical way to restore the effectiveness of galvanizing after welding.

Galvanizing after fabrication is still done routinely, but it has to be done very carefully. The fabrication has to be cleaned in acid, the acid has to be neutralized, and then the fabrication had to be immersed in a pot of liquid zinc at over 900°F. One has to be very careful that the fabrication is dry when it is lowered into the zinc, since any trapped water will flash to steam, exploding zinc everywhere. One also has to be careful that the zinc can flow easily into and out of any nooks and crannies to achieve complete coverage; this is especially difficult if the fabrication is made of tubes, since the tube has to be open at both ends to allow the zinc to flow properly. Achieving uniform coverage on any but the simplest fabrication can be very difficult. Finally, the fabricated product has to be able to fit into the pot of molten zinc -- a difficult challenge with large structures.

Plates, sheets, wires, structural shapes and especially tubes are very easy to galvanize before being made into products, since their shapes are simple - no nooks or crannies, no hidden cavities, no place for water to get trapped.

Products which are ordinary hot dipped galvanized as opposed to being galvanized "in line" exhibit special problems when welding, mostly due to the uneveness of the coating. Edges and corners -- typically right where welding is being done -- frequently have very thick, heavy zinc deposits which may interfere with welding much more than where the zinc has been applied evenly. In addtion, hot dipped products typically have rough finshes which do not top coat very well, and top coating, especially with powder topcoats, has to be done within 48 hours to avoid difficulty with white rust formations.

Summary

In short, it's usually a lot easier and less expensive to galvanize steel before it is welded into useful products than it is to galvanize it afterwards.

Welding Galvanized Steel -- Safely

1) Galvanized steel can be welded using the same arc welding processes that are being used for fabrication today.

2) Galvanized steel can be arc welded safely with little increase in cost or welder discomfort.

3) Corrosion resistance at welds can be effectively restored by application of paint coatings which are high in elemental zinc or by thermal spraying zinc over the weld areas.

4) Galvanizing simple shapes can be controlled better than psot-fabrication galvanizing, resulting in smoother surfaces and a more uniform top coating appearance.

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