Technical Report

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Report Prepared for:

Mr. Brandon Wesley
Tarter Farm and Ranch Equipment

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Introduction

EAG, Incorporated (EAG) was queried by Mr. Brandon Wesley of Tarter Farm and Ranch Equipment Company, to research and write a white-paper addressing the following questions concerning a fire ring made of galvanized steel:

- Inhalation of the smoke that burns from the melting of the galvanized coating
- Ingestion of food cooked over the fire that melts the galvanized coating
- Consumption of vegetables planted in a galvanized raised garden planter
- Consumption of water from a galvanized tank

This investigation will include a comprehensive literature search and the findings will be explained and summarized in this document.

Background

Tarter Farm and Ranch Company is in the process of developing and manufacturing galvanized fire rings to contain a fire in areas such as campgrounds and backyards. Questions concerning the safety of using a galvanized fire ring for this type of application arose due to the low melting and vaporization temperatures of zinc. The melting temperature of zinc is 420°C (788°F) and the vaporization temperature is 907°C (1665°F).[1] Obviously the temperature in a wood fire can exceed the melting temperature of zinc and possibly even the vaporization temperature, so the effects of any potential zinc vapors to people near the fire are a potential concern, as well as the possible ingestion of food cooked over a fire within a galvanized fire ring.

Discussion

Figure 1 shows the cross section of the galvanized zinc layer on a base steel substrate. The zinc is not simply a thin layer of zinc adhering to the base steel similar to paint, but the zinc forms a metallurgical bond with the iron in the steel that permanently bonds the zinc to the base steel. The zinc forms three different alloy layers and then a layer of pure metallic zinc on the exterior surface. Starting at the interface between the zinc and the base steel, the metallurgical layers are:

- A thin Gamma layer comprised of an alloy that is 75% zinc and 25% iron with an approximate melting temperature of 783°C (1441°F),
- A Delta layer comprised of an alloy that is 90% zinc and 10% iron with an approximate melting point of 640°C (1184°F),
- A Zeta layer comprised of an alloy that is 94% zinc and 6% iron with an approximate melting point of 530°C (986°F),
- An outer Eta layer that is comprised of pure zinc with a melting point of 420°C (788°F).

[1] Metals Handbook, Volume 8, Metallography, Structures and Phase Diagrams, 8th Edition, ASM International.

It is important to note that the melting temperature increases as each metallurgical layer (phases) increases in iron content, so the outside portion of the pure zinc Eta layer and Zeta layer might melt but the underlying layers may not depend upon the temperature of the wood fire.

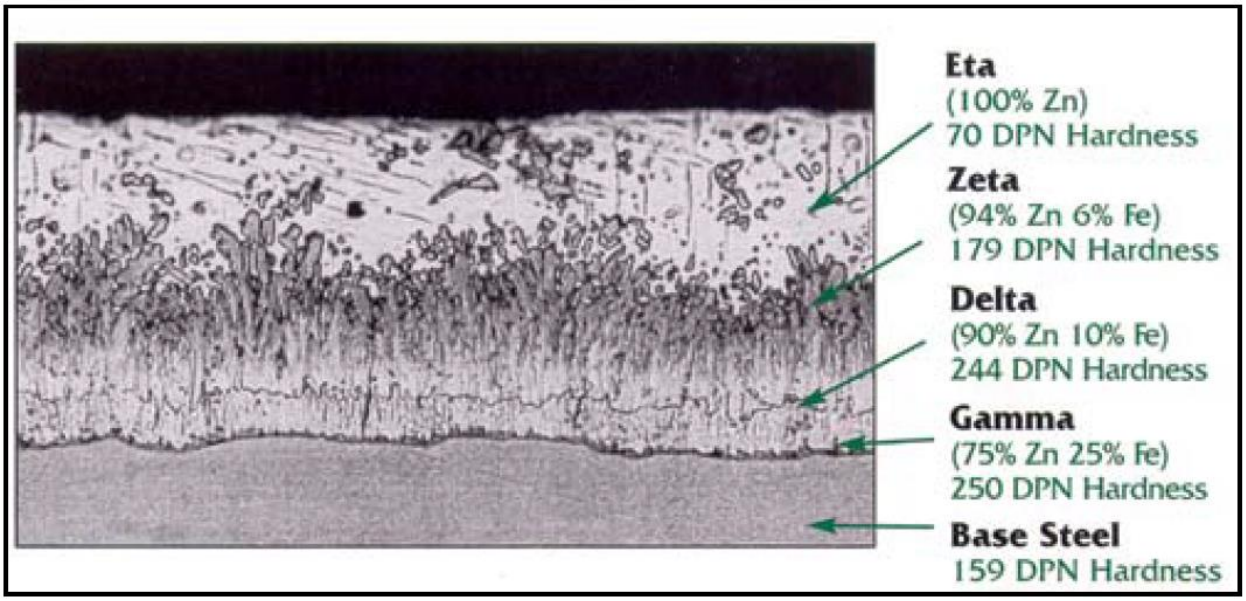

Figure 1. A photomicrograph of the galvanized zinc coating on a base steel alloy showing the metallurgical bonding.[2]

Fire Damage to Galvanized Steel

The melting temperature of most steel alloys is approximately 1370°C (2500°F) and wood fires typically burn at temperatures that range from 600 to 1030°C (1112 to 1886°F).[3,4] Since zinc starts melting at 420°C (788°F), the obvious question is how will the galvanized zinc coating respond when exposed to wood fires? Engle et al evaluated wire fencing material that had been repeatedly exposed to wildfires up to six times.[5] The coating thickness on all the burned wires was measured and compared to unused wire from the same lot that had been in storage since the fence installation. The galvanized coating thickness on the burned wires was generally equivalent to the unused wire and it was apparent that repeated wildfire exposure did not adversely affect the coating thickness nor the corrosion resistance of the galvanized wire. In some cases, the coating thickness actually increased due to wildfire exposure due to the growth of the underlying zinc-iron alloy layers. The burned wires did exhibit some staining or discoloration; however, this was only a cosmetic issue. The American Galvanizers Association is occasionally asked whether the galvanized coating is adversely affected by exposure to fire. *"Temperatures in fires can easily exceed 1,000 F. There is a potential for coating damage, but many have found fire damage to be minimal on galvanized steel. Often a layer of carbon dust coats the galvanized surface and under this layer the coating is intact."*[6] The Industrial Galvanizers of Australia evaluated the effect of bushfires on galvanized steel components and determined that the pure zinc of the surface will diffuse into the

[2] Hot-Dip Galvanizing for Corrosion Protection, American Galvanizers Association, Centennial, CO www.galvanizeit.org.
[3] G. Krauss, Steels: Processing, Structure and Performance, 2nd Edition, ASM International.
[4] NFPA 921, Guide for Fire and Explosion Investigations, 2014 Edition, 2014.
[5] Engle, Weir, Gay, Dugan, Grassland Fire Effects on Barbed Wire, J. Range Management, 51, 6, November 1998, pp 621-624.
[6] B. Duran, Galvanized Steels Performance in Extreme Temperatures", AGA, https://galvanizeit.org/knowledgebase.

deeper layers and form thicker zinc-iron alloys with higher melting temperatures. The galvanized coatings remain relatively unaffected through bushfire events.[7] The American Galvanizers Association published research showing that at 200°C (390°F) some minor peeling might initiate on the very outside layer of the galvanized coating and the peeling may become more significant above 250°C (480°F). The peeling is caused by closely spaced voids forming between the pure-zinc layer and the underlying zinc-iron alloys.[8] Figure 2 illustrates the peeling affect that can occur at higher temperatures. The underlying zinc-iron alloy layers with higher melting temperatures will remain after wood fire exposure.

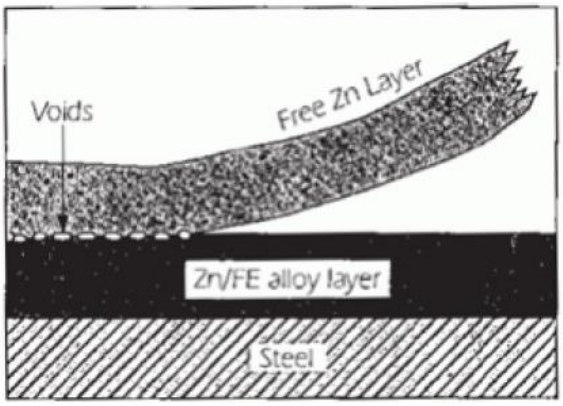

Figure 2. An illustration showing the peeling process of the outside pure-zinc layer.[8]

Overall Health Issues of Zinc

Zinc is an essential element for human health, especially for prenatal and postnatal development.[9] Zinc deficiency adversely affects about two billion people in the developing world and is associated with many diseases.[10] In children, deficiency causes growth retardation, delayed sexual maturation, infection susceptibility, and chronic diarrhea. Zinc is available as an over-the-counter daily vitamin supplement in the form as zinc oxide, zinc acetate, or zinc gluconate.[11] Zinc is usually considered to be an antioxidant and many zinc supplements are marketed for treatment of the common cold. The recommended dietary allowance (RDA) for zinc in the United States is 8 mg per day for women and 11 mg per day for men, and doses as high as 75 mg per day within 24 hours of the onset of symptoms has been shown to reduce the duration of the common cold.[12]

Zinc is also used as a topical preparation for use on the skin, often in the form of zinc oxide. These over-the-counter preparations are used to prevent sunburn, windburn and also for the treatment of severe diaper rash.[13] It is also used in toothpastes and mouthwashes to prevent bad breath as well as in shampoos to prevent dandruff.

[7] Industrial Galvanizers, PTY, Box 191, Carole Park, QLD 4300, 2013.
[8] B. Duran, Galvanized Steels Performance in Extreme Temperatures", AGA, https://galvanizeit.org/knowledgebase.
[9] Hambidge and Krebs, "*Zinc Deficiency: A Special Challenge*", Journal of Nutrition, 137, 4, p1101-1105, 2007.
[10] Prasad, A.S., *"Zinc Deficiency: Has Been Known for About 40 Years But Has Been Ignored",* British Medical Journal, 326, 7386, p 409-410, 2003.
[11] DiSilvestro, R.A., "*Handbook of Minerals as Nutritional Supplements",* CRC Press, p 135-155, 2004.
[12] *"Zinc – Fact Sheet for Health Professionals",* Office of Dietary Supplements, US National Institutes of Health, 2016.
[13] Emsley, J., *Zinc – Natures Building Blocks,* Oxford University Press, p 499 – 505, 2001.

Although zinc is an essential requirement for good health, excess zinc can have adverse effects including lethargy and ataxia (lack of bodily coordination) in the form of shakes. These occurrences have been attributed to people taking excessive dietary supplements or ingesting pennies and other zinc coins.[14]

Food and Agricultural Uses of Galvanized Steel

The Food and Drug Administration (FDA) has approved the use of galvanized steel for food preparation and conveyance for all applications with the exception of foods with a high acid content, such as processed tomatoes, oranges, limes and other similar fruits. Since many of these foods are stored on racks or in walk-in coolers with shelving, the problem is with the acidic foods corroding the metal and not with zinc contaminating the food.[15,16] Some of the applications include food storage racks, bar counter tops, coolers and meat storage hooks, as well as many products at the site of food production. In agricultural facilities galvanized components include dairy stalls, milk cans, chicken coops, feeding troughs, watering troughs, grain elevators, and many other animal containment systems.[17] *"Hot-dip galvanized steel offers a safe, reliable, durable coating to protect structures within a food processing facility, while the natural zinc poses no threat to the products transported through the facility".*[18]

For decades people in rural areas have collected rainwater for drinking from galvanized roofing.[19] Drinking water in urban areas continues to be supplied through galvanized steel pipes in many older communities and buildings without any adverse health risks. The problem with galvanized steel pipes for drinking water occurs when the galvanized steel gets old. After 50 to 75 years of water exposure, the zinc coating deteriorates and exposes the underlying steel to water causing it to corrode. The corrosion residue will color the water; however, these residues are not harmful to human health. These residues will slowly buildup along the inside diameter of the pipe and slowly restrict the water flow over time.[20]

Welding Galvanized Steel

Very little information could be found about melting and vaporization of galvanized steel components at or near high temperature sources such as a wood fire. However, there is information about welding galvanized steel and the precautions that need to be taken.[21,22] When welding galvanized steel components, the welder is usually about 18 – 24 inches from the weld zone which will melt steel and instantaneously vaporize zinc, and these temperatures are much higher than a typical wood fire. Welding of galvanized steel should be done in well ventilated locations to prevent excessive inhalations of fumes due to over exposure. If welding of galvanized steel must be done in a confined space, such as pressure vessels or closed tanks, external ventilation must be used or an air supplied mask. However, in areas with sufficient ventilation, no additional precautions are

[14] Bennet, D.R., et al, "*Zinc Toxicity Following Massive Coin Ingestion",* American Journal of Forensic Medicine, 18, 2, 148 – 153, 1997.
[15] *Hot-Dip Galvanized Food and Beverage Facilities*, American Galvanizers Association, Centennial, CO, 2016.
[16] Langill, T., *Hot-dip Galvanized in Contact with Food,* www.galvanizeit.org, 2002.
[17] *Galvanizing Our World – Food and Agriculture*, American Galvanizers Association, www.galvanizeit.org.
[18] *Hot-Dip Galvanized Food and Beverage Facilities*, American Galvanizers Association, Centennial, CO, 2016.
[19] "Is Galvanized Steel Toxic?", Bucket Outlet, www.bucket outlet.com, 3/31/2020.
[20] "What You Should Know About Galvanized Steel Pipes", The Clean Plumbers, www.thecleanplumbers.com.
[21] American Welding Society Handbook, 8th Edition, Vol 4, p118 – 155.
[22] American Welding Society, D19.0, Welding Zinc Coated Steel.

necessary.[23] *"When welding directly on galvanized steel is unavoidable, OSHA permissible exposure limits may not be surpassed in an open area but may be exceeded in confined areas…".*[24]

It should be noted that welders in confined spaces over-exposed to zinc fumes can develop metal fume fever, more commonly called "zinc chills" or "zinc shakes". The temporary illness initiates a few hours after over-exposure, or more frequently during the night. Some of the symptoms include a sweet taste in the mouth, dryness of the throat, fatigue, nausea, possibly vomiting, chills or a mild fever.[25] Complete recovery is normally within 24 - 48 hours. In addition, repeated exposure to moderate concentrations of zinc oxide in the air has not been proven permanently harmful.[26] The amount of zinc fumes developed from welding far exceeds any zinc fumes that may form from the heat of a wood fire based on the much higher temperatures involved, close proximity to the source of the fumes, and duration of exposure.

Zinc Fume Exposure From a Galvanized Fire Ring Due to a Wood Fire

The previous discussions were developed as background information to answer the two questions described at the beginning of the report. The first question concerned the inhalation of the smoke that burns from the melting of the galvanized coating. The previously described worst-case scenario was welding of galvanized steel which will have temperatures in excess of 1500°C (2730°F) and will instantaneously vaporize zinc and form fumes. The only concern for welders was the situation where they would be welding in a confined space with very little fresh air and the fumes get concentrated over time. This situation would never occur with a wood fire ring. The fire ring would obviously be used outdoors in a well-ventilated area. If the fire ring was used in a confined space for a wood fire, then more severe problems with inhalation of the wood smoke would be a concern. Any exposure of people near the fire ring to zinc fumes would also be very limited due to the small amount of zinc being heated to temperatures high enough for vaporization. Even though some portions of the fire ring may be directly exposed to the fire, the bulk cooling of the ring from the outside surface will limit the maximum exposure temperature.

The second question posed at the beginning of the report was ingestion of food cooked over the fire that melts the galvanized coating. Again, as previously discussed, the amount of zinc vapors developed will be very limited and some exposure will not be harmful. Once an initial layer of zinc has been exposed to wood fire temperatures, additional fires will have little to no additional damage to the zinc coating. As long as food is not in direct contact with the fire ring (such as a galvanized grill surface) then no molten metal will be in direct contact with the food and adhere to cooked food.

Use of Galvanized Steel as Vegetable Gardening Beds

Using galvanized steel containers for vegetable and herb gardening beds is absolutely safe and is becoming a popular method for raised beds.[27] They are sturdy, durable, resistant to rot (unlike wood), and will last for decades. Galvanized steel may have problems in very acidic soils[28], however most soils are not acidic and will not cause health problems for growing edible vegetables and herbs.[29] Placing small holes in the bottom of the

[23] Du Plessis, J., *Welding Considerations with Hot-dip Galvanized Steel,* AWS paper, American Welding Society.
[24] Welding and Hot-dip Galvanizing, American Galvanizers Association, www.galvanizeit.org, 2009.
[25] Ask Dr. Galv, Galvanizing, Vol 23, January/February 1996.
[26] Ask Dr. Galv, Galvanizing, Vol 23, January/February 1996.
[27] Epic Gardening, January 3,2020, www.epicgardening.com/galvanized-steel.
[28] Food Sanitation Rules, Oregon Administrative Rules, Oregon Health Authority, 4-101.15, February 2020,
[29] Seeds for Thought, University of California Cooperative Extension, 2014, Vol 9, Issue 3.

galvanized containers will assist with proper drainage for optimum growing conditions.[30] The dangers associated with zinc from consuming garden vegetables is very low. In fact, in many areas, drinking water supplies have been, and sometimes still are, carried by galvanized pipes. Consequently, the amount of zinc that may be absorbed by plant roots and into vegetables is insignificant.[31]

Safe to Consume Water From a Galvanized Tank

As stated previously, for decades people in rural areas have collected rainwater for drinking from galvanized roofing materials without adverse health effects.[32] Drinking water in urban areas continues to be supplied through galvanized steel pipes in many older communities and buildings without any adverse health risks. In the mid-1980s Congress passed the Clean Water Act Amendment, which includes the Safe Drinking Water Standard. This standard requires that any material or coating that comes in contact with drinking water must be tested.[33] The EPA contracted the National Sanitation Foundation (NSF) to write the test procedure, which after many drafts and public meetings, was finally published as NSF Standard 61: Drinking Water Systems Components - Health Effects.[34] Therefore, only galvanizers that have submitted test coupons of their galvanized steel and have been approved by the NSF have the authority to galvanize steel for use with potable water. Despite the great lengths that a galvanizer must endure to gain this certification, hot-dip galvanized steel is a very suitable application for potable water.[35,36]

Conclusions

The following conclusions are, in addition to those expressed throughout this report, stated to a reasonable degree of engineering and scientific certainty. They are based on the review of materials provided to EAG, analysis performed in this matter and presented in this report, as well as prior education, training, and professional experience.

- Inhalation of fumes from melted and/or vaporized zinc from a galvanized zinc coating on steel fire ring will have no danger to people standing or sitting near the fire. If the fire ring is being used in a ventilated area as expected for a wood fire, then exposure to any small amounts of zinc will be insignificant. If a galvanized fire ring were to be used in an area with limited ventilation, then the smoke from the wood fire would be a primary concern for human inhalation and exposure.

- Any exposure of food to any zinc fumes from the galvanized fire ring exposed to a wood fire is also not a concern as long as the food is not in direct contact to any potential molten zinc.

- Galvanized steel gardening bed containers are safe for growing edible vegetables and herbs.

[30] Are Galvanized Troughs Safe to Use for Veggie Gardens?, Homes and Gardens, January 26, 2020.
[31] Metal Plant Containers: Growing Plants in Galvanized Containers, Gardening Know How, www.gardeningknowhow.com/special/containers, 2020.
[32] "Is Galvanized Steel Toxic?", Bucket Outlet, www.bucket_outlet.com, 3/31/2020.
[33] EPA (1987). "National Primary Drinking Water Regulations – Synthetic Organic Chemicals; Monitoring for Unregulated Contaminants; Final Rule." Federal Register, 52 FR 25690, 1987-07-08.
[34] NSF/ANSI/CAN 61, https://www.nsf.org/testing/water/municipal-water-systems/nsf-ansi-can-61.
[35] In Water, The American Galvanizers Association, galvanizeit.org/hot-dip-galvanzing/how-lon-does-it-last/in-water.
[36] Industrial Galvanizers Specification Manual, Chapter 17, Zinc, Human Health and the Environment, 2013, p 65-66.

- Storing and transporting potable water in galvanized steel containers is safe as long as the galvanizer has complied with National Sanitation Foundation (NSF) Standard 61.

###End of Report###