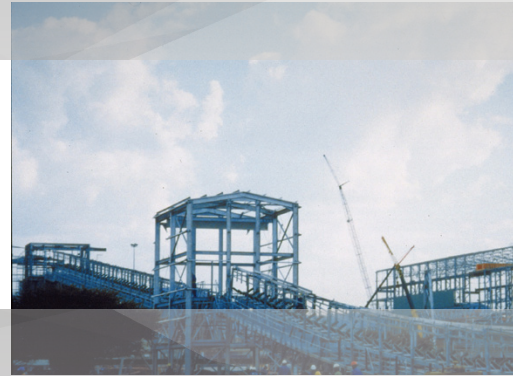


Hot Dip Galvanizing in Mining



Introduction

The mining industry represents a significant investment in infrastructure of which steel plays a key role. Many structures in a mine are made of steel, including shaft structures (buntons, station steelwork and headgear); stop structures (roof supports, pipe hangers); haulageway structures (ore transfer stations, electrical stubbies); and surface structures (plant buildings, tank supports, pipe gantries, conveyor belts, stacks, stockpile structures, stairways and railings).

Maintenance of structural components can often be difficult because of the environment of exposure (including those where corrosive fumes persist) or limited access (such as in shafts where access is limited to short maintenance shifts and limited working space is available). Thus a cost-efficient, long-lasting and maintenance-free protection system for steel should be specified.



Galvanizing provides tough and abrasion-resistant, long-term corrosion protection to steel. Galvanizing provides protection in two ways, as a physical barrier to corrosion and by means of galvanic or sacrificial protection that is unique to zinc, extending significantly the service life of steel even in the most challenging environments.

Left: Kinross Mine

Cover Photo: Vaal Reefs shaft steelwork

Galvanizing

Hot dip galvanizing has been used to protect steel against corrosion for more than 150 years. By dipping steel into molten zinc, the zinc reacts with the steel to form a metallic coating.

Dual Protection

All coatings are designed to provide barrier protection. Zinc is the only coating providing dual protection to steel: barrier protection plus galvanic protection.

Hot dip galvanized coatings provide a continuous, impervious metallic barrier that does not allow moisture to contact the steel. Without moisture contact, there is no corrosion. The nature of the galvanizing process ensures that the metallic zinc coating has superior adhesion, abrasion, and corrosion resistance. However, because zinc does eventually corrode—albeit very slowly—coating life is proportional to coating thickness. Continuous galvanized coatings applied to steel coil products tend to be thinner than general galvanized coatings. Continuous galvanized coatings typically have thicknesses of 20-40 microns, while general galvanized coatings applied to steel articles in turn by a batch dipping process are in the range of 85-200 microns. For steel coil products, alloy coatings are also offered, but their improvement over pure zinc in mining applications should be carefully checked if they are considered, rather than relying on accelerated corrosion tests. For general galvanized steel products, the use of thicker zinc coatings in excess of 85µm is typical, and improves both corrosion and abrasion resistance.

**Zinc coatings provide a continuous, impervious metallic barrier...
Zinc's unique ability to galvanically protect steel provides a powerful second shielding mechanism.**

Barrier protection is effective as long as the coating remains intact. When damaged, corrosion will begin at the unprotected surface. Zinc's unique ability to galvanically protect steel provides a powerful second protection mechanism. Zinc corrodes preferentially to steel so when galvanized steelwork is scratched or cut during transportation or assembly, the steel is galvanically protected by the sacrificial corrosion of the zinc coating adjacent to the steel. In practice, this means that a zinc coating will not be undercut by rusting steel because the steel cannot corrode adjacent to

the zinc coating. Any exposure of the underlying steel will not result in corrosion and has minimal effect on the overall performance of the coating.

Zinc Corrosion Rates

Zinc has a very long life. Zinc corrosion rates depend upon the environment. Corrosion only occurs when the surface is wet; even then, it depends on the duration of wetness and the type of moisture. When a galvanized surface is completely wet for long periods of time, especially by a strong electrolyte, such as saline mine waters, for example, relatively large areas of steel will be protected as long as any zinc remains. In air, where wetting is discontinuously present, (e.g. from dew or rain), smaller areas, typically on the scale of several millimeters, of bare steel are protected. The pH (acidity or alkalinity) of water or other liquids that contact zinc, has a significant effect on the corrosion rate. The relationship between pH and corrosion rate for zinc is shown in Figure 1. Zinc is stable in a wide range of corrosivity conditions relevant to mining applications.

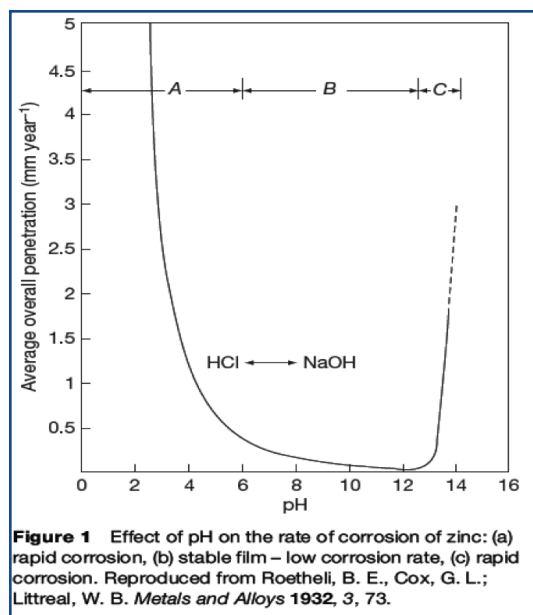
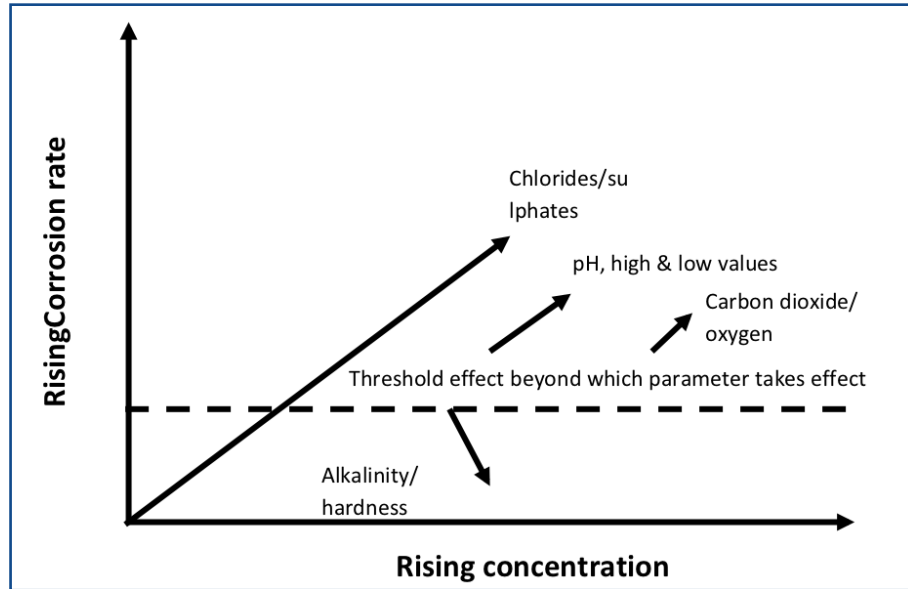


Figure 1. Effect of pH on the rate of corrosion of zinc: (a) rapid corrosion, (b) stable film - low corrosion rate, (c) rapid corrosion. Reproduced from Roetheli, B.E., Cox, G.L.; Littreal, W.B. *Metals and Alloys* 1932, 3, 73.

In addition, water contains numerous dissolved salts. In mine waters, dissolved carbon dioxide and oxygen can also be found. The effects of all of these impurities on corrosion rate are summarized in Figure 2.

Figure 2. Effects of water quality on corrosion rate of HDG



In hard waters, high chloride levels ($>2000\text{mg/l}$) can be tolerated. Sulphates, nitrates and phosphates are generally considered to be protective towards galvanizing. However, when combined with ammonia compounds (common as explosives residues in mines) soluble zinc compounds may be formed and acid conditions can arise causing attack of galvanized steel. Organic compounds such as tannins will arrest the corrosion of galvanized steel but the settling of solids can create conditions for crevice corrosion. Similarly, slime build-up should be avoided as microbiologically induced corrosion (MIC) can occur leading to rapid attack. It is important when testing water lines that clean water be used and the system drained if it is to be left unused for some time. Chlorination has no deleterious effect upon the protection properties of galvanizing. Copper should only be used downstream of galvanized piping. This will avoid the possibility of pitting corrosion.



Mining Industry Environment

The environmental conditions in the mining industry can often be aggressive, and the service demands on steel are often extreme, subjecting steel to maximum demands. These conditions include:

- Full water immersion
- Impact and abrasion conditions
- Long-term surface wetness
- Elevated temperatures
- Acidity and alkalinity
- Impact and abrasion conditions



The primary mine environments are the underground environment, the surface minerals beneficiation environment, and the transportation environment. Hot dip galvanized coatings have a good track record in protecting many structural steel parts in these environments.

Underground Environment

With increasing depth and distance from the shaft towards the working area, the corrosion severity and incidence of mechanical damage increases substantially. Underground workings are often wet and the waters tend to be corrosive due to pickup of fumes (such as blasting fumes) and ingress of acidic waters into the working areas. Shaft areas can become aggressive to steelwork due to water, falling objects and dust, resulting in the formation of poultrices, which allow corrosion to continue under the poultrice.

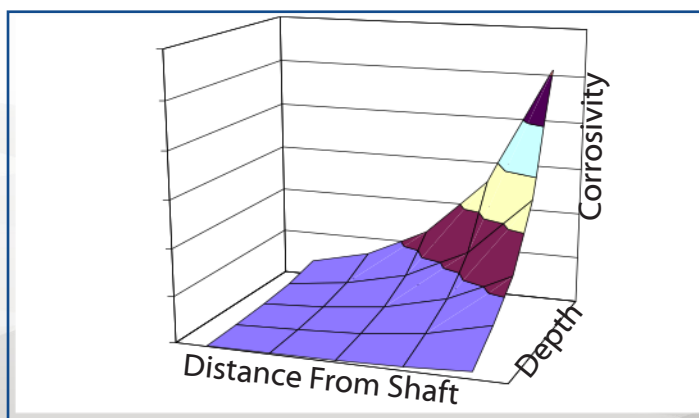


Figure 3. Corrosivity underground rises with increasing depth and distance from shaft

Surface Facility Environment

Atmospheric environments are classified into different categories of severity by ISO 9223, which also provides a range of lifetimes for steel and zinc in these environments, as shown in Table 1.

Table 1. ISO 9223 Environment Categories

ISO 9223		Typical Environment
Category	Description	
C3	Medium	Coastal or Industrial
C4	High	Calm Seashore
C5	Very High	Surf Seashore
CX	Extreme	Ocean/Off-shore

The relationship between galvanized coating thickness and expected coating life (defined as the time that can pass before coating maintenance is required to restore protection to the base metal) is shown in Table 2.

Table 2. Relationship between coating thickness and expected lifetime

Reference Standard	Minimum Thickness μm	Selected Corrosivity Category (ISO 9223) Life Min./Max. (Years)			
		C3	C4	C5	CX
ISO 14713-1	85	40 / >100	20 / 40	10 / 20	3 / 10
	140	67 / >100	33 / 67	17 / 33	6 / 17
	200	95 / >100	48 / 95	24 / 48	8 / 24

The data of Table 2 is shown graphically in Figure 4.

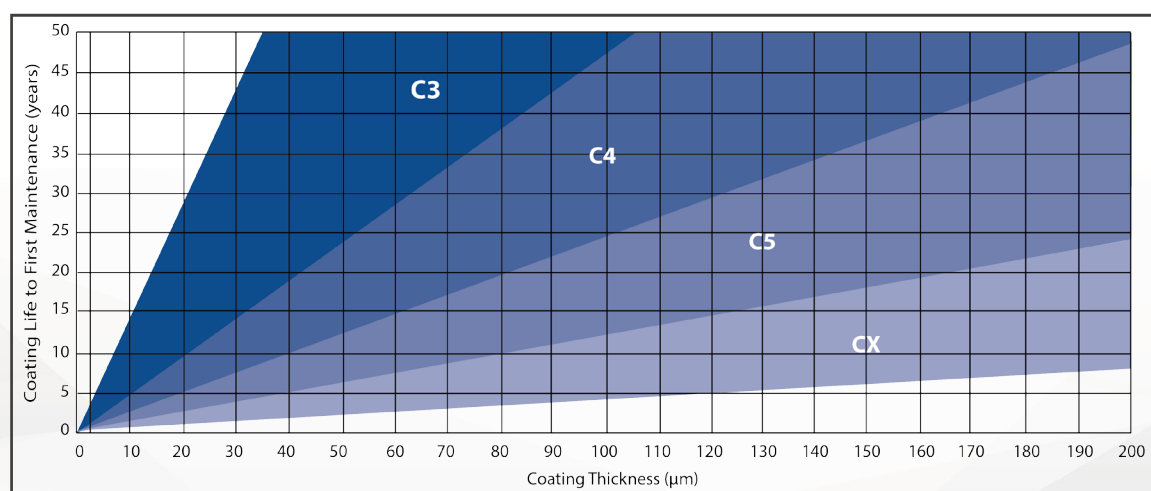


Figure 4. The relationship between galvanized coating thickness and expected coating life

Added Protection and Aesthetics

Organic (paint) coatings can be added for improved corrosion protection and aesthetics. Continuous galvanized sheet is generally pre-painted in the same facility in which the galvanized coating is applied. This allows for precise preparation of the galvanized surface prior to coil coating. Painted galvanized sheet can be roll-formed to give profiles as specified by the customer. Recent advances in galvanizing technology and paint systems enable pre-painted galvanized sheet to be roll-formed with striking patterns, allowing architects new roofing and cladding possibilities for industrial, commercial and residential buildings.

Galvanized coatings can be covered with organic coatings when required for added corrosion protection, safety, statutory or aesthetic reasons. This would include the use of green and red coatings applied to piping to indicate conveyance use.



The combination of paint coatings on top of galvanized coatings is termed a “duplex system”. Duplex systems benefit from a synergistic effect, which enables the combined life of the painted galvanized steel to be longer than the sum of the individual lives of the paint and galvanized coatings in the same environment. The synergy multiplier ranges from 1.8 to 2.7 depending on the severity of the corrosion conditions. The synergy equation and synergy factors are shown in Table 3.

Table 3: Synergy Effects on Service Lives of Painted Galvanized Steel

Duplex Service Life = Synergy Factor x (Zn Life + Paint Life)	
Example: Service Life = 1.5 x (9 years + 5 years) = 21 years to 5% rust	
Synergy Factor Values:	
Industrial/Marine	1.8 to 2.0
Sea Water (Immersion)	1.5 to 1.6
Non-Aggressive Climate	2.0 to 2.7

The specification of paint systems for use with galvanized steel is provided in ISO 12944 Part 5, shown in Table 4 below. The corrosivity categories C2, C3 etc. refer to the ISO 9223 corrosion environment shown above in Tables 1 and 2. Many paint suppliers refer to the paint system specifications of this standard specification, for example A7.13, in their product literature.

Table 4: Excerpt from ISO Standard 12944 Part 5, showing paint systems to be used in the indicated corrosion environments with galvanized steel

Substrate: Hot-dip-galvanized steel																						
ISO 12944-4 gives some examples of surface preparation. The type of surface preparation depends on the type of paint system, and should be stated by the paint manufacturer.																						
System No.	Priming coat(s)			Subsequent coat(s)	Paint system		Expected durability ⁹ (see 5.5 and ISO 12944-1)															
	Binder	No. of coats	NDFT ^b in µm		Binder type	No. of coats	NDFT ^b in µm	C2			C3			C4			C5-I			C5-M		
								L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
A7.01	—	—	—	PVC	1	80																
A7.02	PVC	1	40	PVC	2	120																
A7.03	PVC	1	80	PVC	2	160																
A7.04	PVC	1	80	PVC	3	240																
A7.05	—	—	—	AY	1	80																
A7.06	AY	1	40	AY	2	120																
A7.07	AY	1	80	AY	2	160																
A7.08	AY	1	80	AY	3	240																
A7.09	—	—	—	EP, PUR	1	80																
A7.10	EP, PUR	1	60	EP, PUR	2	120																
A7.11	EP, PUR	1	80	EP, PUR	2	160																
A7.12	EP, PUR	1	80	EP, PUR	3	240																
A7.13	EP, PUR	1	80	EP, PUR	3	320																

Type of binder	No. of components	Water-borne possible	Binder for subsequent coat(s)	No. of components	Water-borne possible
AY = Acrylic	1-pack	X	AY = Acrylic	1-pack	X
PVC = Poly(vinyl chloride)	1-pack		PVC = Poly(vinyl chloride)	1-pack	
EP = Epoxy	2-pack	X	EP = Epoxy	2-pack	X
PUR = Polyurethane, aromatic or aliphatic	1- or 2-pack	X	PUR = Polyurethane, aliphatic	1- or 2-pack	X

^b NDFT = Nominal dry film thickness. See 5.4 for further details.

⁹ The durability is in this case related to the adhesion of the paint system to the hot-dip-galvanized substrate.

Hot Dip Galvanizing: A Cost-Efficient Protection System

When comparing hot dip galvanizing with other protection systems, two elements have to be taken into consideration: the initial costs of applying the protection system and the life-cycle costs, including maintenance, to ensure the steelwork is protected against corrosion throughout the entire lifetime of the mine project. Whereas initial costs are typically a small fraction of the total

lifetime costs, life-cycle costs, especially if frequent maintenance is required, can be several times the initial costs.

Initial costs of applying a zinc coating through hot dip galvanizing are comparable to those of a quality paint-only protection system. However, hot dip galvanizing's major advantage is its maintenance-free longevity. Once applied, no further costs occur throughout the project life. Paint-only systems show failure after a few years, requiring regular maintenance thereafter, making maintenance costs a major expenditure. Hot dip galvanizing as a protection system for steelwork in mines can save 50% or more in total steel protection costs over a 30-year project lifetime. No other protection system provides a better return on investment.

A Sustainable Choice

Zinc is an integral part of the environment, naturally present in rock, soil, water and air. It is an essential micronutrient for humans, animals and plants. Zinc coatings greatly improve the durability and life cycle of steel products and, like steel, zinc is 100% recyclable, thus conserving valuable resources and providing economic savings for future generations.



Conclusion

Hot dip galvanizing provides superior corrosion protection to steel. It is easily and swiftly applied and covers the entire surface of the steel article, even in inaccessible areas, provided the article is properly designed. Hot dip galvanized coatings provide a unique dual protection that prevents corrosion even if the coating is damaged. Maintenance painting is often impossible in mining environments, so the only option with paint-only structures is complete replacement. Hot dip galvanized coatings are hard and chip-resistant. They provide long lasting and maintenance-free corrosion protection to steel even in aggressive mine environments and provide significant savings compared with other protection systems that require maintenance.

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The contribution of these case studies from their respective regions by galvanizers and industry associations is gratefully acknowledged. Contact details with these IZA members can be found in the IZA member lists at www.zinc.org.

Surface Project: Goedehoop Colliery (Exxaro)

Location: South Africa

Surface Environment: CX

The Goedehoop Colliery opened in the 1980s. In the mid-1990s, the mine received several extensions, including those to the coal washing plant and the conveyor material supply system.

Inspection of existing facilities showed widespread paint failures. Maintenance of coatings in these applications is almost impossible unless the entire operation is shut down.

Given the difficult access and the extreme climatic conditions, the recommended coating for the extension to the washing plant was a “duplex” system, comprising a single coat high-build epoxy system i.e. no primer applied onto a sweep-blasted hot dip galvanized surface. The epoxy coating was applied on the galvanizer’s premises.

After 10 years, an inspection showed the duplex coating to be in exceptional condition, such that the organic coating had to be purposefully damaged in order to assess the adhesion of the organic coating and the overall condition of the hot dip galvanized coating underneath.



Steel structure at the Goedehoop Colliery



Cross cutting proved that adhesion of the coating was sound.



Hot dip galvanized coating thickness (paint removed)



Total duplex coating thickness

Surface Project: Moma Mine (Kenmare Resources)

Location: Mozambique

Surface Environment: C4 - C5

Moma is the world's largest titanium mineral deposit, located on the Mozambique coast, north of Beira. The project involved the design, off-site fabrication of steel, and hot dip galvanizing, followed by the logistics of loading, ocean transportation of the entire project facility, trans-shipping via a sea barge to the beach, haulage inland over a distance of 3 to 4km to the various sites comprising the project. The project required integrated logistics planning and coordination of all supply arrangements. No infrastructure or formal facilities existed prior to this project.

The corrosive conditions encountered at this remote location can be classified as C4-C5, very high in terms of ISO 9223. The expected corrosion rate of zinc was approximately 2 to 3µm per year in this environment. As a result, the hot dip galvanized structural steel will have a maintenance-free service life of at least 30 years.



Aerial view of processing plant. Photo courtesy of Kenmare Resources.



Wet concentrator plant and dredges operating at night. Photo courtesy of Kenmare Resources.

Surface Project: Phalaborwa Copper Mine (Rio Tinto)

Location: South Africa

Surface Environment: C1-C2; CX in specific areas

General atmospheric conditions at the Phalaborwa Copper Mine are dry and dusty and appear to be a typical C1 to C2 environment. However, it was confirmed that aggressive conditions existed in the acid and zirconia plant where a number of corrosive chemicals, including sulphuric acid were produced this creating a CX environment.

An inspection in 2005 of cable ladders installed in the 1980s showed that the epoxy powder “duplex” system was still in good condition. On crosscutting the coating to ascertain paint adhesion, the coating remained intact despite trying to lift it at the crosscut. However, several other coatings on components located at the site were in the process of breaking down. At the time of inspection, the cable ladders were no longer in use due to the building being declared redundant.



Insitu cable ladders in the redundant Transfer Station No. 1.



Total coating thickness reading on the cleaned up side rail of the cable ladder.



Exposed powder coating subjected to a cross cut adhesion test.



The Phalaborwa open pit copper mine is the largest man-made hole in Africa.

Surface Project: Worsley Alumina Expansion Project (BHP Billiton)

Location: Australia

The Worsley Alumina Refinery is located in Western Australia and has been operating since 1984. In the early 2000s the Worsley Joint Venture extension project was established to raise refinery capacity from 1.88 million tonnes per year (mtpa) to 3.1 mtpa with the shortest project duration. For precautionary reasons, the chemicals used in the alumina process, metallic coatings, had been avoided. However, since existing galvanized items throughout the plant showed excellent service life, such as cable trays and other steel auxiliaries, the situation was reassessed. Particular value was found in galvanized steel's handling capability, solar radiation (UV) immunity, sharp edge protection, and other characteristics complimentary to the design capability of steel.

Accurate and timely supply was critical to meet the tight requirements of the project. 8,000 tonnes of structural steelwork were delivered over a 12-month period. Hot dip galvanizing assisted greatly with:

- Meeting tight schedules: steelwork was ready to erect, no on-site painting was required
- Improving system quality: durable structures provided
- Improving project control: no on-site painting required
- Allowing contract flexibility: steelwork could be galvanized off-site in one of several locations
- Reducing risk: the galvanized coating is much more resistant to transport and erection damage than paint.



Worsley Alumina Refinery

Surface Project: Pinjarra Alumina Refinery Efficiency Upgrade (Alcoa)

Location: Australia

Alcoa's Pinjarra Alumina Refinery, located about 90 kilometers south of Perth in Western Australia, and was upgraded in 2004 to increase alumina production by 660,000 tonnes per year. Substantial structural steel use required corrosion protection.

Hot dip galvanizing offered significant cost and time efficiency. PH limits had to be carefully considered with respect to all coating materials. Due to process improvements and design pH levels were reduced to acceptable alkaline limits, particularly since zinc galvanizing is less affected by moderate caustic solutions and is not prone to dramatic (and often catastrophic) breakdown. The use of similar sized steel members made galvanizing simpler for the galvanizer.

The project was managed by Hatch who recorded the following advantages of using galvanized steelwork:

- Coating, damage free on delivery & installation
- Reduced site congestion
- No weather delays
- Immunity to severe UV



Pinjarra Alumina Refinery



Galvanized structural steel components

Surface Project: Sishen Mine Beneficiation Plant (Kumba Iron Ore / Anglo American)

Location: South Africa

Surface Environment: Arid

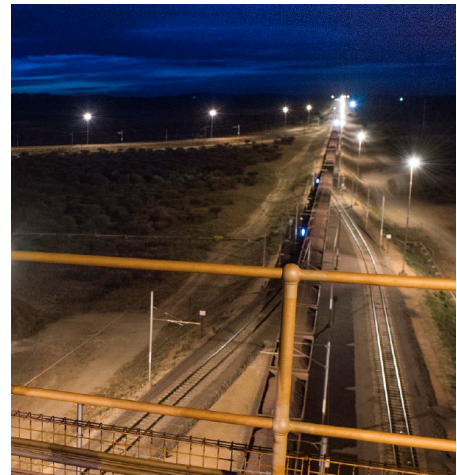
The Sishen Mine is located in the Northern Cape, South Africa. It is the third largest iron ore open pit in the world and produces 30 million tonnes of iron ore per year.

Extensive use has been made of galvanized steelwork in the arid conditions of the site.

The mine exports via the port of Saldhana in the Western Cape Province at a distance of 861km. The trains are, on average 3,780m long – the longest trains in the world. The dedicated line makes extensive use of galvanized trackside equipment such as rail clips, catenary supports, fencing, etc. The longest and heaviest train ever used was a 7,5km train with 660 wagons, which carried 68,640 tonnes of ore.



Sishen Mine. Photo courtesy of Anglo American.



Sishen Mine train cars transporting iron ore. Photo courtesy of Kumba Iron Ore.

Surface Project: Sishen Mine Crusher Construction (Kumba Iron Ore)

Location: South Africa

The new primary crusher is situated at the edge of the existing pit in an area where the existing pit had been backfilled. The primary crusher building was founded at a depth of 35m below the natural ground level.

Mechanically reinforced walls were required to enable access by the 400-tonne tipping trucks to the crusher. The backfill was comprised of magnetite, which had a higher density than typical quarry backfill materials and thus required additional retainment. Tests showed that this had no effect upon either the corrosion of galvanized weldmesh or reinforcing strips.

This novel design, which resulted in a patent being registered in 2006, enabled successful use of galvanizing in a key application encountered in open pit mining.



Wall B of crusher nearing completion



Sishen open pit iron mine. Photo courtesy of Anglo American.

Surface Project: Skorpion Zinc Mine Modular Stockpile Dome (Vedanta)

Location: Namibia

The Skorpion Mine is located in the Southern Namib Desert and is a large opencast operation. The circular stacker was installed to handle a 50,000 tonnes run-of-mine stockpile. Some 300 tonnes of steelwork went into the dome which was clad with 11,300m² of color coated galvanized sheeting. The dome is 93m in diameter and 30m high. There are 25 conveyors, the longest being several kilometers long. Environmental considerations were paramount, with dust being one of the main concerns. The stockpile was stored in the covered dome and all conveyors had dust control systems. Feed conveyors were covered with profile color coated galvanized sheeting.

The remoteness of the site necessitated large sections of the stacker/reclaimer to be prefabricated and transported to site for erection, with little sub-assembly occurring on site. The largest prefabricated section was approximately 45m long, 2.5m deep and 2m wide. It was critical that the stacker/reclaimer was erected before any work on the dome began. Erection of the dome took careful planning, as the structure would only self-support once the final structural elements were in place. Consideration of the dome's erection formed a significant part of its engineering. Temporary support was required during construction. The center column of the stacker/reclaimer provided some support, reducing the need for additional support structures. Erection of the dome was without incident, due to computer-orientated steelwork detailing and trial assembly in the workshop prior to transportation to site.



Skorpion Mine stockpile dome under construction



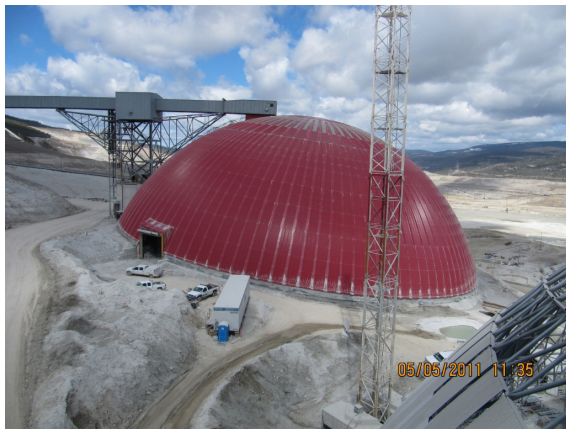
Skorpion Mine stockpile dome near completion

Surface Project: Highland Valley Copper Stockpile Dome (Teck Resources)

Location: Canada

The Highland Valley Copper Stockpile Domes are located at Logan Lake, British Columbia.

Dust emissions were a problem at the site and it is not possible to spray the ore on the conveyor belts with water to reduce dust. To minimize dust emission, three geodesic domes were fabricated to cover each of the three stockpiles. The domes were made with the intent that the stockpiles would remain operational during the entire construction period. The domes were designed using a tubular frame structure in galvanized steel and a galvanized steel cladding system. Each dome has a basic diameter of 100m, and an overall surface area of 11,000m². Dome cladding is a curved corrugated galvanized steel deck with custom formed galvanized steel infill panels. The maple leaf on the center dome is made of 864 metal sheets and is bigger than a football field, measuring 100m wide and 80m high.



Highland Valley Copper Stockpile dome.



Highland Valley Copper Stockpile domes.

Surface Project: Red Dog Mine (Teck Resources)

Location: Alaska, U.S.A.

The Red Dog mine is located 200km north of the Arctic Circle and 90km inland from the Chukchi Sea.

The ore is mined and processed at the mine site and then transported 86km by truck to the sea-port where it is stored in the huge concentrate storage building during the winter until the 90 – 100 day shipping season begins during the arctic summer.

The link from the mine to the port presented a great challenge. In order to deal with extensive drainage required during summer, about 10km of the culvert was used to allow for 646 drainage crossings. There were 9 major stream crossings, requiring bridges with spans up to 100m. The bridges used galvanized fabrications and the concentrate building (the largest structure in Alaska) is clad with pre-painted galvanized steel sheeting.

As much fabrication as possible was carried out off site due to the remoteness of the locations. The accommodation complex was built in Idaho in the USA and the milling facilities in the Philippines. Hot dip galvanizing was specified for all exterior building components.

Inspections after eight years indicated that there was no corrosion damage to any of the galvanized structures.



Steel support column for the concentrate storage building. Because of their size, each column required double dipping in the galvanizing kettle.



Support columns loaded onto a transport truck. A total of 100 columns each weighing about 3 600 kg were hot dip galvanized for the storage building.

Surface Project: Polaris Lead/Zinc Mine (Teck Resources)

Location: Canada

The Polaris Lead/Zinc mine was located on Little Cornwallis Island, 100km from the magnetic north pole. The average summer temperature is around 0°C with winter norms of -45°C. The concrete-hard permafrost is a quarter of a mile thick, there are continuous winds of greater than 80km/hr., and for six months of the year there is total darkness. Under these conditions, even commonplace tasks become difficult problems requiring innovative solutions.

Teck specified the use of hot dip galvanized steel as the building material for all three major structures of the Polaris Mine, (the processing plant, the concentrate storage building, and the accommodation complex) as well as the many ancillaries. The three main structures employed over 50,000m² of pre-painted galvanized sheeting and over 5,500kg of galvanized light structural steel. A significant challenge was the fact that, where possible, complete installations were fabricated elsewhere and shipped to site.



The processing plant on a barge in Trois-Rivieres, Quebec on its way to site. On-site, this plant houses the concentrator, the mine's maintenance and storage areas, workshops and four diesel generators to supply the total electricity needs of the operation.



Galvanized steel retaining walls make up the base of the concentrate building. The insert shows the assembly of the crib walls.



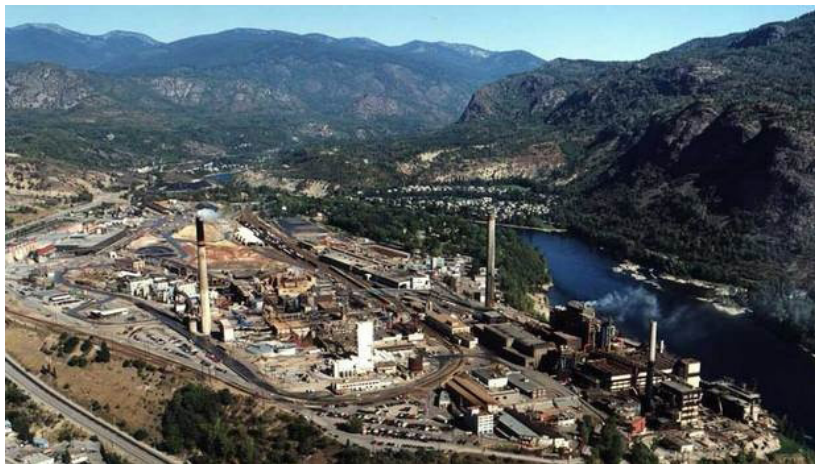
The 275m long accommodation building is a modular structure consisting of a linear arrangement of alternating two and three story units. Built under a large movable hangar, this award winning design in galvanized steel allowed work to proceed at a rapid rate even throughout the worst winter conditions.

Surface Project: Trail Operations (Teck Resources)

Location: Canada

Located in Trail, British Columbia, the Trail Zinc Refinery is one of the largest zinc producers in the world.

Extensive use of galvanized steelwork was used in the construction of the facility ranging from siding and flooring to cable racks, hand-railing, floor-grating and electrical sub stations. The trestle that carries the rail line to the feed preparation plant for the lead smelter contains 460 tonnes of hot dip galvanized structural steel and 4,000m² of galvanized floor grating.



Trail, British Columbia, Canada



Trail Zinc Refinery

Underground Mining: Kinross Mine Steelwork (closed)

Location: South Africa

Much of the experience which has enabled the specifying of hot dip galvanizing for mine shaft steelwork dates back to an early inspection carried out after 10 years at the Kinross Mine. Installed in 1975, this case history showed that galvanizing will provide useful life in excess of the previously employed paint systems (generally epoxies). The shaft is more than 2km deep and can be divided into three zones: the dry zone (0 to 400m), an intermediate zone (400 to 1400m) and the wet zone (below 1400m) where deposits landing on the steelwork and piping remain saturated.

On inspection in the dry zone where continuous streams of water do not flow over the steelwork, coating thickness measurements in excess of 110µm (i.e. no measurable loss) were made on buntons and pipe columns.

In the intermediate zone, the presence of flowing water increases substantially. However, the corrosive effects were restricted to the top 15% of the buntons where a complete removal of the zinc protection was observed. This confirmed the predictions of the probability model proposed.

In the wet zone, the galvanized steelwork was protected with an epoxy coating. Little degradation of the duplex system was evident where full saturation was not occurring. Some blistering of the epoxy was noticed on the pipe column but the galvanized coating continued to provide excellent protection of the underlying steel. Both the zinc and paint were destroyed on the top surfaces of the buntons because of continual impacts from falling debris. The nearby galvanized station steelwork was still in good condition; this area is normally not exposed to continual saturation by water or impact damage by falling debris.



Deposits over "duplex" and hot dip galvanized shaft steelwork at Kinross



After ten years bunttons were shown to be in good condition, although, as would be expected, the top surfaces did show strain. However, no perforation was noted requiring no costly replacement.

Underground Mining: Rasimone Platinum Mine (Amplats, now Royal Bafokeng Platinum)

Location: South Africa

Surface Environment: CX

The construction of the Bafokeng Rasimone Platinum Mine began in 1997. The mine is located 150km northwest of Johannesburg. Unlike deep level gold mines, platinum mines tend to be shallow with depths ranging from about 500 to 1200m. The mine waters tend to be less aggressive than those encountered within gold mines. They are hard and close to neutral in pH, although high chloride levels are still common (750mg/l).

8,000 tonnes of steelwork was used for the two incline shafts and the surface plant. Previous experience with hot dip galvanizing indicated that it would be suitable for both types of structures. Galvanizing included the structural steelwork as well as building framework, conveyors, grid flooring, hand railing and equipment frames.

An inspection carried out in 2002 showed that the anticipated life of 25+ years would easily be met. Hot dip galvanizing performed well in the milling area, the flotation area (especially on flooring where frequent spillage occurs), underground steelwork (where abrasion due to falling debris and accumulation of deposits often compromises alternative coatings) and shaft headgear and conveyors. Galvanized steel was used to coat some chutes; these had perforated because of the highly abrasive conditions. In the reagent area, the coating specification excluded the use of hot dip galvanized steel due to incomplete performance data; however, small items (such as pipes and hand rails) that were galvanized performed very well. By contrast, the conventional organic paint system (a three-coat vinyl co-polymer system over a Sa 2½ or near white metal surface preparation grade) used for other applications in the reagent area showed marginal performance, requiring replacement or maintenance at best about every second year.



Bafokeng Rasimone Platinum Mine. Photo courtesy of Royal Bafokeng Nation.

Underground Mining: Vaal Reefs Shaft Steelwork (AngloGold Ashanti)

Location: South Africa

Planning for the Vaal Reefs number 11 shaft (now Moab Khotsong Mine) started in 1988. Some initial studies of the water quality likely to be encountered indicated that performance of galvanizing should be fair. Shaft sinking started in 1992. The shaft is 10.6m in diameter and 3.16km deep. All of the shaft steelwork was galvanized.

A follow-up inspection was carried out in 2006, during which the coating thickness was found to be 150 to 300 μ m. At some areas of mechanical damage, the coating had chipped; however, measurement showed that a coating thickness of 25 to 35 μ m was still present (mainly an iron zinc alloy layer). No under-film creep or other evidence of steel attack was observed, despite this damage; the galvanized coating was still protective.



Shaft steelwork assembled above ground to ensure fit-up.



Hot dip galvanized shaft guides correctly laid out on site, awaiting installation in the shaft.



The coating thickness on shaft buntions at four different levels were inspected but as they were similar in residual coating thickness, only two have been reported. The calcareous growth in most instances was removed prior to measuring the residual coating thickness.



Coating thickness of shaft station steelwork

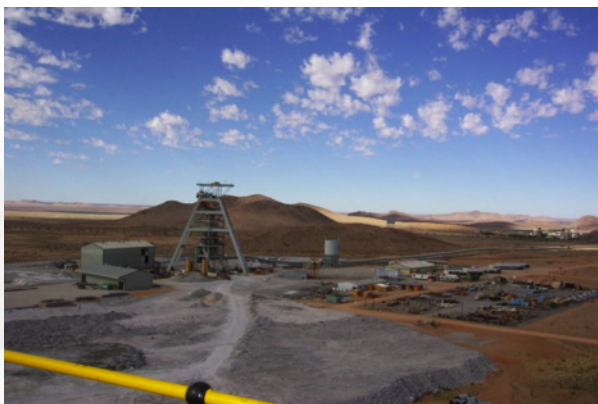
Underground Mining: Black Mountain Deeps Project (Anglo Operations, now Vedanta)

Location: South Africa

Black Mountain is a zinc, lead, copper mine located in the Northern Cape Province of South Africa. The project comprised the installation of the infrastructure to two shafts – the operational shaft, 7.4m in diameter, and the ventilation shaft, 6.2m in diameter. 2360 tonnes of galvanized steelwork were used. Hot dip galvanizing was identified as the most efficient method for corrosion protection of the shafts, which were classified as “wet shafts.” The alternative use of organic coatings was considered to be unsuitable and impossible to maintain.

Notwithstanding the choice of hot dip galvanizing for corrosion protection, a number of issues arose which should be noted:

- Make allowances in clearances and tolerances to ensure that flange and faces bolted joints are easily managed. Variations in galvanizing thicknesses may become a problem with steelwork fitting requiring excessive use of packers.
- Carefully check drawings to ensure no further changes will be required. Some design changes may be required.
- Close co-operation between designer, fabricator, galvanizer and erector is recommended to ensure that all involved understand where special considerations are required for galvanizing.
- Training in the use of galvanized steelwork, (e.g. correct handling, etc.) is recommended.
- Careful inspection and clearing of hollow steelwork sections prior to slinging is recommended.
- Clear repair method to repair damaged galvanizing should be recorded.



Black Mountain Deeps



Galvanized steel structural components

Underground Mining: Coal Mine Drift Supports (KWK „Mysłowice-Wesoła”)

Location: Poland

During 1990, 174 tonnes of steel was galvanized and installed in underground drifts at a bituminous coal mine in Mysłowice, Poland. This mine is characterized by very corrosive underground water with a chloride content of 17,000–18,000mg/l. (Levels above 200mg/l are classified as strongly corrosive.) Sulphate ion content in the same water varied between 221 and 500g/l. Moreover, a high rate of ventilation maintained mist in the air resulting in a constant layer of moisture on the galvanized surfaces; coal dust also deposited on these surfaces. In many locations, there was a constant flow of water contacting the structures. Water pH was about 7, or neutral. Non-galvanized steel structures were also placed in the same drifts.

The structures were evaluated after 20 years. External inspections proved that zinc coating remained on the mine support surfaces, with a remaining thickness range of 10–83µm. There was no evidence of red corrosion rust on the galvanized parts, confirming the continuing protective function of the coating. In contrast, active steel corrosion was observed on the surface of ungalvanized parts of the mine supports. Layers of non-adherent iron corrosion were observed, as well as surface cracks in the non-galvanized parts. Because of the longer functional life of the galvanized structures, it is permitted to increase the distance between the galvanized supports. Ungalvanized mine supports are spaced 75cm apart, while galvanized mine supports are placed 100cm apart.

The wire mesh between the galvanized supports was also galvanized and only occasionally showed red rust. In contrast, the ungalvanized mesh was highly corroded.



KWK Mysłowice-Wesoła Coal Mine.

Conveyors: Conveyor Systems at Douglas Colliery (BHP Billiton)

Location: South Africa

Surface Environment: from C2 to high corrosivity

Overland conveyors require a coating that can offer extensive years of service-free life due to the often dusty conditions and the unlikelihood of adequate surface preparation coupled with their often extraordinary length. The V3, V4 and V5 overland conveyors at Douglas Colliery are such a system and are estimated to be over 25 years old.

From a general atmospheric corrosion perspective, the conditions are most probably a C2 category, suggesting that the corrosion of zinc would be very low. However, the additional problems caused by the presence of coal dust and particularly coal ash, along with the presence of moisture would indicate that conditions might be very corrosive.

Inspection after 25 years of service showed the steelwork to be in excellent condition with coating thickness varying between 117 to 279 μ m, with a mean coating thickness of 140 μ m. The coating thickness readings are still well in excess of that required by the specification and suggested an additional 40 to 60 year maintenance-free service life. The only concern was that the conveyor idlers were only painted and the electroplated fasteners were in need of replacement.



General view of Douglas Colliery.



The V3 overland conveyor has been exposed to the elements for in excess of 20 years.



The hot dip galvanized structural steelwork is still performing exceptionally well after 20 years of service.



Coating thickness readings taken on the supporting steelwork were still in excess of that required by the specification.



Coating thickness readings taken on the conveyor steelwork were still in excess of that required by the specification.

Conveyors: Overland Conveyor Belt (Doña Inés de Collahuasi Copper Mining Company)

Location: Chile

The Collahuasi Copper Mine is located near the northern tip of Chile, 185km southeast of the city of Iquique. It is the world's third largest copper deposit.

This plant includes a 2,600m long overland conveyor that transports the ore from the primary crusher in Rosario, to the Ujina concentrator plant, with a length of 2,600m. The general galvanized steel structure supporting the conveyor was erected in 2004.

After nine years, visual inspection reported it to be in good condition without any corrosion.



Collahuasi Copper Mine. Photo courtesy of Collahuasi.

Conveyors: Brockman 4, Iron Ore Mine (Rio Tinto)

Location: Australia

Surface Environment: from C2 to high corrosivity

Rio Tinto's Brockman 4 iron ore mine is located in Pilbara, Western Australia and was opened in September 2010. Traditionally, paint was used to protect the steel from corrosion in this arid environment, i.e. a one-coat system (with blasting for surface preparation) consisting of a green 75µm inorganic zinc rich silicate primer. At Brockman 4, preference was given to galvanized steelwork since no maintenance would be required during the life of the mine.

Hot dip galvanizing was used as a corrosion protection in the conveyor modules, stringers, trestle legs, piping, brackets, cable ladders and conveyor frames.

Tight coordination with the fabricators on the design of the steel components enabled fast and efficient delivery of the galvanized steelwork.



Brockman 4 Mine

Conveyors: Worsley Alumina Overland Conveyor (BHP Billiton)

Location: Australia

Worsley's bauxite mines are located near the town of Boddington, approximately 112 miles south of Perth in Western Australia.

The bauxite is transported by overland conveyor to the Worsley Alumina Refinery. From there, the alumina is transported by rail to the Port of Bunbury. The conveyor belt is 52km, making it one of the longest conveyor belts in the world. The entire steelwork was hot dip galvanized. The conveyor was roofed with 67,000 sheets of a color-coated aluminum zinc alloy galvanized steel product.



Worsley Refinery Conveyor

Marine Terminal: Marine Terminal for Oil and Sulphuric Acid Delivery (Interacid Chile)

Location: Mejillones Bay, Chile

Surface Environment: C5 - M

The marine terminal is located in the Antofagasta region of Chile, which has a desert climate. The terminal was opened on 19 June 2007. Three coal-fired power plants are located nearby.

The structural steel used for the pier was hot dip galvanized prior to installation. Afterwards, the galvanized steel for the top surfaces was painted with an epoxy primer with a polyurethane or acrylic topcoat, providing a duplex system suitable for this C5-M climate.

The lower structure, below the wooden floor, was galvanized but not painted.

The zinc coating thickness has been monitored at two points:

	Galvanized structure under the floor of the access bridge (Fig.1)		Galvanized structure at head of pier (Fig.2)		
Year of thickness measurement	2011	2012	2009	2011	2012
Measured average thickness of coating	208µm	201µm	148µm	144µm	141µm



Figure 1. There were some white zinc corrosion products on the surface of these beams, but no steel corrosion was observed.



Figure 2. Coating thickness losses were in agreement with the reference range for the CSM climate according to ISO specifications 9223, 14713 and 12944.

