# Sustainability of steel corrosion protection by hot dip galvanizing

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**Abstract**. It becomes more obvious nowadays that in order to sustain a long-term economic development, a solution is to lower the maintenance and repair costs. For the iron and steel industry, this means to apply protection systems with longer durability. Technologies of the future are based on the best available techniques, which mean low energy and materials consumption and low or no waste. Hot dip galvanizing is such a technology that is adequate for recycling, allowing a reduced energy and materials consumption. Also, an economic approach and analysis of the hot dip galvanizing in the frame of the sustainable development is shown, analysis made in the frame of the European General Galvanizers Association (EGGA). This work comprises results and discussions regarding the industrial, economic and environment protection importance and advantages of the hot dip galvanizing applied in constructions. By using the "whole-life cost" method, it was observed that the metal structures are the most rentable choice on long term, and their hot dip galvanization corrosion protection system is the most effective choice from all points of view. Hot dip galvanizing ensures the environment and natural resources efficient protection. Thus, it brings an important contribution to the sustainable development.
**Key Words**: corrosion protection, steel structures, net present value, zinc recycling, sustainability.

**Introduction**. It is generally accepted that the sustainable development concept is, according to Brundtland Report (Suciu & Suciu 2007), "*the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs*." Thus, to follow the sustainability criteria it means to avoid, reduce and/or control the damaging impact on environment and population, by complying the legislation, and meeting at the same time the users and population requirements for all products and technologies developed. A deeper analysis of sustainability definition leads us to the conclusion that it implies intra and intergenerational equity. This means the use of resources for the benefit of the current generation but also taking into account the costs and the "legacy" left to the future generations. According to Hartwick's rule, there are two interconnected attitudes, which can be generalized to any domain: "me, now" vs "others, now and later" (Suciu & Suciu 2007). As such, nowadays, the "win-win" type preventive developments are preferred to the alternative ones of "reactive post-factum" type. The present direction is toward a responsible approach by implementing and maintaining sustainable technologies development in the industry. Such technologies are based on the best available techniques, which mean low energy and materials consumption, and low or no residues. Hot dip galvanizing process is suitable for recycling, ensuring reduced energy and reduced materials consumption when processing new goods.

Sustainable development (long term development and its results) implies the following:

- prudent use of natural/renewable resources in respect of the ecosystem balance, to produce a large variety of goods and to sustain an optimal living standard;
- economic management and industrial activity in balance with natural systems, with no impact on human health, on environment integrity, as well as recycling/renewal of resources for the benefit of the human communities and environment.

The concept of sustainability is set out to meet four objectives:

- social progress, towards meeting the needs common to all humanity;
- high and stable economic growth and jobs;
- efficient protection of the environment;
- prudent use of natural resources, reuse and recycling of materials, to help environmental protection.

Hot dip galvanizing contributes to the environment and natural resources protection, thus bringing a vital contribution to sustainable development.

The aim of this paper is to present an analysis of hot dip galvanized rebars in concrete structures' compliance to Law 10/1995 regarding quality in constructions (including subsequent amendments and additions), and satisfying of sustainability criteria.

**Mechanical strength, reinforced concrete structures stability, low energy consumption and fire safety criteria**. Replacement of classic steel rebars with hot dip galvanized rebars, as shown in literature, does not result in reduced mechanical strength and stability of reinforced concrete elements, but on contrary, it improves concrete structures durability by corrosion resistance improvement (Fratesi 2002; Hanna & Nassif 1984; Hegyi et al 2010a; Hegyi et al 2010b; Hegyi et al 2010c; Rus et al 2015; Sistonen 2009; Tan & Hansson 2008; Yeomans 1994, 2004).

It is estimated that corrosion costs around 4-5% of GDP in the high developed countries (Fratesi 2002; Hanna & Nassif 1984; Manzini et al 2004; Yeomans 2004). The use of hot-dip galvanizing to prevent rust means that energy demands, materials and maintenance costs are reduced, thus being an effective cost reducing method. Use of hot dip galvanizing to prevent rust means that for every one tone of steel protected, it is conserved enough energy to satisfy an average family's energy needs for several weeks (Yeomans 1994, 2004).

Compared to the corrosion protection systems that use paints, the major advantage of the hot dip galvanizing method is the high adherence of the protective coat due to the intermetallic bonding between the base metal and the zinc layer. During the metallurgic reaction between the steel and the zinc bath, the following layers form on the steel surface: *eta* (η) – pure zinc; *zeta* (ζ) – Zn alloy with maximum 6% Fe; *delta* (δ) – Zn alloy with maximum 10% Fe; and *gamma* (Γ) – Zn alloy with maximum 23% Fe, which have different hardness and corrosion behavior (Marder 2000; Reumonta et al 2001; Shibli & Manu 2006; Sistonen 2009). The metallurgic bonding of the zinc to the steel is gradually built by a series of Fe/Zn alloys layers, as shown in Figure 1.

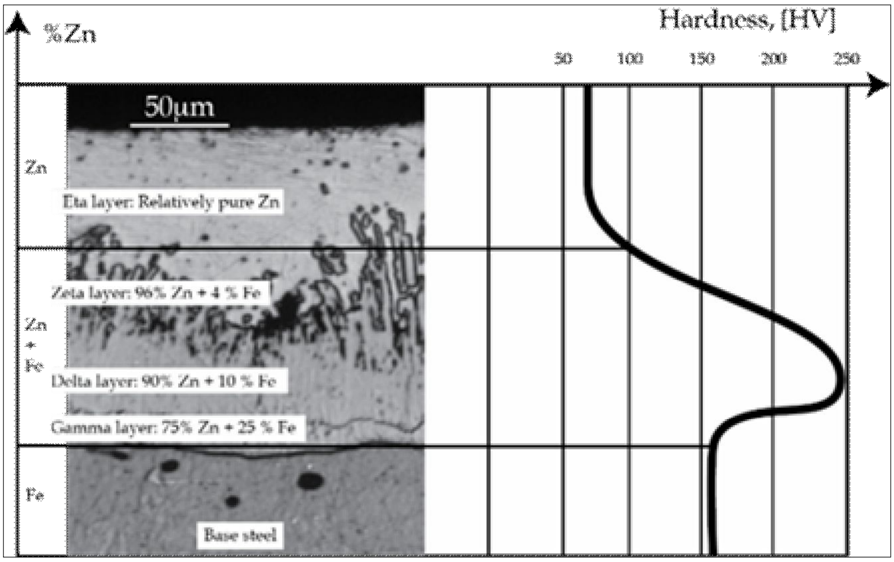


Figure 1. Hot dip galvanized coating composition (Marder 2000; Reumonta et al 2001; Shibli & Manu 2006; Sistonen 2009).

Regarding the fire safety of hot dip galvanized products, the structures using such products do not show increased susceptibility to fire. The hot dip galvanized products are incombustible. In contrast to the corrosion protection based on polymer, alkyd or bituminous films etc., when exposed to high temperatures or open flames, hot dip galvanized products do not release toxic substances, smoke or burning drops.

**Sustainable use natural resources, hygiene, health and environment**. Hot-dip galvanizing is probably the most environmentally friendly process available to prevent corrosion of steel and iron, and complies with the environment protection demands, having a reduced impact on environment. It does not imply the use of solvents (volatile compounds) dangerous for the environment and human health, as it is the case of the painting and repainting systems. Also, as opposed to the paint layer, the zinc layer is not flammable.

In the hot dip galvanizing process iron or steel articles are dipped into a bath containing molten zinc just above the melting point (450°C). Any zinc that does not form a coating on the metal remains in the bath for further re-use. Residues – dross and zinc ash – are recovered and zinc is recycled for further use (Hanna & Nassif 1984; Marder 2000).

As well as zinc recovered from these residues, recycled zinc from other resources – such as zinc scrap – is often used in hot dip galvanizing. Hot dip galvanized steel can be recycled easily with other steel scrap in the steel production process.

Improvement in gas burner technology has also greatly improved energy efficiency in heating the hot dip galvanizing bath. Exhaust heat is not wasted and is used to heat pre-treatment chemicals or dry work prior to immersion.

In recent years, the hot dip galvanizing industry implemented and maintained a policy of environment protecting through products and technological improvements. Since 2001, the LCI system (Life Cycle Inventory) is implemented in Europe, which allows the product life cycle assessment (IPPC 2001).

In the life cycle assessment procedure, the environmental product declaration (EPD) is a standardized method of quantifying a product or a system environmental impact. The declaration includes information on the environmental impact of raw material acquisition, energy use and efficiency, content of materials and chemical substances, emissions to air, soil and water, and waste generation. Products and company information is also included and the life cycle assessments on structures involving hot dip galvanized steel (Manzini et al 2004; Wimmer et al 2004).

***Hot dip galvanizing emissions****.* Emissions to the atmosphere from the hot dip galvanizing are inherently very low and are strictly governed by the Industrial Emissions Directive 2010/75/EU. The hot dip galvanizing bath must capture the particulate emissions to air; this is successfully accomplished by the use of bath enclosures endowed with filtering system. Hot dip galvanizing installations "use less than 25 litres of water per tonne of product, compared with 2000 litres in the general metal finishing industry" (According to a Survey by the Environment Technology Best Practice Programme) (Akamphona et al 2012; Bhadra et al 2013; Kong & White 2010; Schultz & Thiele 2012; IPPC 2001).

Aqueous emissions are used acids mostly and are controlled by three methods (Bhadra et al 2013; Kong & White 2010):

- collection and neutralization by specialist firms;
- use for other waste neutralization;
- technologies improvement to reduce used acids use per tonne of steel processed.

***Recycling****.* Zinc is the main raw material in hot dip galvanizing. Zinc is an inherently recyclable non-ferrous metal. It can be recycled indefinitely without any loss of physical or chemical properties. This is a major advantage for the hot dip galvanizing process ensuring its environmental sustainability and cost effectiveness. Figure 2 is a schematic representation of the zinc cycle extracted from primary sources and from recycling sources respectively. Hot dip galvanizing is very efficient in its use of zinc, as any of the molten metal not forming a coating on the steel will run back into the galvanizing bath. Estimates suggest that 80% of zinc available for recycling is in fact recycled (with today's technology) (Akamphona et al 2012; Cook 2006; Marder 2000; Zhang 2012). This means that much of the zinc in use today has probably been used before. About 30% (2 million tonnes) of the world's zinc consumption is from recycled sources (Akamphona et al 2012; Cook 2006; Kong & White 2010; Schultz & Thiele 2012; Tan & Hansson 2008). A figure which is rising with increased environmental awareness and improvements in recycling technology.

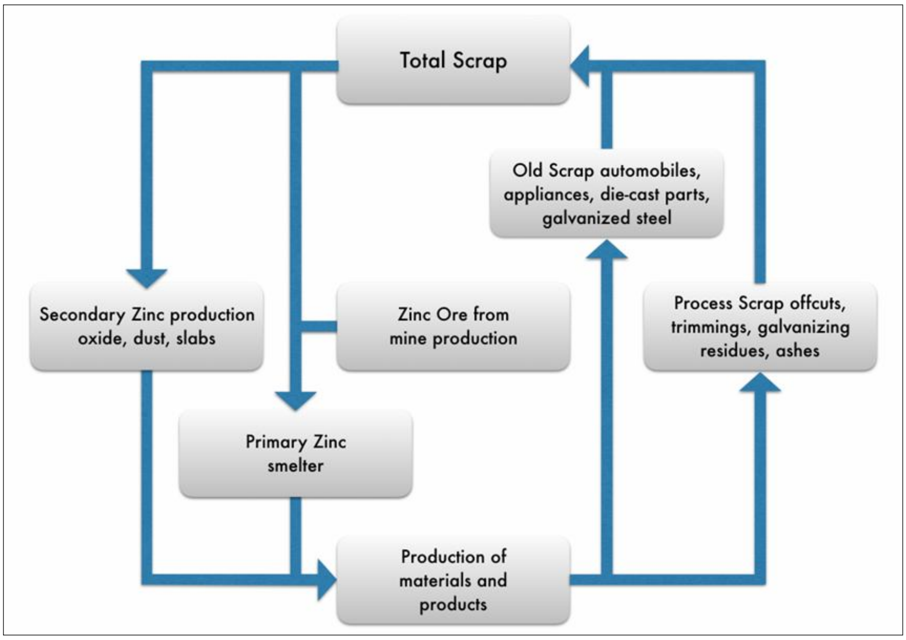


Figure 2. Zinc cycle.

The presence of a zinc coating on steel does not restrict its recyclability. Galvanized steel is recycled with other steel scrap in the steel production process; it volatilizes early in the process and is collected for reprocessing.

Three residual products are formed during the process: a zinc/iron mix called dross (96% zinc + 4% iron), zinc ash (around 80% zinc) and flux skimming (Kong & White 2010; Marder 2000; Zhang 2012). All of these contain valuable zinc and are recovered and recycled by specialist firms and the recycled zinc is often returned to the galvanizer. Zinc oxide is recovered from galvanizers' ashes and used in pharmaceutical/beauty products.

Other examples of uses and markets for recycled zinc:

- zinc oxides – pharmaceuticals, food, fertilizers and for curing rubber;
- zinc dust – paints, chemicals, lubricants, batteries and in gold recoveries;
- alloyed with other metals – cast into precision parts for appliances, hardware, electronics and toys.

***Users health***. Hot dip galvanized rebars in concrete do not damage human health and do not emit damaging substances for the ozone layer. It does not contain dangerous chemical substances (biocides) or potential carcinogens, and is not classified as hazardous for health or environment according to HG 1408/2008 amended by HG 937/2010 regarding classification, packaging and labeling of dangerous substances introduced on the market.

**Cost and economics**. The true cost of protecting steelwork from corrosion has to take into consideration two important elements (Akamphona et al 2012; Cook 2006):

• the initial cost of corrosion protection;

• the lifetime cost, which includes the cost of maintenance. This is the cost of ensuring that steelwork is protected from corrosion throughout its service life.

***Initial cost***. Hot dip galvanizing is often perceived to be more expensive than it is. The reason for this is mainly because such a high performance coating is automatically assumed to be expensive. On the other hand, the initial cost of galvanizing relative to paint has changed significantly over recent years. Painting costs have steadily increased, mainly due to the environment protection costs, whilst galvanizing costs have remained stable.

In Figure 3 is shown that for many applications the cost of hot dip galvanizing is lower than the cost of applying alternative coatings. Alternative corrosion protection processes, such as painting, are very labor intensive compared with hot dip galvanizing, which is a highly mechanized, closely controlled, factory process.

The hot dip galvanized labor costs are around 30% of the total costs, while in the painting process, the labor costs can go up to around 60% of the total costs (surface preparation is also included) (Cook 2006; anaz.ro; egga.com).

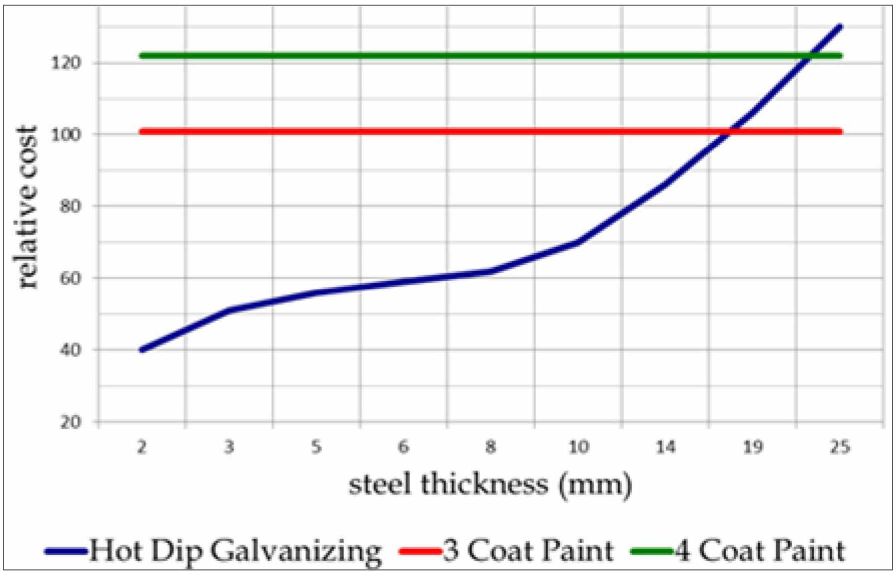


Figure 3. Comparison between initial costs (Cook 2006; anaz.ro; egga.com).

***Whole-Life Cost***. The whole-life cost is an economic/financial analysis technique that has over recent years become accepted in practice in construction of buildings/structures. The whole-life cost of a building can be defined as the cost of a building/structure, which includes: initial design, building, operation, maintenance, repairs and disposal at the end of the life cycle (Table 1). It is estimated that up to 80% of a building's whole-life cost can be attributed to running, maintenance and refurbishment costs. As shown in Figure 4, there are spikes in expenditure at 10 years and every 5 years after that.

Table 1

Whole-life cost distribution for a building/Structure (data processed from ANAZ and EGGA statistical data) (Cook 2006; anaz.ro; egga.com)

| | *Initial design* | *Build* | *Operate* | *Total* |
|---|---|---|---|---|
| *Costs* | 3% | 17% | Run/maintain 40% | 100% |
| | | | Repair 30% | |
| | | | Periodic replacement/refurbish 10% | |
| Estimate duration | 1 year | 2 years | 25 years | |

The initial choice of materials and the way that they are protected obviously plays an important role within the maintenance and refurbishment costs of a building over its lifetime. By using the whole-life cost method, it can be concluded that the buildings and the halls made of metal structures are the most cost effective, and their corrosion protection by hot dip galvanizing is the most efficient choice, from all points of view.

Thus, in the majority of applications, hot dip galvanizing will provide a long, maintenance free life, without any requirement for maintenance painting.

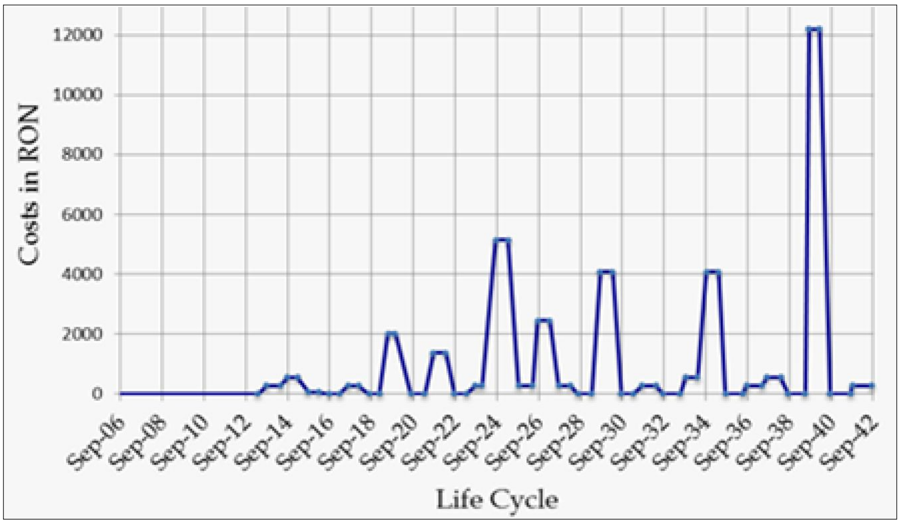


Figure 4. Life cycle expenditure for buildings/Structures (data processed from statistical data of ANAZ and EGGA) (Cook 2006; anaz.ro; egga.com).

***Net present value.*** The most common method to calculate the benefits or disadvantages of different methods of corrosion protection is to calculate the Net Present Value (NPV) of each method and compare the results. This calculation takes into account the cost of the bank discount rate on loan for investment, the initial cost of protection, subsequent maintenance costs and the lifetime of the project. This method is frequently used by companies to measure the likely outcome of a capital investment project.

In order to illustrate the above method, a case study data provided by *Turner and Townsend, Construction and Management Consultants* was processed by EGGA and ANAZ, Figure 5 (Galvanizing and Sustainable Construction – A Specifier's Guide, EGGA, 2008). The case studied was of a steel structure that has a projected life of 25 years and for which the discount cost ($r$) of capital was 5%, for three corrosion protection systems, as shown in Table 2.

Table 2

NPV calculated for three corrosion protection systems (Cook 2006; anaz.ro; egga.com)

| *System 1 – Hot Dip Galvanizing* | *System 2 – Painting 1* | *System 3 – Painting 2* |
|---|---|---|
| Hot dip galvanize to BS EN ISO 1461 was used, with a minimum average coating of 85μm on steel of 6mm or thicker. As hot dip galvanizing to this standard has an average life expectancy of more than 50 years, it is very conservative to project a life of 25 years without further maintenance. The cost of galvanizing was considered to be a base figure of 100 units. There are no further maintenance costs. | A paint system consisting of cleaning followed by an undercoat and two top coats of paint was used. This system has a life expectancy of 8 years and so will need to be repainted three times in 25 years. The initial cost is slightly cheaper than hot dip galvanizing at 90 units. The cost of repainting for the first two occasions is 45 units but goes up to 90 units for the third repaint when the original paint must be removed. | A superior paint system consisting of blast cleaning followed by three coats of higher quality paint was used. This system has a life expectancy of 11 years and will need to be repainted twice in 25 years. The initial cost is higher than the other paint system at 135 units. The cost of repainting is half this value at 67.5 units. |
| *NPV = 100* | *NPV = 169* | *NPV = 197.5* |

Note: NPV = initial cost+NPV1+NPV2+NPV3+...

$$NPV = I + \frac{M_1}{(1+r)^{P_1}} + \frac{M_2}{(1+r)^{P_2}} + etc.$$

where:
I - initial cost of protective system;
$M_1$ - cost of maintenance in year $P_1$;
$M_2$ - cost of maintenance in year $P_2$;
r - discount rate.

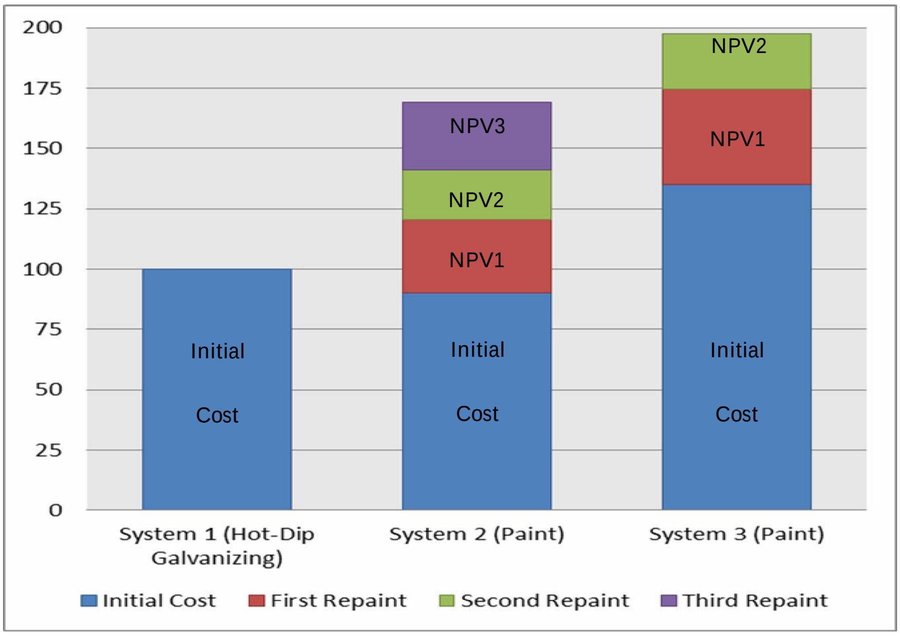


Figure 5. Net Present Values compared (data processed from ANAZ and EGGA statistical data) (Cook 2006; anaz.ro; egga.com).

**Conclusions**. The use of hot dip galvanizing method for iron and steel corrosion protection has important advantages and benefits from environment protection point of view:

- it is a method that implies a low consumption of raw material from ore, as the majority of zinc used comes from recycled zinc;
- the energy consumption is lower due to the industrial processes improvement and partial recovery of the energy used;
- the aqueous or gas process emissions are low and controllable, and they can be neutralized.

Based on the three corrosion protection systems comparison, it can be seen that over a 25 years project life the cost of a ‘cheaper’ paint system is almost 70% more than the cost of hot dip galvanizing. Likewise, the cost of a more ‘expensive’ paint system is almost double that of hot dip galvanizing. The initial cost of the hot dip galvanizing system is comparative with the paint systems initial costs.

However, when looking at lifetime costs, hot dip galvanizing works out to be considerably cheaper than most other systems.

Due to the hot dip galvanizing advantages compared to the painting systems, if in USA around 20% of the bridges were painted during sixties, only around 4% are painted nowadays.

Hot dip galvanizing has many benefits as a method of corrosion protection, of which the most important are:

- it provides steel with a coating which has a long, predictable and maintenance free life;
- is highly competitive on a first cost basis;
- is the most economical way to protect steel over long periods;
- is a sustainable solution.

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