ECONOMICAL ADVANTAGES OF COROSION PROTECTION BY HOT-DIP GALVANIZING OF STEEL STRUCTURES

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Abstract: Today, it is increasingly evident that to achieve long-term economic development, one solution is to reduce the maintenance and repairs costs. For metallic structures, this means applying protection systems with the highest durability possible. One of the most appropriate technologies available is hot-dip galvanizing. This study is an analysis of the implementation and maintenance costs of corrosion protection for a complex steel structure by various methods of painting vs. costs of corrosion protection by hot-dip galvanizing. The study analyses both, the initial costs of the corrosion protection and the maintenance and repairs costs, for the structure, over a period of 100 years (lifetime), considering the studied building as subjected to an industrial environment (corrosion class C3) and also to a marine environment (corrosion class C5-M). Estimation of costs has been carried out for different types of corrosion protection systems by coating (using alkyd products, using epoxy products, using metallization, all of them applied in either 2 or 3 layers) and for hot-dip galvanizing. By using the ”whole-life cost” method it was observed that hot dip galvanizing is the most efficient method, with regard to maintenance and repair costs, of protecting the studied metallic structure against corrosion over its entire service life. The paper also contains a comparative study for the discussed protection systems, which details the time periods up to the first necessary maintenance, the first necessary major repair and also, the number of necessary maintenance and repair interventions over the whole service life of the structure, which is considered to be 100 years. The comparative study showed higher maintenance and repair costs for the painted corrosion protection systems, and also revealed the possibility of reducing these costs by over 80% and prolonging service life of the steel structure, and the time between maintenance and repair needs, if corrosion protection is achieved by hot-dip galvanizing. By the interdisciplinary character, this paper responds the questions of the construction specialists, of the electrochemistry and corrosion protection specialists, as well as those of specialists in economics.

Keywords: whole-life costs, corrosion protection, hot-dip galvanized steel, steel structure, cost reduction.

Introduction

Corrosion of steel and iron products is a problem for today’s civilization, just as it was a problem for past civilizations and will probably be for future civilizations. Current estimates show that around 4-5% of the GDP in developed countries is lost annually due to corrosion. In the US, it is estimated that $297 billion [22] are lost each year because of corrosion. Around the world, every 90 seconds, one ton of steel turns to rust; so, if two tons of steel were produced every 90 seconds, one ton will be used to replace rusted steel. [16, 8]. Future technologies will be based on the best currently available techniques, which first of all mean low energy and material consumption and minimization or ideally complete absence of waste.

It is believed that hot-dip galvanizing is the best currently available for prevention of corrosion in steel and iron products. Numerous studies prove the effectiveness of the cathode protection given to steel products by zinc, which is owed to the zinc layer's anode character making it act as a sacrifice layer. Furthermore the zinc coating acts as a barrier against external corrosive agents in a way similar to epoxy coating, thus giving extra protection to the metal substrate. Research into this technology has been carried out in numerous countries such as the US, UK, Canada, Japan, India and Australia, funded by both government research grants and grants from the private sector [1, 11, 15].

The advantages of hot-dip galvanizing as an anti-corrosion protection for steel and iron products are as follows [2, 4, 5, 17, 18]:

- Green technology: meets the requirements of environmental protection and does not use solvents;
- The zinc layer, as opposed to paint, is not flammable;
- Minor degradation due to mechanical action, impacts and scratches do not take away the protective characteristics and do not create the need to reapply the protective layer; this is due to the zinc layer's anode character which makes it act as a sacrifice layer for steel and iron. Hot-dip galvanizing creates a very powerful bond between the coating layer and its substrate, called a metallic bond, a series of Zn-Fe alloys form, which increase in zinc content from substrate to surface. Practically, there is no clear interface between the substrate and the zinc layer, only a gradual transition through combination of the two metals. [12, 18];
- Zinc and galvanized steel can be recycled and reused, while corrosive protection using paint leads to the accumulation of permanent residue in the environment. [4, 5, 6];
- From an economical point of view, hot-dip galvanizing is a highly competitive form of protection against corrosion when compared to other technologies. Even though production costs seem to increase, in fact, a less qualified work force is easier to tolerate and over the life of the metal structure operating, maintenance and repair costs are greatly diminished. Hot-dip galvanizing protects steel structures over many decades, thus reducing maintenance costs [2, 3, 20];
- Current scientific literature indicates a period of approximately 70 years during which metal elements that are protected using hot-dip galvanizing do not require expenditures for maintenance or repair of the anti-corrosive protection [8, 11, 12, 13, 15, 19].

This paper will identify and demonstrate the benefits in terms of reducing costs over the lifespan of a metal structure when using corrosion protection by hot-dip galvanizing as compared to other methods, namely painting with various products. Available technical literature contains studies that analyze the costs of different technologies for corrosion protection of steel structures, but so far, no comparative analysis has been made that addresses the issue in terms of production costs, maintenance and repair costs and also the period of use of the steel structure until it first needs maintenance, it first needs major repairs and the number of necessary interventions, all calculated for the same design life of the steel structure.

Calculation methods

Current technical literature contains several methods for estimation of costs for construction projects [14]. These can be *definitive estimations*, used to establish the overall plan of a project; *parametric estimations* which entail breaking down the project into smaller units that are easily quantifiable and to which costs can be attributed based on previous experience and *estimations by analogy* which, in order to estimate the costs of the current project, rely on the actual costs of similar projects that have been finalized [10]. Cost estimations at the design stage, includes on the one hand construction and maintenance costs for the metal structure, and on the other the costs of the structures anti-corrosive protection.

The term *whole-life cost* can be defined as the sum total of all costs required for the structure, which include: design, construction, operation, maintenance, repairs and post use costs (decommissioning, recycling) at the end of the structures service life (Figure 1). If for the same structure design and construction costs are constant, the costs for the anti-corrosive protection, inspection, maintenance and repair vary based on the materials that are used and especially based on the method used to apply the protection and its efficiency.

The costs entailed by the anti-corrosive protection of steel structures include two very important elements, each of them containing direct and indirect expenditures:

- The initial cost of the anti-corrosion protection system;
- The cost of the anti-corrosion protection of the structure over its entire service life – which include maintenance and upkeep costs of the system.

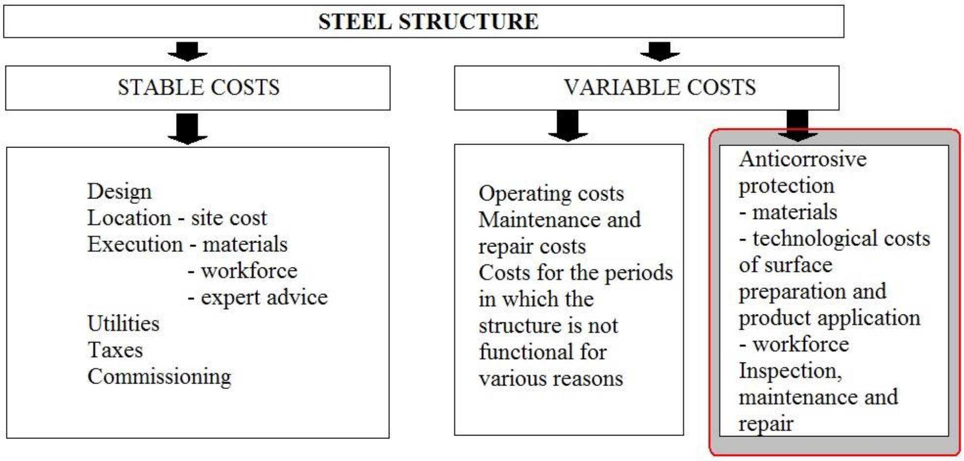


Figure 1 Lifetime costs for a steel structure

Hot-dip galvanizing is often perceived as being more expensive than it actually is. This common mistake stems first of all from the fact that such an effective method is automatically perceived as being expensive. In recent years, the ratio between the initial production costs of hot-dip galvanizing and the initial production costs of painted anti-corrosion systems has changed considerably. Painting costs have increased constantly, mainly due to restrictions imposed in order to protect the environment, while hot-dip galvanizing costs have remained nearly constant.

By using the *whole-life cost* method it has been determined that steel structures are the most cost effective, and that hot-dip galvanizing is the most effective of anti-corrosion protection for them from all points of view.

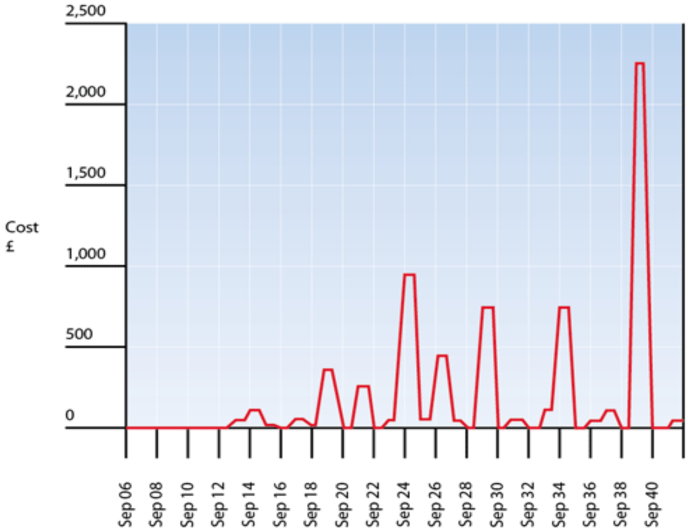


Figure 2 Costs variation on service life of buildings/structures [22, 23]

A recent study by Turner and Townsend, Construction and Management Consultants, the data of which was made available to and processed by EGGA (European General Galvanizers Association) and ANAZ (Romanian National Galvanizers Association), considering a steel structure, has shown that in the first 8-10 years starting from the beginning of the structures service life, maintenance and repair costs and small, negligible. After this initial period comes the first peak in maintenance and repair costs, which then reappears at intervals of 3-5 years. Figure 2 presents this variation over time of maintenance and repair costs in the case of a steel structure for a period of 36 years beginning at the start of the structures service life. By using hot-dip galvanizing as an anti-corrosion protection system the peaks in maintenance and repair costs can be pushed further away in time and can be diminished in value, which can translate in lower maintenance and repair costs that are required less often, easing amortization of the investment in the structure [22, 23, 24] .

The present study analyzed production, maintenance and repair costs for the anti-corrosion protection system of a steel structure, using the parametric estimation method, estimating the per surface unit cost for galvanizing the entire steel structure and by attributing these costs values based on available technical literature, previous experience and information provided by EGGA (European General Galvanizers Association), AGA (American Galvanizers Association) and ANAZ (Romanian National Galvanizers Association).

The economic advantages of corrosion protection of steel structures by galvanizing

The purpose of this paper was to highlight the economic advantages, namely cost reduction, in the case of corrosion protection of a steel structure by galvanizing as compared to various painting methods. For this analysis a complex steel structure was considered, the height of the structure varies between 15 and 30 m and it has a total surface area of 100 m^2 with a designed service life of 100 years. Due to the fact that the corrosive nature of the environment in which the structure will be placed greatly influences its corrosion rate, two different environments were considered in the analysis, namely an industrial environment with an average corrosion level, corrosion class C3 and a marine environment, with a high corrosion level, corrosion class C5-M. By considering as constant the costs for design and construction it was considered that the variable costs will be those for the corrosion protection: materials, application, inspections, maintenance and repair over the 100 year service life of the structure. On the basis of the data made available by EGGA, AGGA and ANAZ, several parameters regarding cost were estimated, time period between interventions and number of interventions required, for each type of corrosion protection system in each environment considered. For the cost analysis a constant inflation rate of 1% / year was considered over the entire service life of the structure. Costs were calculated in EURO/ m^2.

The anti-corrosion systems considered in the study are detailed in Table 1.

Table 1. Types and component of anticorrosive protection systems

<table>
<tr><th>Corrosive environment</th><th>Type of anticorrosive protection</th><th>Corrosive environment</th></tr>
<tr><td rowspan="7">Industrial environment, C3</td><td>Hot-dip galvanizing with 100 µm minimum DFT</td><td rowspan="7">Marine, aggressive, C5M</td></tr>
<tr><td>2-Coat sistem comprised of Alkyd / Alkyd with 100 µm minimum DFT</td></tr>
<tr><td>3-Coat sistem comprised of Alkyd / Alkyd / Alkyd with 150 µm minimum DFT</td></tr>
<tr><td>2-Coat sistem comprised of Epoxy / Epoxy with 150 µm minimum DFT</td></tr>
<tr><td>3-Coat sistem comprised of Epoxy / Epoxy / Epoxy with 250 µm minimum DFT</td></tr>
<tr><td>1-Coat sistem comprised of Zinc Metallizing (min 90% zinc) with 125 µm minimum DFT</td></tr>
<tr><td>3-Coat sistem comprised of Zinc Metallizing / Sealer / Polyurethane with 400 µm minimum DFT</td></tr>
</table>

*DFT – Dry Film Thickness (average thickness of the dried coating)

Cost estimation for the production, maintenance and repair of the considered anti-corrosion protection systems in relation to the corrosive nature of the environment are shown in Figure 3 – 7.

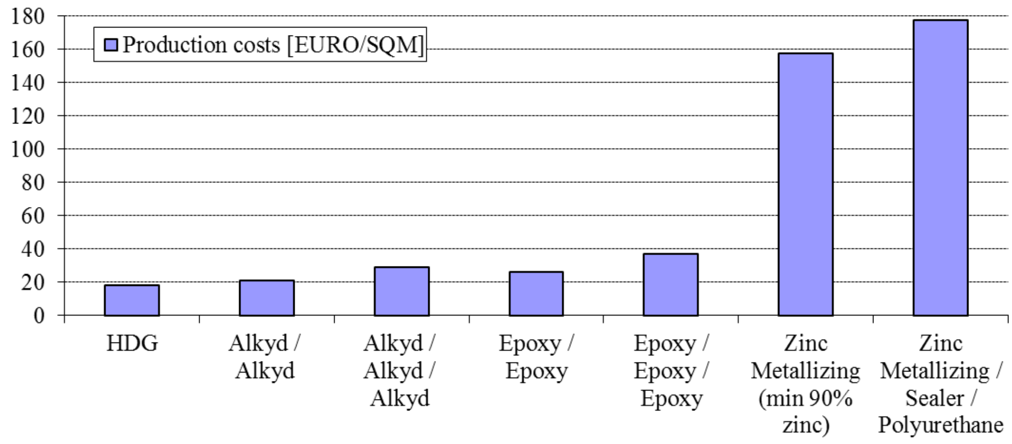


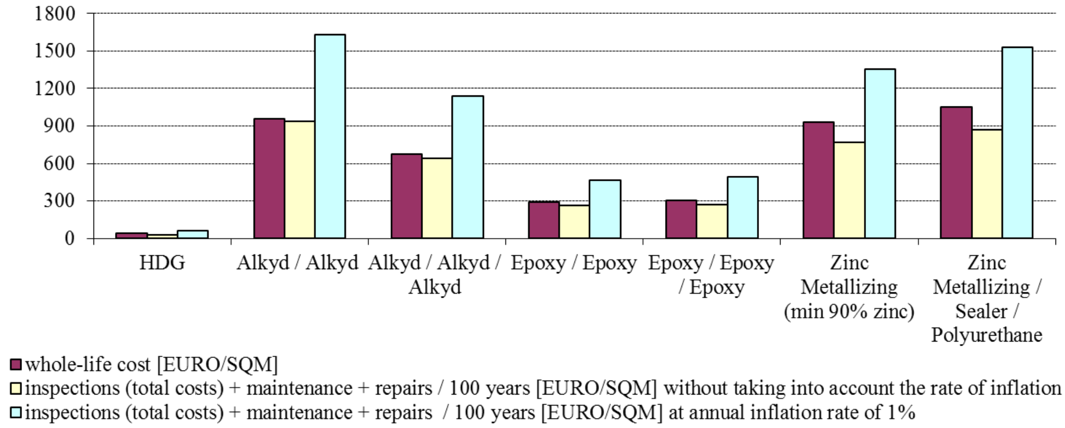
Figure 3 Production costs of anticorrosive protection systems

Figure 3 shows the production costs for all the anti-corrosion protection systems considered in the study. It is clear that hot-dip galvanizing (HDG) requires costs that are comparable to a 2 coat Alkyd coating and much lower costs than those necessary for painted anti-corrosion protection systems of higher quality such as 3 coat Alkyd coating, coating with epoxy or Zinc Metallizing.

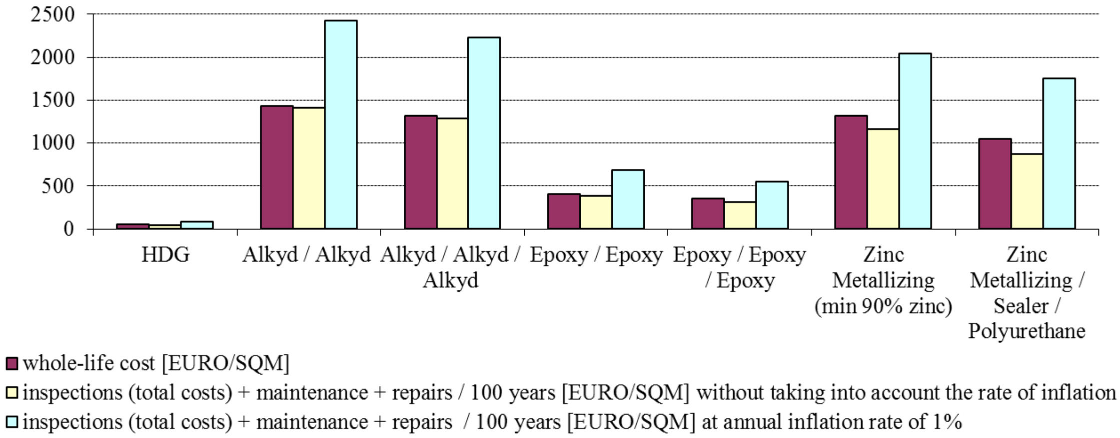
The increase in painting cost is due to ever stricter environmental protection requirements that are being implemented in order to adhere to European directives which impose supplementary technological requirements and implicitly, higher costs, when producing and using painting materials. Hot-dip galvanizing technology can be easily controlled in terms of toxic emissions (into the atmosphere, in water and in soil) and waste products, and most of the times any waste can be recovered and reintroduced into the industrial process, thus causing a decrease of production costs for the anti-corrosion system [7, 9, 16].

Figure 4 shows the costs over the entire service life of the structure (without considering the rate of inflation), the maintenance and repair costs needed over the entire service life of the structure (with and without considering the rate of inflation) when considering that the structure is in an industrial environment with moderate corrosion characteristics, C3, and considering the structure as being in a highly corrosive marine environment, C5M. As can be seen, the costs are influenced by both the technique and quality of the anti-corrosive protection used and the environment in which the structure resides. A cheap painted anti-corrosive protection system, using alkyd products, requires lesser production costs (figure 3) but will require higher maintenance and repair costs due to its reduced durability, costs that increase with the aggression class of the environment. In the case of anti-corrosive protection systems that use painted epoxy products, although initial production costs are slightly higher, over the 100 year service life considered, maintenance and repair costs will be much lower than those necessary for the cheaper painted alkyd products. In the case of zinc metallizing the initial protection costs were the highest (Figure 3) and the maintenance and repair costs are comparable to those of the cheaper painted protection that uses alkyd products. The advantages brought by the zinc metallizing are revealed in figures 5 and 6. Of all the anti-corrosive systems hot-dip galvanizing entails the lowest maintenance and repair costs due, on the one hand, to its high durability and reduced need for maintenance, and on the other hand to its chemical and metallurgic properties. As it has been shown before, zinc protects steel with its anode properties, that make it act as a sacrifice material, and with the metallic bond that forms between the zinc layer and the steel substrate which bonds the protection layer to the substrate much better than in the case of the paint systems.

By analyzing the costs over the entire life of the structure without considering the inflation rate and the maintenance and repair costs, for the same protection system, Figure 4 shows that an increase of the corrosion class of the environment in which the structure is situated leads to an increase in costs.



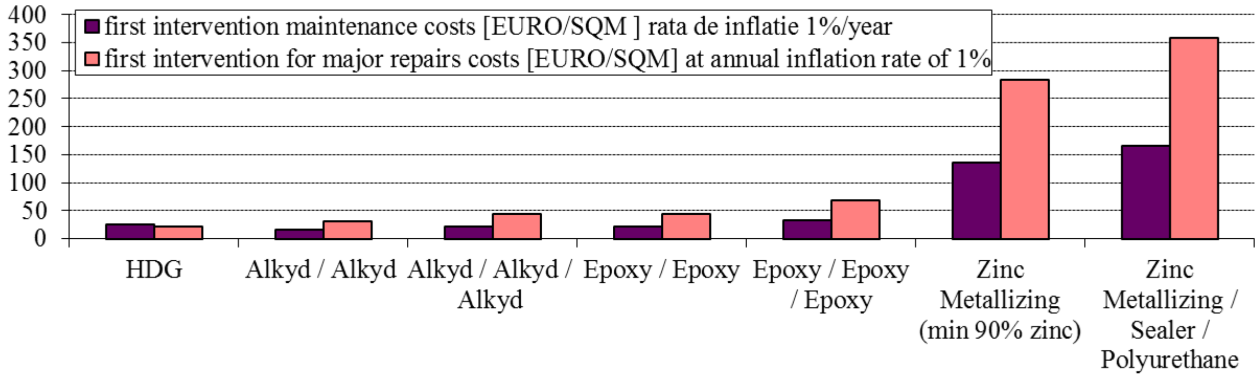
a) Moderately corrosive environmental conditions C3



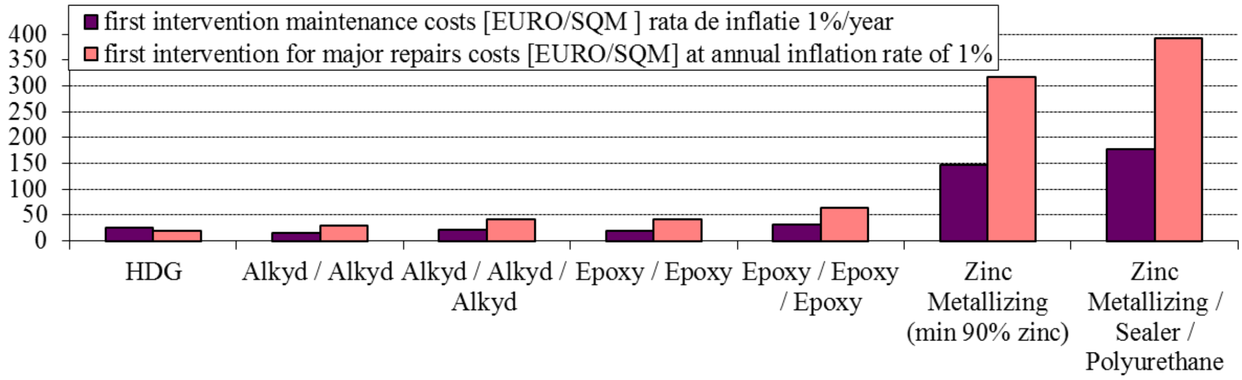
b) Aggressive corrosive environment conditions C5M

Figure 4 Estimated costs for the entire lifetime without taking into account inflation and the cost of maintenance and repairs, with and without taking into account the inflation rate

Figure 5 shows the estimated costs for the first maintenance and the first major repair for each of the studied anti-corrosive system in the environments considered in the study. It can be seen that higher corrosion classes of the environment determine an increase of the costs, the same as can be identified in figure 4 for the costs over the entire service life of the structure. For the same aggression class, it can be observed that the first maintenance requires approximately equal costs for hot-dip galvanizing and painting with alkyd or epoxy products and much higher costs in the case of zinc metallizing. The costs of the first major repair are smallest for hot-dip galvanizing and slightly higher for painting with alkyd or epoxy products. In the case of zinc metallizing costs are again much higher. These differences are due, for the most part, to the high prices of the materials and to the high costs of the technological process needed to prepare the surface which requires skilled labor.



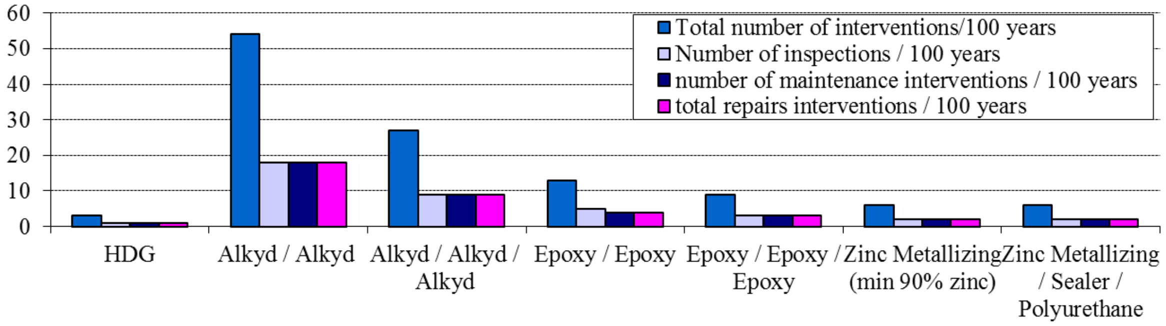
a) Moderately corrosive environmental conditions C3



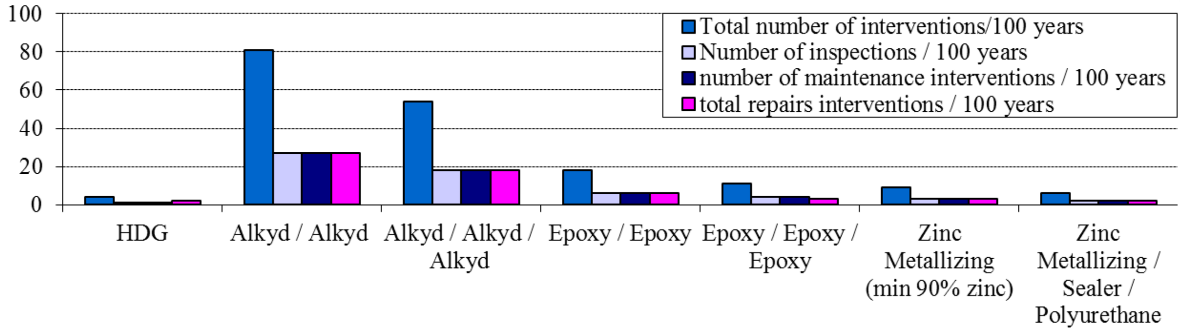
b) Aggressive corrosive environment conditions C5M

Figure 5 Estimated costs for the first maintenance and repair and first major intervention of the anticorrosive protection, with an annual inflation rate of 1%

Over the 100 year service life of the steel structure considered, depending on the type of protection system chosen, the number of required interventions for inspection, maintenance and repair is greatly influenced by the corrosion class, but most of all by the durability of the protection system. As can be observed from figure 6, a protection system initially considered inexpensive, painting with alkyd products, requires a large number of interventions which will lead to a higher overall cost for the entire service life considered. Painting with epoxy products, even though it requires higher initial costs will require fewer interventions then the system using alkyd paint. Metallizing, which up to this point, from the point of view of costs seemed to be completely ineffective, has proven to be an efficient solution when considering the small number of interventions needed. Hot-dip galvanizing requires the least interventions for inspection, maintenance and repair. This is also due to the long period of time from the application of the protection system to the first need for repair (after 70 years) as has been proven by numerous studies contained in the technical literature [8, 11, 12, 13, 15, 19] and as can be seen in figure 7.

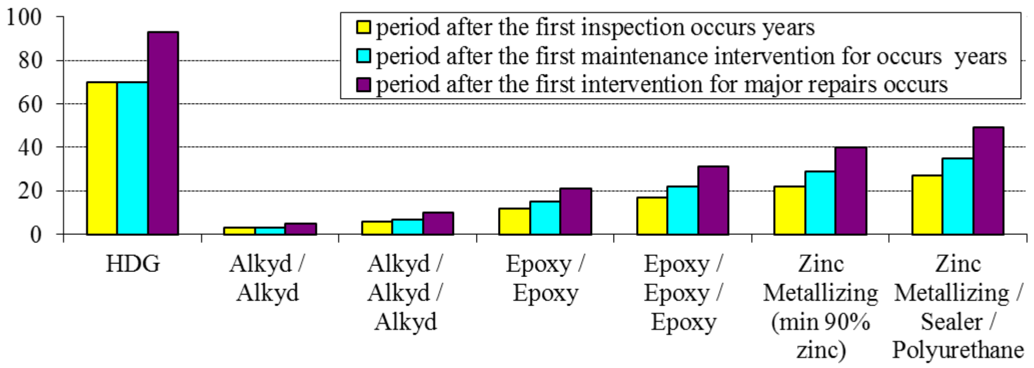


a) Moderately corrosive environmental conditions C3

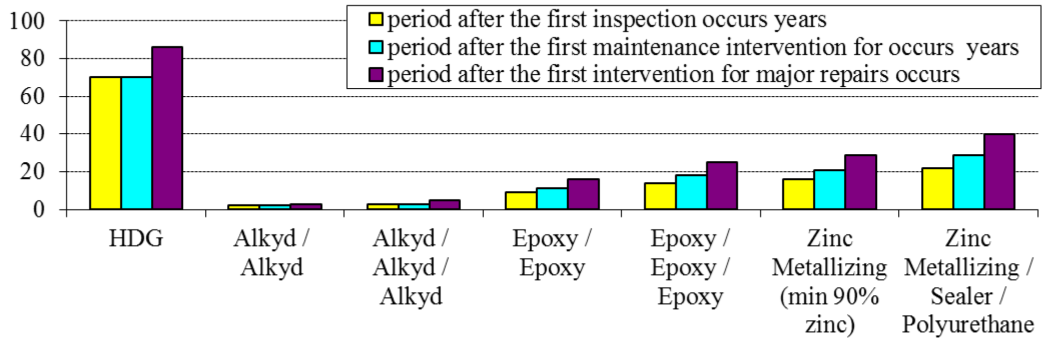


b) Aggressive corrosive environment conditions C5M

Figure 6 Estimation of the number of interventions for inspection, maintenance and repair



a) Moderately corrosive environmental conditions C3



b) Aggressive corrosive environment conditions C5M

Figure 7 Period that occurs after first inspection, first maintenance and first repair

In calculating the profitability of an anti-corrosive system it is preferable to have a minimal number of interventions for inspection, maintenance and repair, and as long as possible time between them. A small number of interventions for inspection, maintenance and repairs, besides leading to reduced costs will also favor the increase of the time that the structure can be utilized fully thus increasing the chances of obtaining a profit from its use. From this perspective it is preferable to use an anti-corrosive protection system that uses hot-dip galvanizing (small number of interventions spaced a long time apart) or zinc metallizing. But the initial costs of metallizing are high, as are the maintenance costs. As a consequence, hot-dip galvanizing is a technology that combines the advantages of small implementation, maintenance and repair costs with the advantage of being able to use the structure for a longer uninterrupted period of time, the interruptions of use due to maintenance and repair operations only appearing after a long period of time (after 70 years) and reoccur after long periods of time.

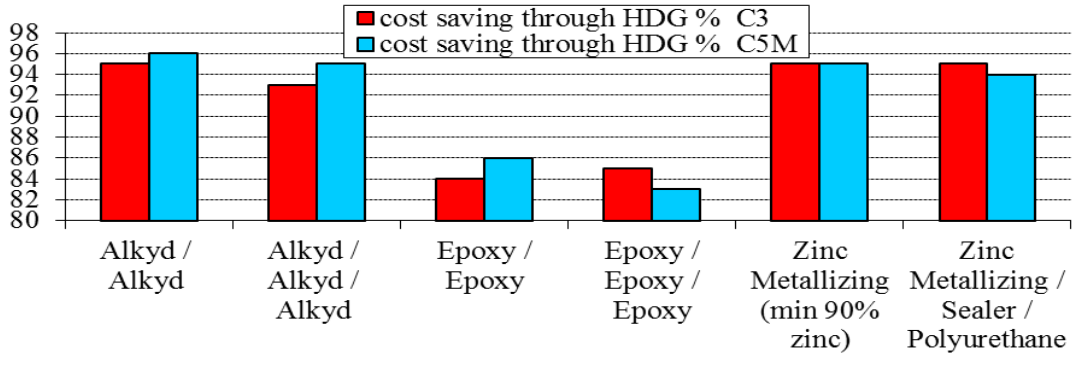


Figure 8 Reduced of execution costs and maintenance of anticorrosive protection by coating or plating compared to hot dip galvanizing

The ratio of construction, maintenance and repair costs of anti-corrosive protection systems that uses painting or metallizing to the costs required by hot-dip galvanizing, shows that for a designed service life of 100 years of the structure, depending on the environment it is placed in, the costs can be 80-96% higher (figure 8). So using hot-dip galvanizing can lead to a significant reduction in costs necessary for implementation, maintenance and repair of the protection system. Each of the technologies analyzed have advantages and disadvantages:

painting with alkyd products has low initial costs but requires high efforts for maintenance and repairs, frequent interventions which overall become costly. Metallizing has high durability over time, the required interventions are few and far between, but the technology, materials, preparation of the surface and the skilled labor required are all expensive. Painting with epoxy products is the most convenient option from the group of painted anti-corrosive protection systems, the number and cost of interventions over the 100 year service life, being lower than for the alkyd paint, but with higher costs starting even with the raw material. Even so, painting with epoxy products is, over the entire life of the structure it is 80% more expensive than hot-dip galvanizing.

Conclusions

This study was conducted in order to highlight the advantages of using anticorrosive protection achieved by galvanizing of steel compared with those obtained by dyeing processes.

Based on the analysis of the technical literature, it was highlighted the significant difference between bonding coverage achieved by galvanizing (much stronger bonding, based on intermetallic contact), compared to the classic bonding of a paint coating to the steel substrate, as well the role of the sacrificial anode of zinc towards the steel. This contributes substantially to the increase of durability of anticorrosive protection achieved by galvanizing and implicitly to reducing need for interventions needed for maintenance and repairs.

The estimations of execution costs, inspection, maintenance and repair, the whole lifetime of considered steel structure, have indicated that:

- the execution costs of anticorrosive protection by galvanizing are compared to those of protection by painting with alkyd products and smaller if the painting is performed with epoxy or metallization. These is due to the increasing of costs of painting because of the need of conformation of environmental conditions on one hand, and on the other hand, of technological possibility of recovery and recycling of many waste from hot dip galvanizing;
- throughout the whole life of the steel structure, because for about 70 years the hot dip galvanizing coating (HDG coating) does not require interventions, costs are much lower compared to other analyzed procedures which either are requiring cheaper but more frequent interventions, either are requiring more rare interventions, but more expensive;
- due to the low number of interventions for maintenance and repair, by galvanizing is effectively extended the service life of the steel structure. Reducing the time in which the structure activity is stopped for maintenance work and repairs, it can function and earn income and thus a higher profit.

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